U.S. Department of the Interior
U.S. Geological Survey

Prepared in cooperation with the

Virginia Department of Environmental Quality
Maryland Department of Natural Resources
Susquehanna River Basin Commission
U.S. Environmental Protection Agency

Factors Affecting Nutrient Trends in Major Rivers of the Chesapeake Bay Watershed

Water-Resources Investigations Report 00-4218

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U.S. Department of the Interior
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By Lori A. Sprague[1], Michael J. Langland[1], Steven E. Yochum[1], Robert E. Edwards[2], Joel D. Blomquist[1], Scott W. Phillips[1], Gary W. Shenk[3], and Stephen D. Preston[1]

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Richmond, Virginia
2000

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CONVERSION FACTORS, WATER-QUALITY UNITS, CREDITS FOR BASE MAPS, AND ABBREVIATIONS AND ACRONYMS

Multiply	By	To obtain
	Area	
acre	4,047	square meter
acre	0.4047	hectare
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Mass	
pound (lb)	0.4536	kilogram
pound per acre (lb/acre)	1.121	kilogram per hectare

Temperature: Temperature in degrees Farenheit (°F) may be converted to degrees Celsius (°C) as follows: °C = (°F - 32) / 18

Water-Quality Units: Chemical concentration is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

Credits for base maps:
Albers Equal-Area Conic projection
County boundaries are from 1:2,000,000 TIGER files, 1994
State lines are from 1:100,00 TIGER files, 1990
Hydrography is from USEPA River Reach Files Version 1 at 1:500,000, 1982
Watershed boundaries are from 1:250,000 USGS Hydrologic Units, 1994
Physiographic provinces are from 1:500,000 USGS files, 1995

Abbreviations and Acronyms:

BMPs	Best Management Practices
BNR	Biological Nutrient Removal
CBP	Chesapeake Bay Program
HSPF	Hydrologic Simulation Program—FORTRAN
MDNR	Maryland Department of Natural Resources
MWCOG	Metropolitan Washington Council of Governments
RIM	River Input Monitoring Program
SPARROW	USGS “Spatially Referenced Regressions on Watershed attributes” Model
SRBC	Susquehanna River Basin Commission
USEPA	U.S. Environmental Protection Agency
VDEQ	Virginia Department of Environmental Quality
WSM	Chesapeake Bay Watershed Model

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ABSTRACT

Trends in nutrient loads and flow-adjusted concentrations in the major rivers entering Chesapeake Bay were computed on the basis of water-quality data collected between 1985 and 1998 at 29 monitoring stations in the Susquehanna, Potomac, James, Rappahannock, York, Patuxent, and Choptank River Basins. Two computer models—the Chesapeake Bay Watershed Model (WSM) and the U.S. Geological Survey's "Spatially Referenced Regressions on Watershed attributes" (SPARROW) Model—were used to help explain the major factors affecting the trends. Results from WSM simulations provided information on temporal changes in contributions from major nutrient sources, and results from SPARROW model simulations provided spatial detail on the distribution of nutrient yields in these basins. Additional data on nutrient sources, basin characteristics, implementation of management practices, and ground-water inputs to surface water were analyzed to help explain the trends.

The major factors affecting the trends were changes in nutrient sources and natural variations in streamflow. The dominant source of nitrogen and phosphorus from 1985 to 1998 in six of the seven tributary basins to Chesapeake Bay was determined to be agriculture. Because of the predominance of agricultural inputs, changes in agricultural nutrient sources such as manure and fertilizer, combined with decreases in agricultural acreage and implementation of best management practices (BMPs), had the greatest impact on the trends in flow-adjusted nutrient concentrations. Urban acreage and population, however, were noted to be increasing throughout the Chesapeake Bay Watershed, and as a result, delivered loads of nutrients from urban areas increased during the study period. Overall, agricultural nutrient management, in combination with load decreases from point sources due to facility upgrades and the phosphate detergent ban, led to downward trends in flow-adjusted nutrient concentrations at many of the monitoring stations in the watershed. The loads of nutrients, however, were not reduced significantly at most of the monitoring stations. This is due primarily to higher streamflow in the latter years of the monitoring period, which led to higher loading in those years.

Results of this study indicate a need for more detailed information on BMP effectiveness under a full range of hydrologic conditions and in different areas of the watershed; an internally consistent fertilizer data set; greater consideration of the effects of watershed processes on nutrient transport; a refinement of current modeling efforts; and an expansion of the non-tidal monitoring network in the Chesapeake Bay Watershed.

INTRODUCTION

Chesapeake Bay, the Nation's largest estuary, has been adversely affected by nutrient enrichment. Excessive nutrients have caused eutrophication, contributing to periods of hypoxia (dissolved-oxygen concentrations lower than 1.0 mg/L) and poor water-clarity conditions that deprive living resources of necessary oxygen and sunlight.

The Chesapeake Bay Program (CBP), a multi-jurisdictional restoration effort, established a goal to reduce controllable nutrient loads into the estuary by 40 percent by the year 2000 (U.S. Environmental Protection Agency, 1988). Results from CBP Watershed Model (WSM) and Estuarine Water-Quality Model simulations had indicated that water quality in the Bay would be improved enough to adequately support living resources if the 40-percent load-reduction goal was met. Individual nutrient-reduction goals and associated strategies were developed for the major rivers entering Chesapeake Bay on the basis of WSM predictions. The WSM was used to simulate the differences in watershed conditions (nutrient sources, land use, management practices) in the mid-1980’s and those projected for 2000. The same hydrologic data (based on 1984 to 1987 conditions) were used in both model simulations (for the mid-1980's and for 2000) so that the results for the two periods could be compared to assess changes in nutrient loads that result from changes in watershed conditions, rather than from changes in hydrologic conditions.

To assess water-quality changes as the nutrient-reduction strategies are implemented in the river basins, water-quality data are collected and temporal trends in streamflow, loads, and concentrations (including trends in concentrations after the natural effects of flow and season are removed) are computed. One of the major programs collecting data and computing loads and trends is the Chesapeake Bay River Input Monitoring (RIM) Program. In 1983, the U.S. Geological Survey (USGS), in cooperation with the Maryland Department of Natural Resources (MDNR) and the Metropolitan Washington Council of Governments (MWCOG), began the RIM Program for Maryland. In 1988, the USGS, in cooperation with the Virginia Department of Environmental Quality (VDEQ), expanded the RIM Program to include the major rivers in Virginia. The program provides long-term streamflow and water-quality monitoring data that can be used to quantify nutrient loads and trends in the major rivers entering the tidal portion of the Chesapeake Bay Watershed.

RIM stations were established on the Susquehanna, Potomac, James, Appomattox, Rappahannock, Pamunkey, Mattaponi, Patuxent, and Choptank Rivers (fig. 1, table 1). Each station was established at the farthest possible point downstream that is unaffected by tides. Consequently, many of the stations are near the “Fall Line,” which is located along the boundary between the Piedmont and Coastal Plain physiographic provinces (fig. 2).

The water-quality and streamflow data collected by the RIM Program were used to help calibrate the WSM and to assess water-quality responses to nutrient-reduction strategies. In 1998, the USGS, the Susquehanna River Basin Commission (SRBC), and the CBP began a cooperative project to improve the integration of modeling and monitoring efforts. The project’s goal is to describe the factors affecting the nutrient trends in the major rivers monitored in the RIM program, so that the CBP can further assess the effectiveness of, and refine, nutrient-reduction strategies. During the first year of the project, techniques were developed to assess trends in load, streamflow, and concentrations at stations in the nontidal portion of the watershed (Langland and others, 1999).

Purpose and Scope

This report describes the factors affecting nutrient trends in the major rivers entering Chesapeake Bay, with an emphasis on the nine stations monitored by the RIM Program. These trends were computed using water-quality data collected from 1985 to 1998 at 29 monitoring stations in the Susquehanna, Choptank, Patuxent, Potomac, Rappahannock, York, and James River Basins (Langland and others, 1999). Two computer models—the Chesapeake Bay WSM and the USGS Spatially Referenced Regressions on Watershed attributes (SPARROW) model—were used to help identify the major factors affecting the trends. Results from WSM simulations provided information on changes over time in contributions from major nutrient sources, and results from SPARROW model simulations provided spatial detail on the distribution of nutrient yields in the basins. In addition, data on nutrient sources, basin characteristics, implementation of management practices, and ground-water inputs to surface water were analyzed to help explain the trends.

Acknowledgments

The River Input Monitoring Program is supported through an inter-agency cooperative agreement between MDNR, VDEQ, and USGS. Additional support for preparation of this report was provided by SRBC, the Chesapeake Bay Program Office of the U.S. Environmental Protection Agency (USEPA), and the USGS National Water-Quality Assessment Program’s Potomac River Basin study.

The authors wish to thank Sarah Kelley and John Brakebill of the USGS for their technical expertise in compiling much of the data presented in this report, and Brent Banks for his work on the illustrations and layout of the report. They also wish to acknowledge the

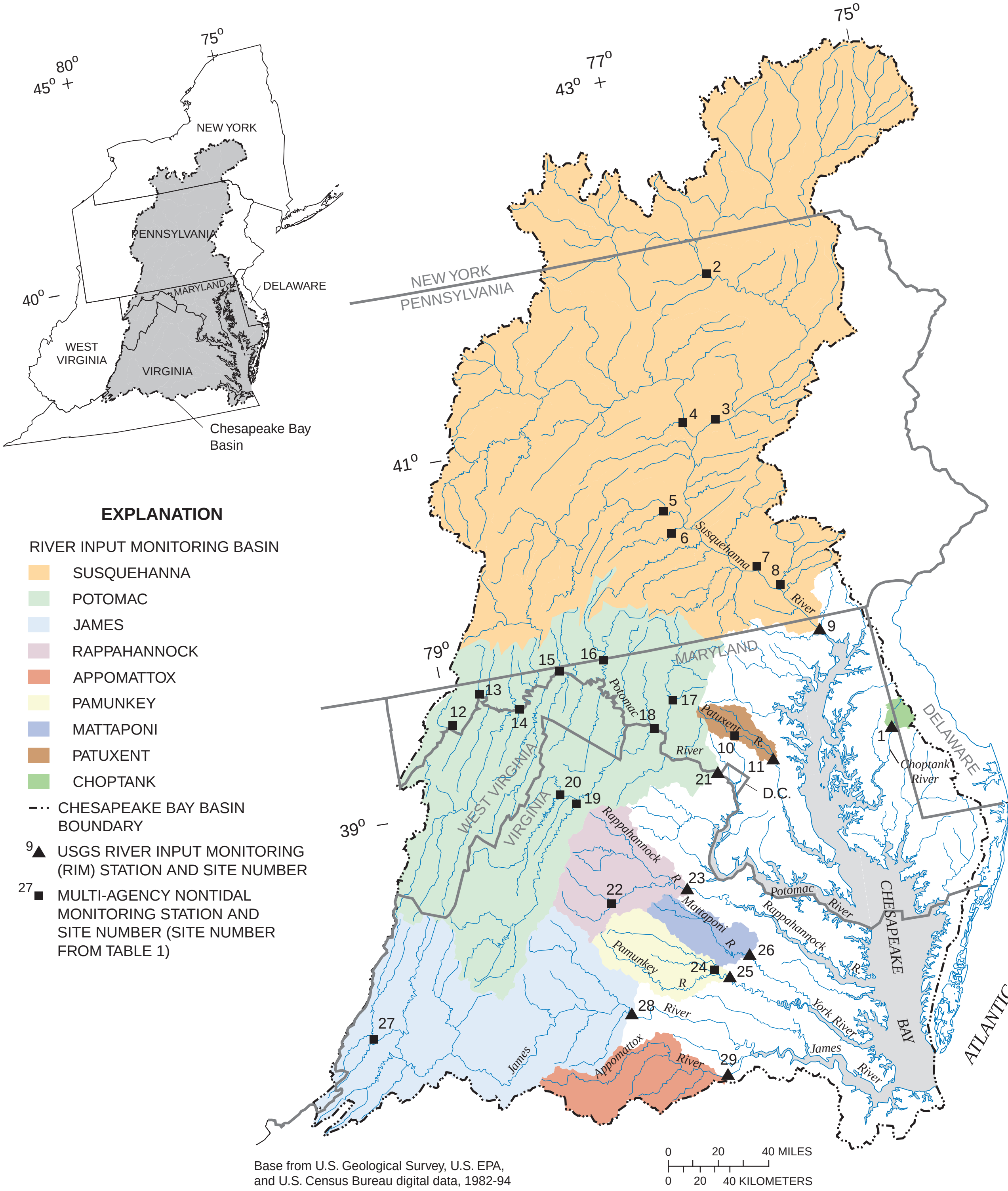


Figure 1. Location of the 29 monitoring stations in the Chesapeake Bay Watershed used in this study.

Table 1. Streamflow and water-quality station numbers and drainage areas for the 9 River Input Monitoring (RIM) Program and 20 Multi-Agency Nontidal stations in the Chesapeake Bay Watershed

[Latitude and longitude in degrees, minutes, and seconds. Station locations shown in figure 1.]

Stream-flow station number	Water-quality station number	Latitude	Longitude	Site number	Drainage area (square miles)	Station name
			River Input Monitoring Program Stations			
01491000	01491000	38 59 50	75 47 10	1	113	Choptank River near Greensboro, Md.
01578310	01578310	39 39 28	76 10 29	9	27,100	Susquehanna River at Conowingo, Md.
01594440	01594440	38 57 21	76 41 36	11	348	Patuxent River near Bowie, Md.
01646580	PR01	38 55 46	77 07 01	21	11,600	Potomac River at Chain Bridge, Washington, D.C.
01668000	01668000	38 19 20	77 31 05	23	1,596	Rappahannock River near Fredericksburg, Va.
01673000	01673000	37 46 03	77 19 57	25	1,081	Pamunkey River near Hanover, Va.
01674500	01674500	37 53 16	77 09 48	26	601	Mattaponi River near Beulahville, Va.
02035000	02035000	37 40 15	78 05 10	28	6,257	James River at Cartersville, Va.
02041650	02041650	37 13 30	77 28 32	29	1,344	Appomattox River at Matoaca, Va.
			Multi-Agency Nontidal Stations			
01531500	01531500	41 45 55	76 26 28	2	7,797	Susquehanna River at Towanda, Pa.
01540500	01540500	40 57 29	76 37 10	3	11,220	Susquehanna River at Danville, Pa.
01553500	01553500	40 58 03	76 52 36	4	6,859	West Branch Susquehanna River at Lewisburg, Pa.
01567000	01567000	40 28 42	77 07 46	5	3,354	Juniata River at Newport, Pa.
01570000	01570000	40 15 08	77 01 17	6	470	Conodoguinet Creek near Hogestown, Pa.
01576000	01576000	40 03 16	76 31 52	7	25,990	Susquehanna River at Marietta, Pa.
01576754	01576754	39 56 17	76 22 05	8	470	Conestoga River at Conestoga, Pa.
01592500	PXT0809	39 07 00	76 52 31	10	132	Patuxent River at Laurel, Md.
01599000	GEO0009	39 29 39	79 02 42	12	47	Georges Creek near Franklin, Md.
01601500	WIL0013	39 39 41	78 46 50	13	247	Wills Creek near Cumberland, Md.
01610000	POT2766	39 32 18	78 27 17	14	3,109	Potomac River at Paw Paw, W. Va.
01613000	POT2386	39 41 49	78 10 36	15	4,073	Potomac River at Hancock, Md.
01614500	CON0180	39 42 56	77 49 31	16	501	Conococheague Creek at Fairview, Md.
01643000	MON0155	39 23 13	77 21 58	17	817	Monocacy River at Reels Mill Road, Md.
01638500	POT2386	39 16 24	77 32 38	18	9,651	Potomac River at Point of Rocks, Md.
01631000	1BSSF003.56	38 54 49	78 12 40	19	1,642	South Fork Shenandoah River at Front Royal, Va.
01634000	1BNFS010.34	38 56 36	78 20 11	20	768	North Fork Shenandoah River at Strasburg, Va.
01666500	3-ROB001.90	38 19 30	78 05 45	22	179	Robinson River near Locust Dale, Va.
01671020	8-NAR005.42	37 51 00	77 25 41	24	463	North Anna River at Hart Corner near Doswell, Va.
02013100	2-JKS023.61	37 47 19	80 00 03	27	614	Jackson River below Dunlap Creek at Covington, Va.

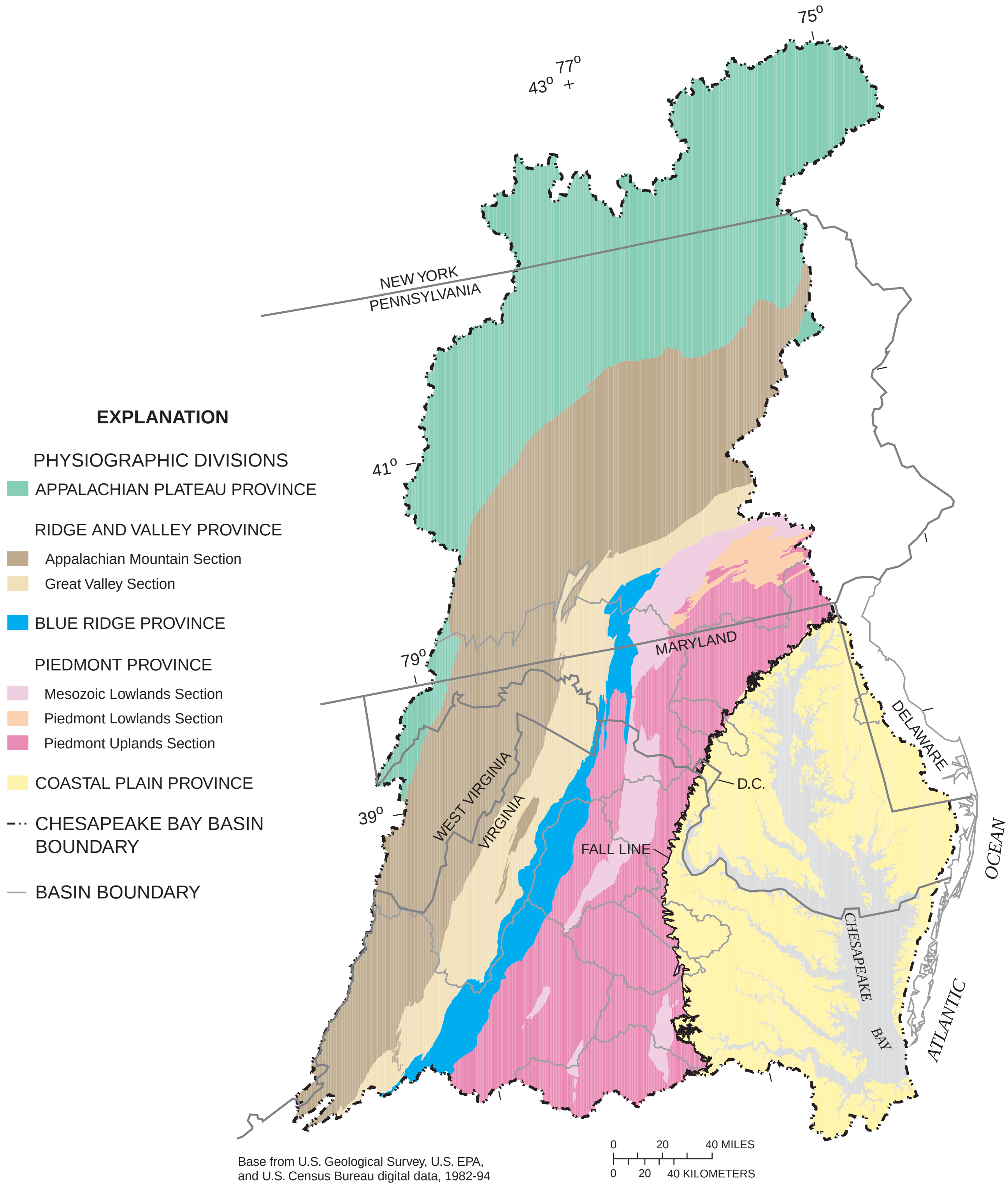


Figure 2. Physiographic provinces in the Chesapeake Bay Watershed.

contribution of the numerous USGS, VDEQ, MDNR, and MWCOG personnel who collected much of the water-quality and streamflow data presented in this report.

APPROACH AND ASSOCIATED DATA

The approaches for explaining the trends, and the methods and data sources for each approach, are presented in this section.

Surface-water trends

ESTIMATOR Model

Water-quality and streamflow data used in the trend analyses were collected at the 9 USGS RIM stations and at 20 additional stations upstream monitored by the VDEQ, the MDNR, the MWCOG, the Pennsylvania Department of Environmental Protection, the USEPA, the SRBC, and the Interstate Commission on the Potomac River Basin (fig. 1, table 1). Data for each of the stations covered a minimum of 10 years and contained a minimum of 100 monthly samples or a combination of 75 monthly and quarterly samples with no gaps longer than 3 months. Data at the RIM stations were collected semimonthly and during storm events throughout each year.

Loads of nutrients at each station were estimated using the observed concentration and streamflow data in the USGS ESTIMATOR model, a log-linear regression model that uses time, flow, and season terms to predict daily nutrient concentrations (Cohn, 1989). These predicted daily concentration values are then multiplied by measured daily mean discharge values to estimate daily load values. Daily loads are then summed to obtain monthly and annual loads. This model incorporates a minimum variance unbiased estimator to correct for log-transformation bias and an adjusted maximum likelihood estimator to handle data below the detection limit. Trends in load were subsequently determined through linear regression of log-transformed monthly loads.

Because variations in streamflow can affect the concentration and load of nutrients, it is helpful to remove the effects of streamflow in order to evaluate the impact of other factors, such as changes in nutrient sources, land use, nutrient-management actions, and ground-water inputs. To obtain these flow-adjusted concentrations, daily concentration values were predicted using only season and streamflow terms in the ESTIMATOR model, and the residual concentrations were obtained by subtracting these predicted concentrations from the observed concentrations, in effect removing the effects of flow. Trends in flow-adjusted concentrations were then determined using the residual concentrations in a non-parametric Kendall-Theil test. The trend slope in the Kendall-Theil analysis is the overall median slope of all pairwise slopes on the residual data over the entire period of record (Helsel and Hirsch, 1992).

A detailed discussion of the methodologies and results of the trend analyses is presented in Langland and others (1999).

Chesapeake Bay Watershed Model

The WSM has been used by the Chesapeake Bay Program since 1982, and the model has been upgraded and refined many times; in this study, version 4.1 was used. The model is based on the Hydrologic Simulation Program-FORTRAN (HSPF) Version 11 (Bicknell and others, 1997). HSPF is a widely used public domain model supported by the USEPA, the USGS, and the U.S. Army Corps of Engineers. In the model, the watershed is divided into 89 major model segments based on hydrologic units, each with an average area of 1.87×10^9 m^2 (187,000 hectares). Model segment boundaries are adjusted so that model segment outlets are close to the monitoring stations that provide input data, including the 29 stations used in this study. Observed water-quality and streamflow data used in the model are obtained from Federal and state agencies, universities, and other organizations that collect information at multiple and single land-use stations (Langland and others, 1995).

The WSM is calibrated by adjusting a large number of physical parameters until the best fit is achieved between the model output data and the observed data. Once the model is calibrated, different “scenarios” are simulated using these parameters along with input data that allow the investigation of different watershed conditions.

For this study, two WSM scenarios were utilized. In the 1985 scenario, all watershed conditions (land use, point sources, and management practices) were input at their 1985 levels for the entire period of simulation. In the 1998 scenario, all watershed conditions were input at their 1998 levels for the entire period of simulation. Each period of simulation corresponds to the period of the input hydrologic data; in both scenarios these data were from the years 1985 to 1994. This period covers a wide range of hydrologic conditions; therefore, the WSM can be used to predict loads under varying hydrologic conditions. In effect, the WSM is using an "average hydrology" based on the hydrologic conditions from 1985 to 1994 to predict loads under 1985 and 1998 watershed conditions. Load results for 1985 and for 1998 are reported as an average of annual loads from 1985 to 1994 calculated in the respective scenarios. Use of the same, or "constant", hydrology in both scenarios allows WSM results to be used to estimate trends due solely to changes in watershed conditions between 1985 and 1998.

The WSM calculates nutrient and sediment loads delivered to Chesapeake Bay from all areas of the watershed (Donigian and others, 1994; Thomann and others, 1994; Linker and others, 1996; Linker, 1996). Nutrient transport from cropland, pasture, urban areas, and forests is simulated to trace the fate and transport of input nutrient loads from atmospheric deposition, fertilizers, animal manure, and point sources. The fate of input nutrients is simulated as either uptake by crop or forest plant material, incorporation into soil, or discharge to rivers and the Bay. Additional nitrogen attenuation processes simulated in the model include volatilization into the atmosphere and denitrification. Sediment is simulated as eroded material washed off land surfaces and transported to tidal areas of Chesapeake Bay.

The 12 years of hourly precipitation input data were obtained from 147 precipitation stations. Temperature, solar radiation, wind speed, snow pack, and dew-point temperature data were obtained from seven primary meteorological stations in the watershed. Three back-up meteorological stations are used when data are missing from the primary stations (Wang and others, 1997).

State agricultural engineers provided fertilizer application rates, timing of applications, information on crop rotations, and the timing of field operations. Manure application rates were determined on the basis of data from the U.S. Census of Agriculture for 1982, 1987, and 1992 (volume 1, Geographic Area Series) published for each state. Point source information was supplied by state representatives (Wiedeman and Cosgrove, 1998). See Table 2 for more information on source data.

A more detailed discussion of the WSM is presented in Donigian and others (1994), Thomann and others (1994), and Linker and others (1996).

Comparing ESTIMATOR model results with the Watershed Model results

While the results of both the USGS ESTIMATOR model and the CBP WSM identify changes in nitrogen and phosphorus delivered to the Bay due to factors other than natural changes in flow, comparisons of the USGS "flow-adjusted concentration" trend results and the WSM "constant-hydrology load" trend results should be made with caution. In the ESTIMATOR model, the variation in concentrations caused by factors other than flow and season is determined statistically over time throughout the entire study period. In contrast, hydrology is held constant in the WSM simulations by using the same 1985-94 hydrology for both the 1985 and 1998 scenarios, and the trend is the difference in predicted loading between those two years.

The accuracy of both methods depends on the degree to which their underlying assumptions are met. The most important assumptions for the USGS method are that nutrient concentrations fit the specified log-linear model and that prediction errors are independent and normally distributed throughout time. Visual inspection of the residuals assists with the verification of these assumptions. The WSM method assumes that management actions and their effects on edge-of-stream loads are precisely known. Additionally, it assumes that the effect of changes in the edge-of-stream load on nutrient load delivered to the tidal waters is accurately simulated by the model. The first assumption is not easily tested as there is only one source of data on management actions in the Chesapeake Bay Watershed, and the assumed effects are based on a summary of available literature. The second assumption cannot be verified directly, although an informed analysis can be made by reviewing the agreement between the predicted and observed in-stream concentrations of nutrients. There is no mechanism for determining the error of WSM predictions; the trend results obtained from the USGS method include error bounds.

Spatial Distribution of Nutrient Yields

To supplement the WSM, the USGS developed the SPARROW model at the scale of the Chesapeake Bay Watershed (Preston and Brakebill, 1999). The SPARROW model provides additional spatial detail on nutrient sources, nutrient loads, and transport processes throughout the watershed. The model is a non-linear regression model in which source data are weighted by estimates of loss due to land-surface and instream processes. Because the model is linked to spatial information, results can be displayed on maps that illustrate nutrient loading at detailed spatial scales. Spatial referencing is accomplished by linking nutrient-source, land-surface characteristic, and loading information to a geographically defined stream-reach data set that serves as a network for relating upstream and downstream loads. Nutrient inputs to each stream reach include loads from upstream and loads from individual sources in the part of the basin that drains directly to the reach.

In this study, Version 1.0 of the Chesapeake Bay SPARROW model was used, representing the year 1987. Input nutrient-source and land-characteristic data sets were compiled from published data bases that were consistent with the WSM input data sets whenever possible. A separate load data base was developed for the SPARROW model because it can be calibrated using loading information from many more locations than are used in the WSM. Nutrient stream-loading estimates were derived from water-quality and flow data collected by State and Federal agencies at 79 stations for nitrogen and 94 stations for phosphorus within the Chesapeake Bay Watershed (Langland and others, 1995), using the methods described in Smith and others (1997). Nutrient-input sources included atmospheric deposition, point sources, and agricultural sources; potentially significant land-surface characteristics included precipitation, temperature, slope, and soil permeability.

An important difference between the SPARROW model and the WSM is that the WSM is spatially and temporally variable, but the SPARROW model is only spatially variable. Load estimates from the WSM presented in this report are for a limited number of locations in the Chesapeake Bay Watershed between 1985 and 1998. In contrast, load estimates from the SPARROW model are for many more locations, but for the year 1987 only.

The maps generated by the SPARROW model presented in this report show delivered yields of nitrogen and phosphorus. These yields represent the amount of nitrogen and phosphorus originally applied to the land surface that reaches the downstream RIM stations. Only a fraction of the nitrogen and phosphorus applied to the land surface reaches the Bay because of losses due to in-stream processes, crop uptake, volatilization, ground-water storage, and reservoir storage. As a result, the maps showing delivered yields indicate those areas in the watershed that contribute high nutrient loads to the Bay.

A more detailed discussion of the SPARROW model input data sets and the model development is presented in Preston and Brakebill (1999) and Brakebill and Preston (1999).

Understanding Changes in Nutrient Sources, Land Use, and Management Practices

The Watershed Model

Nutrient budgets were generated by the WSM to identify the major sources of nitrogen and phosphorus loadings in each basin and their relative contributions to the total predicted load. Nutrient budgets were generated for 1985 and 1998 to examine how the contribution of these sources has changed during the period of study. These budgets contain loads from the following sources simulated in the WSM: agricultural areas—including conventional-tilled cropland, conservation-tilled cropland, cropland in hay, pasture, and animal waste areas; urban areas—including pervious urban land, impervious urban land, and non-agricultural herbaceous land; forested areas; atmospheric deposition directly to water surfaces; septic inputs; and point source inputs from individual facilities.

A consistent land use data base was compiled for the entire Chesapeake Bay Watershed using a LANDSAT-derived land cover as a base, with additional detailed information on agricultural and urban land incorporated from other sources (U.S. Environmental Protection Agency, 1994; Hopkins and others, 2000). This data base was used in the WSM to determine changes in agricultural, urban, and forested acreage from 1985 to 1998.

Management practices were incorporated into the WSM in three ways. Fertilizer nutrient management plans were incorporated by reducing nutrient inputs from fertilizer applied to the land. Structural best management practices (BMPs) were incorporated by decreasing the export from a land type by a constant factor based on data provided by State representatives (Palace and others, 1998). Biological nutrient removal (BNR), a process that uses microorganisms to enhance the removal of nitrogen and phosphorus from wastewater, was accounted for through the use of USEPA data on point source discharges that reflected changes due to BNR upgrades at individual facilities. Thus, the WSM results provided estimates of nitrogen and phosphorus load reductions from fertilizer nutrient management, BMP implementation, and BNR upgrades in the Chesapeake Bay Watershed between 1985 and 1998.

Additional Data

Data from the WSM included in this report are (1) nutrient source (input) data and (2) nutrient delivered load (output) data. The WSM simulations rely on assumptions about both nutrient source application and delivery processes in order to more accurately predict delivered loads. The validity of these assumptions, however, has not been established under all possible conditions, so additional data also are presented in this report. U.S. Census of Agriculture data on manure generation, animal numbers, and fertilizer sales and USEPA data on point source discharges are presented to allow comparison between basic source information and model input and output. Table 2 lists the source, compilation, calculation, and limitations of basic source data used in the supporting figures in this report (and the SPARROW model) and provides a comparison to the model input source data. More detailed information is presented in Brakebill and Preston (1999) and Gutierrez-Magness and others (1997).

The fertilizer sales data set used as basic source data has important limitations. The data are based on U.S. Census of Agriculture data on state sales disaggregated to county levels. These data were compiled by two different groups using different methods for the 1985-91 and the 1992-98 time periods. Figure 3 shows these data for the Potomac River Basin; the peak in sales in 1992 is readily apparent. It is difficult to discern whether this is an actual increase in sales or an artifact of the data compilation change. Another limitation of fertilizer sales data at a county level is that fertilizer sold in one county is commonly used in another. Therefore, sales data may not provide accurate information on where the fertilizer is being applied. As a result of these limitations, the basic fertilizer data presented in this report should be interpreted with caution.

Nutrient Transport Processes and Ground Water

Nutrient-transport processes have important implications for the trends observed for the tributaries to Chesapeake Bay, particularly as nutrient sources in the watershed changed during the monitoring period. Point source discharges deliver nitrogen and phosphorus directly to streams, and reductions in point source loadings are likely to have an immediate effect on stream quality. Nutrient delivery from the land surface, however, is controlled by the chemical and physical behavior of the nutrient species, movement through ground water, and land-management practices. Thus, the stream response to changes in these nutrient sources may be delayed.

Nitrogen

Nitrogen is delivered to streams from agricultural sources through both ground-water flow and overland runoff following rainfall. If surface runoff were the only major source, nitrate concentrations would decrease with decreasing flow. However, nitrate concentrations are often high at low flows in the tributary basins, suggesting significant ground-water inputs of nitrate. For example, nitrate concentrations at the James River Basin RIM station are moderate at high flows, but are often higher at low flows (fig. 4).

In general, nitrogen fertilizers are more mobile in soils than organically complexed nitrogen in manure. Thus, fertilizers are more rapidly transported to the ground-water system; their delivery to streams is a function of ground-water residence times and degradation rates in ground water. Studies by the USGS have shown that ground-water transport of agricultural nitrogen, particularly fertilizer, is a significant component of the nitrogen transported to streams in the Chesapeake Bay Watershed (Bachman and others, 1998; Ator and others, 1998).

Nitrogen in manure is generally less soluble than commercial fertilizers and is retained in the soil for longer periods. Manure is generated year-round,

Table 2. Sources, compilers, methods of calculation, limitations, Watershed Model (WSM) differences, and references for nutrient source data used in supporting data figures and in the SPARROW model

	Source	Compiler	Calculation method	Limitations	WSM Uses
MANURE GENERATED- 1987, 1992	U.S. Census of Agriculture	U.S. Geological Survey National Water-Quality Assessment Program	Animal numbers converted to animal units, which are multiplied by a nutrient factor based on nitrogen and phosphorus content in manure for each animal type.	Does not account for losses of nutrients from volatilization and storage between generation and land application.	Same source data used, but WSM uses manure *applied* based on assumptions about losses due to volatilization and storage.
MANURE GENERATED-1987, 1992	U.S. Census of Agriculture	John Brakebill, U.S. Geological Survey, based on methods of Puckett and others, 1998	Animal numbers converted to animal units. Animal units multiplied by a nutrient factor based on N and P content in manure for each animal type.	Does not account for losses from volatilization and storage between generation and land application.	Same source data used, but WSM uses manure *applied* based on assumptions about losses due to volatilization and storage.
FERTILIZER SOLD- 1985 - 91	U.S. Census of Agriculture	Division of Resources Management, West Virginia University, in cooperation with the National Fertilizer and Environmental Research Center, Tennessee Valley Authority	State sales data disaggregated to county level by multiplying by the ratio of individual county expenditure to total state expenditure.	Assumes that county-level fertilizer use is directly proportional to the amount spent on fertilizers by farmers within each county. In the early 1990's, unquantified portions of the Maryland and Delaware data are missing.	State agency estimates used in WSM represent fertilizer *application* by crop and tillage type, decreased by an amount based on state-reported implementation of nutrient management plans.
FERTILIZER SOLD- 1992 - 98	U.S. Census of Agriculture	Association of American Plant Food Control Officials at the University of Kentucky	State sales data is disaggregated to county level by multiplying by the ratio of individual county expenditure to total state expenditure.	Assumes that county-level fertilizer use is directly proportional to the amount spent on fertilizers by farmers within each county. Because the Census of Agriculture occurs only every five years, county expenditures were interpolated in each of the years between. County expenditures for 1998 were extrapolated from the most recent Census of Agriculture in 1997. Data compilers pre- and post-1992 differ, so it is likely that data collection and treatment differ between these two time periods.	WSM uses state agency estimates of fertilizer *application* by crop and tillage type and decreases this amount based on state-reported implementation of nutrient management plans.
POINT SOURCES- 1985 - 98	Individual facilities	U.S. Environmental Protection Agency	Point source data are based on facility discharges reported to USEPA as part of the National Pollutant Discharge Elimination System	None known	None
SEPTIC INPUTS- 1985 - 98	U.S. Census of Population and Housing	U.S. Environmental Protection Agency, Chesapeake Bay Program Office	Because this census occurs only every ten years, annual septic inputs of nitrogen estimated from year to year are based on an assumed linear relation between population and septic inputs.	The validity of this assumed relation is unknown.	None
ATMOSPHERIC DEPOSITION- 1985 - 98	National Atmospheric Deposition Program	U.S. Environmental Protection Agency, Chesapeake Bay Program Office	In the SPARROW model, point deposition measurements are converted to a spatial data set through linear spatial interpolation, which is then merged with the stream reach network.	The validity of this interpolation is unquantified.	The WSM uses same source data, but deposition is assumed to be the same everywhere in a given model segment for each land use. Values for each land use change between model segments.

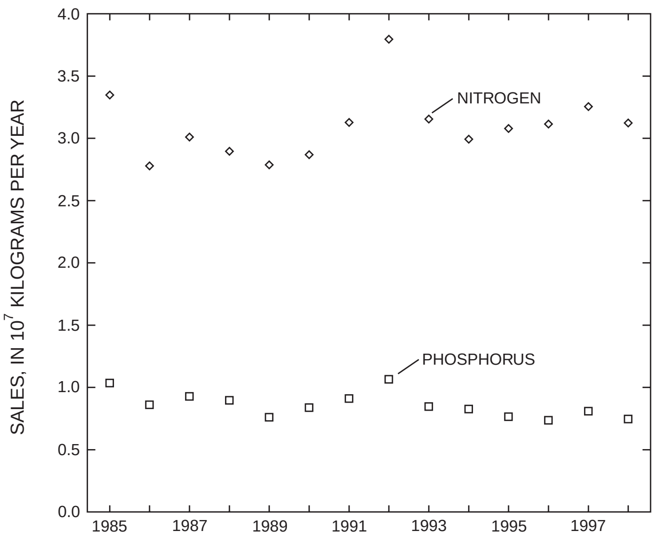


Figure 3. Annual sales of nitrogen and phosphorus fertilizer in the Potomac River Basin, 1985 to 1998.

however, and may be applied when crops have minimal nutrient requirements. Nitrogen in manure is subject to volatilization and interbasin transport through the atmosphere. In addition, because manure is retained in the soil, it is susceptible to transport by runoff events. Thus, stream nitrogen loads from manure are generated largely during storm events and are not as constant as loads delivered through ground water.

Standard field-level nutrient management practices are designed to minimize the overland transport of fertilizers and manure. However, minimizing overland transport may lead to increased transport of nitrogen to ground water as excess nitrogen in the soil can be oxidized to nitrate, which may then infiltrate to ground water. This factor, in conjunction with regular application of nitrogen fertilizer, may lead to a buildup of nitrogen in ground water and, eventually, to increased base-flow nitrogen loads in streams.

Quantifying the load, residence time, and discharge of nitrate in ground water in the Chesapeake Bay Watershed is useful for understanding how nutrients are transported from their sources to streams, and how ground water influences trends of nitrogen in surface water. An initial estimate of ground-water discharge and associated nitrate load for streams and rivers in the Chesapeake Bay Watershed was completed by Bachman and others (1998). Similar techniques were used at the RIM stations in this study to estimate the amount of ground water contributing to total streamflow, the nitrate load from ground water, and the associated trend in nitrate load during ground-water discharge (base flow) conditions. Data on ground-water discharge and nitrate loads were used to assess the magnitude of ground-water influence on surface-water flow and nitrogen load. The trend in nitrate concentrations in base flow was used to help interpret the surface-water trends, and to assess whether ground water influenced the surface-water response to changes in nutrient sources, land use, and management practices.

Phosphorus

Few studies have shown ground water to be a significant transport medium for phosphorus, because phosphorus is strongly sorbed to fine soil material. Transport of phosphorus occurs mainly in the dissolved form or in association with mobilized particulate material. During storm events, most phosphorus transport occurs in association with particulate material generated during surface runoff and concomitant soil erosion. During lower flows, phosphorus transport occurs mainly in the dissolved form. For example, during storm events at the Rappahannock River Basin RIM station, particulate phosphorus concentrations were as much as five times the dissolved phosphorus concentrations (fig. 5). Concentrations of dissolved phosphorus, in contrast, did not vary much over a range of flow conditions. Concentrations and loads of phosphorus are greatest during high flows when phosphorus-laden soils are washed off fields and carried downstream.

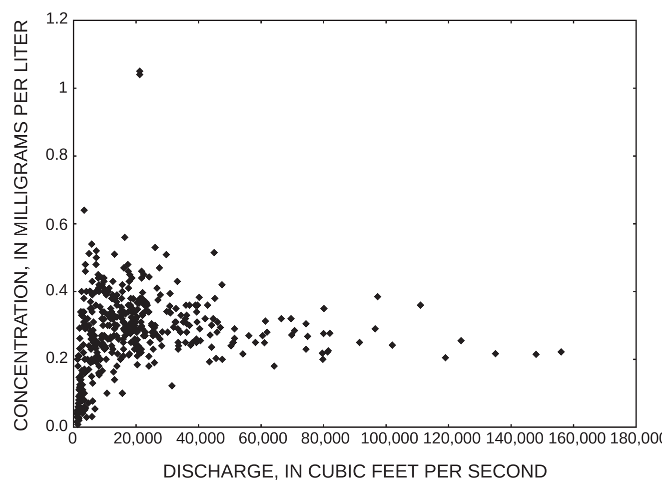


Figure 4. Relation of dissolved nitrate concentration to discharge at the James River Basin River Input Monitoring (RIM) station.

Therefore, the magnitude and number of storm events can affect the variability in concentration and loads of phosphorus, affecting the overall trend.

The presence of reservoirs upstream from a monitoring station also affects phosphorus transport. Sediment and associated phosphorus are trapped in reservoirs, decreasing the phosphorus load delivered downstream. For example, the Conowingo Reservoir in the Susquehanna River Basin is currently trapping an estimated 40 percent of the phosphorus that would otherwise reach the Susquehanna River RIM station (Langland and Hainly, 1997). Such reservoirs likely maintained outflow phosphorus concentrations at a relatively constant level during the study period; once the reservoirs reach storage capacity, however, phosphorus loads delivered to the downstream monitoring stations will increase substantially.

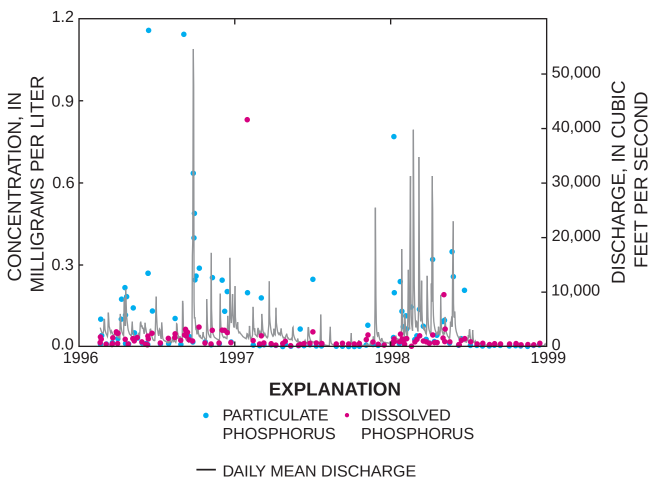


Figure 5. Observed particulate and dissolved phosphorus concentrations and daily mean discharge at the Rappahannock River Basin RIM station, 1996 to 1998.

FACTORS AFFECTING TRENDS IN THE SUSQUEHANNA RIVER BASIN

Basin Description

The Susquehanna River Basin, at 27,500 mi^2, is the largest tributary basin in the Chesapeake Bay Watershed. The Susquehanna River originates in the Appalachian Plateau of south-central New York and central Pennsylvania, flows into the Valley and Ridge and Piedmont Provinces of Pennsylvania and Maryland, and joins Chesapeake Bay near Havre de Grace, Md. The RIM station is approximately 12 mi upstream at the Conowingo Dam Hydroelectric Power Plant in Conowingo, Md. (01578310) (fig. 6). Three hydroelectric dams are located in the lower Susquehanna River Basin; Conowingo Dam is the largest and farthest downstream. The RIM station receives drainage from all but 400 mi^2 of the basin, and no major streams enter the river below the dam (table 3).

Within the Susquehanna River Basin are seven long-term monitoring stations draining sub-basins that have unique physical, chemical, and land-use characteristics. These characteristics may affect the factors controlling nitrogen and phosphorus trends. Because the basin is large, the factors affecting trends in the Susquehanna River Basin are examined at the RIM station at Conowingo, Md., as well as at the seven monitoring stations upstream, which have drainage areas ranging from 470 to 25,990 mi^2 (table 4).

The climate varies considerably from the lower elevations in the southern areas of the basin to the higher elevations in the northern and western areas of the basin. Annual mean temperatures range from 53°F in the lowlands to 45°F in the uplands. Growing seasons range from 160 days to 120 days from the lower to higher elevations. Due to the shorter growing season, many farmers in the northern areas of the basin use more tillable land for hay while farmers in the southern areas use more land for row crops. Annual precipitation ranges from 33 to 48 in.; it is highest in the Valley and Ridge Province in west-central areas of the basin and is fairly uniform at 39 in. per yr elsewhere. The variability in climate influences the location, land use, and type of crop in many agricultural areas of the basin.

Land use in the Susquehanna River Basin is dominated by forest (67 percent), predominantly in the higher elevations of the mountainous northern areas and the western areas of the Valley and Ridge Province (table 3). The West Branch Susquehanna sub-basin contains the largest percentage of forested land (table 4). Agriculture is the second largest land use (29 percent) and is concentrated in the western valleys of the Valley and Ridge and in the Piedmont Province in the southern portion of the basin. The Conestoga River sub-basin contains the largest percentage of agricultural land. Many of the highly concentrated agricultural areas are located in the valleys and Piedmont areas underlain by carbonate rock, which produces fertile soils. There are small urban areas throughout the Susquehanna River Basin. Urban density is highest in the central and southern areas of the basin around the cities of Harrisburg and York, while the forested and mountainous western and north-central areas of the basin contain little urban development.

Of the nine rivers monitored by the RIM program, the Susquehanna River contributes about 60 percent of the streamflow, 62 percent of the total nitrogen load, and 34 percent of the total phosphorus load, making it the largest streamflow and nutrient source to Chesapeake Bay (Belval and Sprague, 1999).

Trends

Stream discharge and observed nitrogen and phosphorus concentrations at the Susquehanna River RIM station from 1985 to 1998 are shown in figure 7. Total nitrogen concentrations at the RIM station ranged from 0.81 to 6.6 mg/L, with a median concentration of 1.7 mg/L. Total phosphorus concentrations at the RIM station ranged from less than 0.01 mg/L to 0.32 mg/L, with a median concentration of 0.05 mg/L. Total nitrogen concentrations at the sub-basin monitoring stations ranged from 0.4 mg/L to 30 mg/L. Total phosphorus concentrations at the sub-basin monitoring stations ranged from less than 0.003 mg/L to 6.3 mg/L.

There were no significant trends in the total nitrogen load or streamflow entering Chesapeake Bay from the Susquehanna River at the RIM station at Conowingo (table 5). In the upstream sub-basins, the only significant trend in total nitrogen load was an increase at the Conodoguinet Creek monitoring station.

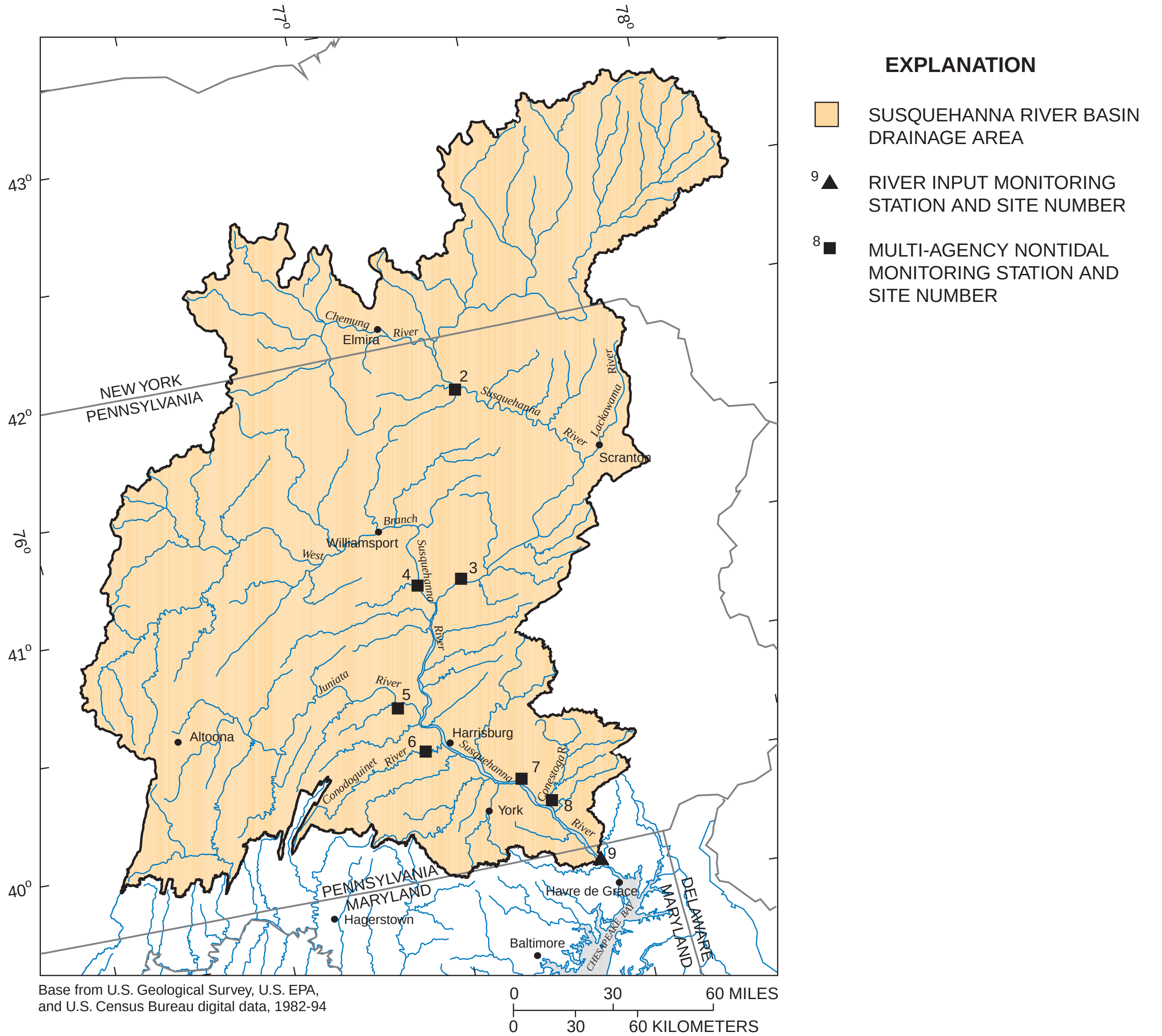


Figure 6. Location of the monitoring stations in the Susquehanna River Basin.

Two sub-basin monitoring stations—on the Juniata River and on Conodoguinet Creek—indicated a significant upward trend in flow between 1985 and 1998.

The small number of significant trends in nitrogen load in the Susquehanna River Basin may be a consequence of two conditions: relatively wet years later in the monitoring period, which led to increased total nitrogen loading in 1996 and 1997 and may have prevented a decreasing overall trend, and the regulation of flow and trapping of sediment in a series of three hydroelectric dams, which dampened fluctuations in loading. When streamflow was removed as a variable affecting in-stream concentrations of total nitrogen, a downward trend of 13 to 25 percent in flow-adjusted nitrogen concentrations was detected at the RIM station during the monitoring period from 1985 to 1998 (table 5). A significant downward trend also occurred at five of the seven sub-basin stations.

A significant downward trend of 17 to 66 percent in total phosphorus loads was detected at the Susquehanna River RIM station at Conowingo (table 5). One of the sub-basin monitoring stations, on the West Branch Susquehanna River, indicated a significant trend (downward) in phosphorus load. A significant

Table 3. Land area, land use, and major wastewater discharge upstream of the RIM stations

[mi^2, square mile; Mgal/d, million gallons per day; land-use data from Vogelmann and others, 1998; land use expressed as a percentage of total land-surface area above each monitoring station; other land use includes barren/transitional and water]

USGS station number	Station name	Site number	Upstream land-surface area (mi^2)	Land use (percent)				Discharge from upstream wastewater facilities (Mgal/d)
				Urban	Agricultural	Forested	Other	
01578310	Susquehanna River at Conowingo, Md.	9	27,100	2	29	67	2	437
01646580	Potomac River at Chain Bridge, Washington, D.C.	21	11,600	3	35	61	1	126
02035000	James River at Cartersville, Va.	28	6,260	1	16	80	3	89.4
01668000	Rappahannock River near Fredericksburg, Va.	23	1,600	1	36	61	2	4.7
02041650	Appomattox River at Matoaca, Va.	29	1,340	1	20	72	7	1.1
01673000	Pamunkey River near Hanover, Va.	25	1,081	1	24	68	7	5.0
01674500	Mattaponi River near Beulahville, Va.	26	601	1	19	69	11	.1
01594440	Patuxent River at Bowie, Md.	11	348	13	41	38	8	30
01491000	Choptank River near Greensboro, Md.	1	113	1	50	29	20	0

Table 4. Land use upstream of monitoring stations in the Susquehanna River Basin

[mi^2, square mile; land use expressed as a percentage of total land-surface area above each monitoring station; other land use includes barren/transitional and water]

USGS station number	Station name	Site number	Upstream land-surface area (mi^2)	Land use (percent)			
				Urban	Agricultural	Forested	Other
	Multi-Agency Nontidal Stations						
01531500	Susquehanna River at Towanda, Pa.	2	7,797	4	35	60	1
01540500	Susquehanna River at Danville, Pa.	3	11,220	5	33	60	2
01553500	West Branch Susquehanna River at Lewisburg, Pa.	4	6,859	2	15	81	2
01567000	Juniata River at Newport, Pa.	5	3,354	2	28	69	1
01570000	Conodoguinet Creek near Hogestown, Pa.	6	470	8	54	37	1
01576000	Susquehanna River at Marietta, Pa.	7	25,990	4	30	64	2
01576754	Conestoga River at Conestoga, Pa.	8	470	14	60	23	3
	River Input Monitoring Station						
01578310	Susquehanna River at Conowingo, Md.	9	27,100	2	29	67	2

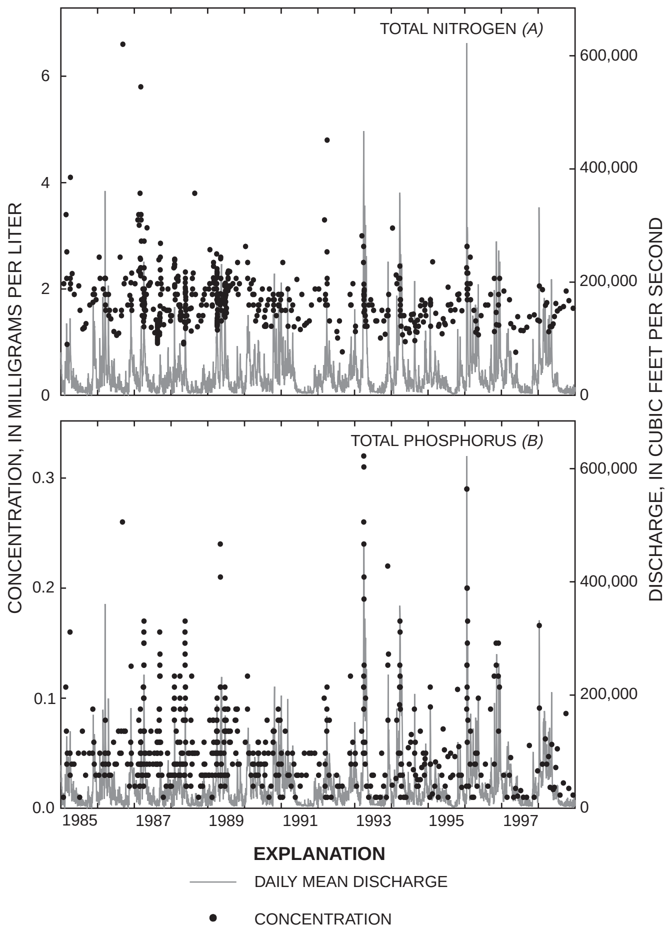


Figure 7. Observed total nitrogen *(A)* and total phosphorus *(B)* concentrations and daily mean discharge at the Susquehanna River Basin RIM station, 1985 through 1998.

downward trend of 36 to 60 percent in flow-adjusted phosphorus concentrations occurred at the RIM station during the monitoring period (table 5). Significant downward trends also were detected at six of the seven sub-basin monitoring stations.

The contribution of the upstream sub-basins to the total nitrogen load at the RIM station is greatest from those in the southern part of the Susquehanna River Basin (fig. 8a). In contrast, the contribution of the sub-basins to the total phosphorus load at the RIM station is generally more evenly distributed throughout the basin. The total phosphorus load from the Marietta sub-basin is greater than the load leaving the Susquehanna River Basin at the RIM station due to the trapping of sediment and associated phosphorus behind three hydroelectric dams located between these two monitoring stations. Though total phosphorus loads from the Conestoga sub-basin are generally lower than those leaving the basin at the RIM station, yields from the intensively agricultural Conestoga sub-basin are 10 times higher than the yield from the entire Susquehanna River Basin.

Nutrient Budgets and Yield Distribution

Nutrient Budgets

Nitrogen and phosphorus budgets were calculated for the Susquehanna River Basin upstream from the Susquehanna River RIM station (fig. 9). These budgets are Chesapeake Bay WSM estimates of the nutrient load delivered from six source categories, and are simulated for 1985 and 1998 using average hydrology in the basin.

Nitrogen

Results of WSM simulations indicate that in 1985, the major contributor to the nitrogen budget in the Susquehanna River Basin was agriculture (53 percent) (fig. 9), despite its constituting only one-third of the land use in the basin. Urban areas (16 percent) and forested areas (16 percent) contributed nearly equally to the nitrogen budget, and point sources, septic inputs, and atmospheric deposition combined made up the remaining 15 percent of the budget. In 1998, the relative contribution of the sources was approximately the same as in 1985. The contribution of urban, forested areas, and point sources increased slightly, whereas the contribution of agriculture decreased to 47 percent of the budget.

The major contributors to the nitrogen budget at the sub-basin monitoring stations varied, largely due to differing land use. For example, the highest relative nitrogen contribution from agricultural areas occurred in the sub-basin that has the greatest amount of agricultural land, the Conestoga River sub-basin. Conversely, the West Branch Susquehanna at Lewisburg, the sub-basin with the greatest amount of forested land, contributed nearly equal amounts of nitrogen from forested and agricultural areas.

Phosphorus

Results of WSM simulations indicate that in 1985, the major contributor to the phosphorus budget in the Susquehanna River Basin was agriculture (59 percent) (fig. 9). Point sources contributed about 27 percent, while urban sources contributed 10 percent. In

Table 5. Trends in monthly mean flow, monthly load of total nitrogen (TN) and total phosphorus (TP), and flow-adjusted concentrations of TN and TP for stations in the Susquehanna River Basin

[TN, total nitrogen; TP, total phosphorus; NS, non-significant; trends expressed as percent change; percent change is reported if significant at the 95-percent confidence level]

Station number	Station name	Site number	Time period of trend	Monthly mean flow trend	Monthly load trend		Flow-adjusted concentration trend	
					TN	TP	TN	TP
	Multi-Agency Nontidal Stations							
01531500	Susquehanna River at Towanda, Pa.	2	1989-98	NS	NS	NS	-22 to -43	NS
01540500	Susquehanna River at Danville, Pa.	3	1985-98	NS	NS	NS	-22 to -36	-30 to -60
01553500	West Branch Susquehanna River at Lewisburg, Pa.	4	1985-98	NS	NS	-30 to -73	-16 to -31	-51 to -79
01567000	Juniata River at Newport, Pa.	5	1985-98	+19 to +131	NS	NS	-19 to -29	-39 to -62
01570000	Conodoguinet Creek near Hogestown, Pa.	6	1985-98	+59 to +207	+84 to +239	NS	NS	-69 to -95
01576000	Susquehanna River at Marietta, Pa.	7	1985-98	NS	NS	NS	-25 to -41	-46 to -71
01576754	Conestoga River at Conestoga, Pa.	8	1985-98	NS	NS	NS	NS	-44 to -67
	River Input Monitoring Program Station							
01578310	Susquehanna River at Conowingo, Md.	9	1985-98	NS	NS	-17 to -66	-13 to -25	-36 to -60

1998, the contribution of agriculture increased to 62 percent and urban contributions increased to 14 percent of the budget. The relative contribution of point sources decreased between 1985 and 1998, to 19 percent. All other contributions remained nearly consistent with 1985 levels.

The major contributors to the 1985 phosphorus budgets in the sub-basins were agriculture, point sources, and urban areas. Agriculture contributions decreased between 1985 and 1998 in all of the sub-basins, with the largest decrease occurring in the northernmost sub-basin, monitored on the Susquehanna River at Towanda, Pa. However, due to the large decrease in point source contributions, the relative contribution of agriculture to the phosphorus budget actually increased at six of the seven sub-basins. The largest decrease in point source contributions to the phosphorus budget occurred at the southernmost basin, monitored on the Conestoga River at Conestoga, Pa. Smaller changes of less than 10 percent in urban and forest contributions occurred in each of the sub-basins.

Nutrient Yield Distributions

The amount of nitrogen and phosphorus delivered to the Susquehanna River RIM station from individual small reaches within the Susquehanna River Basin was estimated using the SPARROW model for 1987 conditions. The yields shown in figure 10 are less than the yields generated within the basin because of on-land and in-stream losses that occur between the point of generation and the monitoring station.

Nitrogen

According to the SPARROW model results, only 18 percent of the total nitrogen generated in the Susquehanna River Basin is delivered to the RIM station at Conowingo (table 6). This is comparable to the low delivery in the upstream sub-basins, with the highest percentage of generated loads (24 percent) reaching the monitoring station on the West Branch Susquehanna River at Lewisburg, Pa. Areas upstream of the RIM station that produce the highest yields of nitrogen that are delivered to the Bay are in the southern parts of the Susquehanna River Basin and include Adams, Cumberland, Dauphin, Lancaster, and York Counties, Pa. An additional area delivering high yields is in southern New York, upstream of the confluence of the Susquehanna and Chemung Rivers.

These areas delivering high yields of nitrogen have intensive agricultural activity. The largest beef and dairy cattle populations are located in the northern and southern areas of the basin, with the largest population in Lancaster and surrounding counties (USDA National Agricultural Statistics Service, 1997). In the northwestern part of the basin, beef cattle populations are large in Steuben and Tioga Counties in New York and Bradford County in Pennsylvania. Dairy cattle populations, however, are more widespread throughout the northern basin, including most of eastern New York. Large swine and poultry populations are generally located in the south-central part of the basin. The greatest amounts of nitrogen fertilizer sold in the basin in 1985 were in counties in the northern and southern ends. In the northern Susquehanna River Basin, sales of nitrogen fertilizer were highest in Steuben County; in the lower part of the basin, the highest fertilizer nitrogen sales were in Lancaster County. Other areas of high nitrogen fertilizer sales include counties along the Pennsylvania-Maryland state line.

The distribution of point source facilities and point source loads varies throughout the Susquehanna River Basin. The highest density of point source facilities is located throughout the lower basin, in the watershed south of Harrisburg, Pa., an area of relatively high population density. A number of facilities are also located along the major river valleys, including the lower reach of the West Branch Susquehanna River and along the Susquehanna River near Danville, Pa. Other locations include the Lackawanna River corridor in the Scranton, Pa., area, and the upper reach of the Juniata River in the Altoona, Pa., area. Point sources in the western and northern parts of the basin are located throughout these sub-basins.

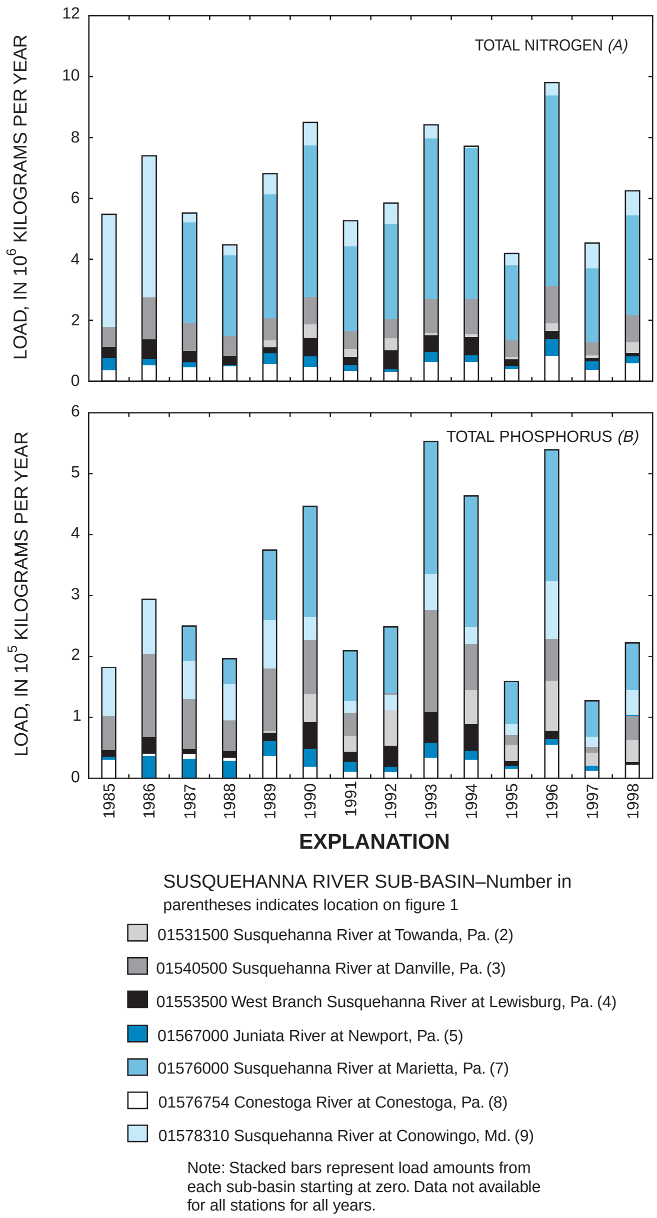


Figure 8. Annual total nitrogen *(A)* and total phosphorus *(B)* loads at the Susquehanna River Basin RIM station, with relative contributions from upstream sub-basin loads, 1985 to 1998.

Phosphorus

According to the SPARROW model results, approximately 3.4 percent of the total phosphorus generated throughout the Susquehanna River Basin is delivered to the RIM station at Conowingo, Md. (table 6). Delivery of phosphorus in the sub-basins ranges from 2.6 to 7.7 percent. The high loss rate observed in the sub-basin upstream from the Newport, Pa., monitoring station may be the result of sediment being trapping behind a major reservoir located near the middle of the basin. The relatively high phosphorus delivery observed at the Lewisburg, Pa., monitoring station may be due to the extensive forest cover and the sandstone-derived soils, soils that limit the amount of fine sediment for the binding of phosphorus.

As with nitrogen, highest delivered phosphorus yields come primarily from areas in the southern part of the basin where agricultural activity is most intense. The amount of manure phosphorus generated declines concentrically away from Lancaster County, with the counties in the western part of the basin and in northeastern Pennsylvania generating the least (USDA National Agricultural Statistics Service, 1997). A slight increase occurs in the counties in the upper part of the basin in New York, but not to the level found in the lower basin. Lancaster County leads all counties in the Susquehanna River Basin in phosphorus fertilizer sales, at as much as two times the rate of sales in the next highest county (Steuben County, N.Y.). Sales of phosphorus fertilizer, similar to nitrogen fertilizer, are high in the northern and southern counties, but also are high

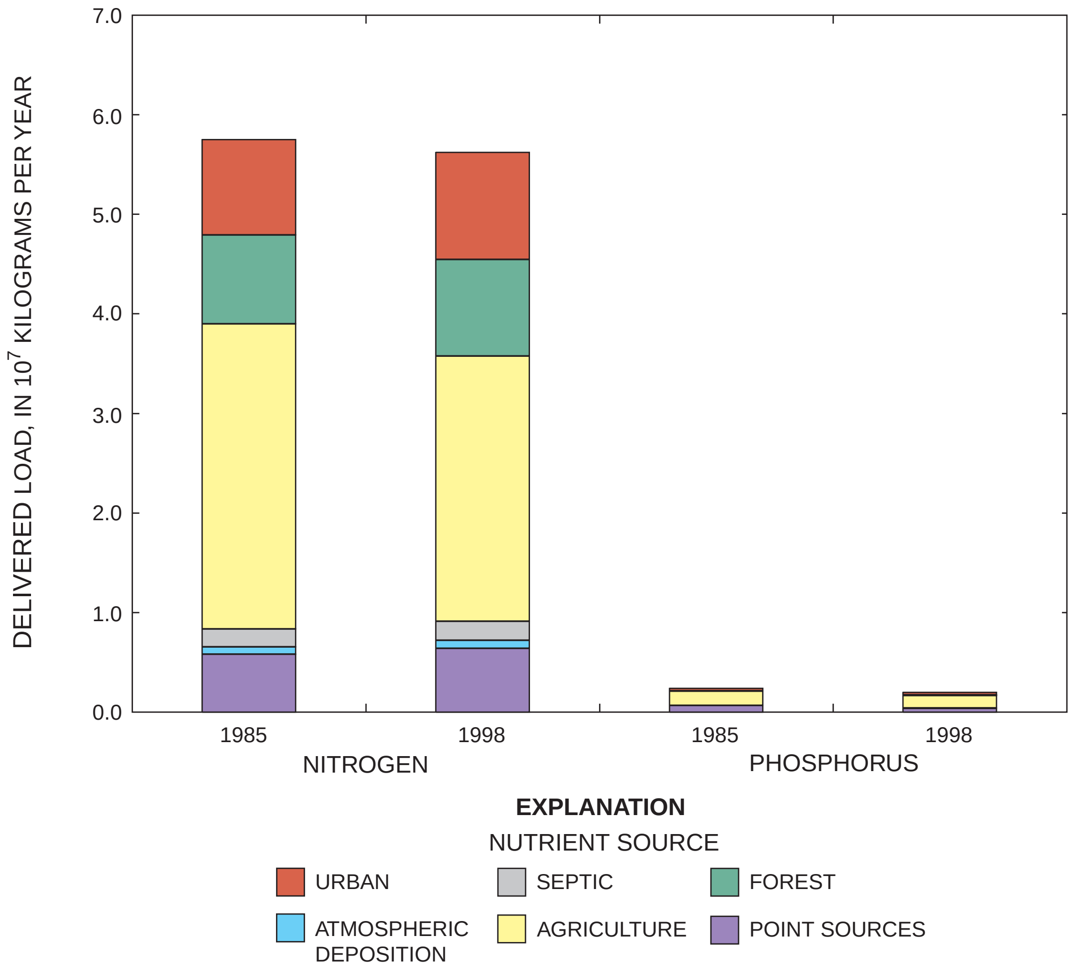


Figure 9. Contribution of major nutrient sources to the nitrogen and phosphorus budgets at the Susquehanna River Basin RIM station during 1985 and 1998, generated by the Chesapeake Bay Watershed Model.

in the central part of the basin in Centre, Columbia, Lycoming, and Northumberland Counties, Pa. The distribution of major phosphorus point sources is similar to that of nitrogen point sources, and loading is greater where the population density increases.

Trends in Nutrient Sources

Estimates of changes in nutrient source loads, land use, and management practices during the study period were provided by WSM simulations. These WSM estimates are described in the following section. Data on manure generation, animal numbers, and fertilizer sales derived from the U.S. Census of Agriculture and data on point source discharges from the USEPA are presented for comparison with model data.

Nitrogen

The dominant source of nitrogen in the Susquehanna River Basin is agriculture, which comprises nearly half of the nitrogen budget (fig. 9). From 1985 to 1998, there was a 13-percent decrease in delivered load of nitrogen from agricultural sources. During this period, agricultural acreage decreased approximately 12 percent (table 7). Within the basin, the greatest percent change in loads from agricultural sources occurred in the sub-basin upstream of the Towanda, Pa., monitoring station, where delivered nitrogen load from agricultural sources decreased 25 percent and agricultural acreage decreased 21 percent. The least amount of change in agricultural loads occurred in the Juniata River sub-basin upstream of the Newport, Pa., monitoring station. Implementation of BMPs accounted for an

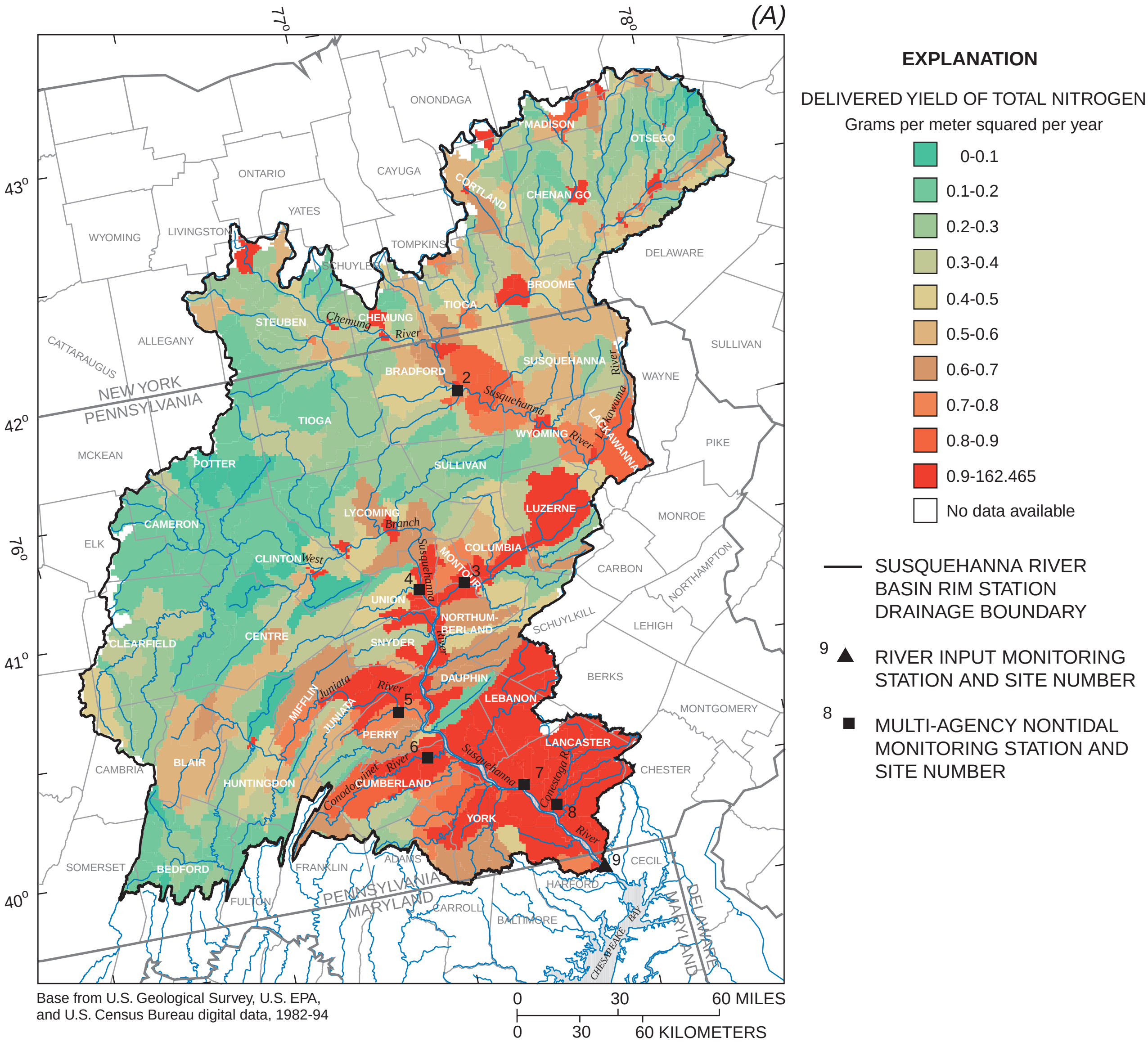


Figure 10. Map showing delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the Susquehanna River Basin in 1987, generated by the SPARROW model.

estimated 8-percent decrease in agricultural nitrogen loads in the Susquehanna River Basin overall (table 7). The greatest load reduction from BMP implementation occurred in the lower Susquehanna River Basin, especially in the Conestoga River sub-basin, where BMP implementation led to an estimated 13-percent decrease in delivered nitrogen loads.

Nitrogen loads from agricultural fertilizer application decreased an estimated 16 percent in the Susquehanna River Basin from 1985 to 1998, in part a result of implementation of fertilizer nutrient management plans (table 7). Nitrogen fertilizer sales were relatively constant during this period (fig. 11) (Bataglin and Goolsby, 1994; D.L. Lorenz, U.S. Geological Survey, written commun., 1999). The fertilizer sales data presented here should be interpreted with caution. On the basis of county-level data, the greatest amounts of nitrogen fertilizer sold in 1985 were in Lancaster, York, and Franklin Counties, Pa., in the southern Susquehanna River Basin, and in Steuben County, N.Y., in the northwestern part of the basin. From 1985 to 1998, fertilizer sales in the southern basin counties showed little change, while sales declined in Steuben County. Sales in the central part of the Susquehanna River Basin,

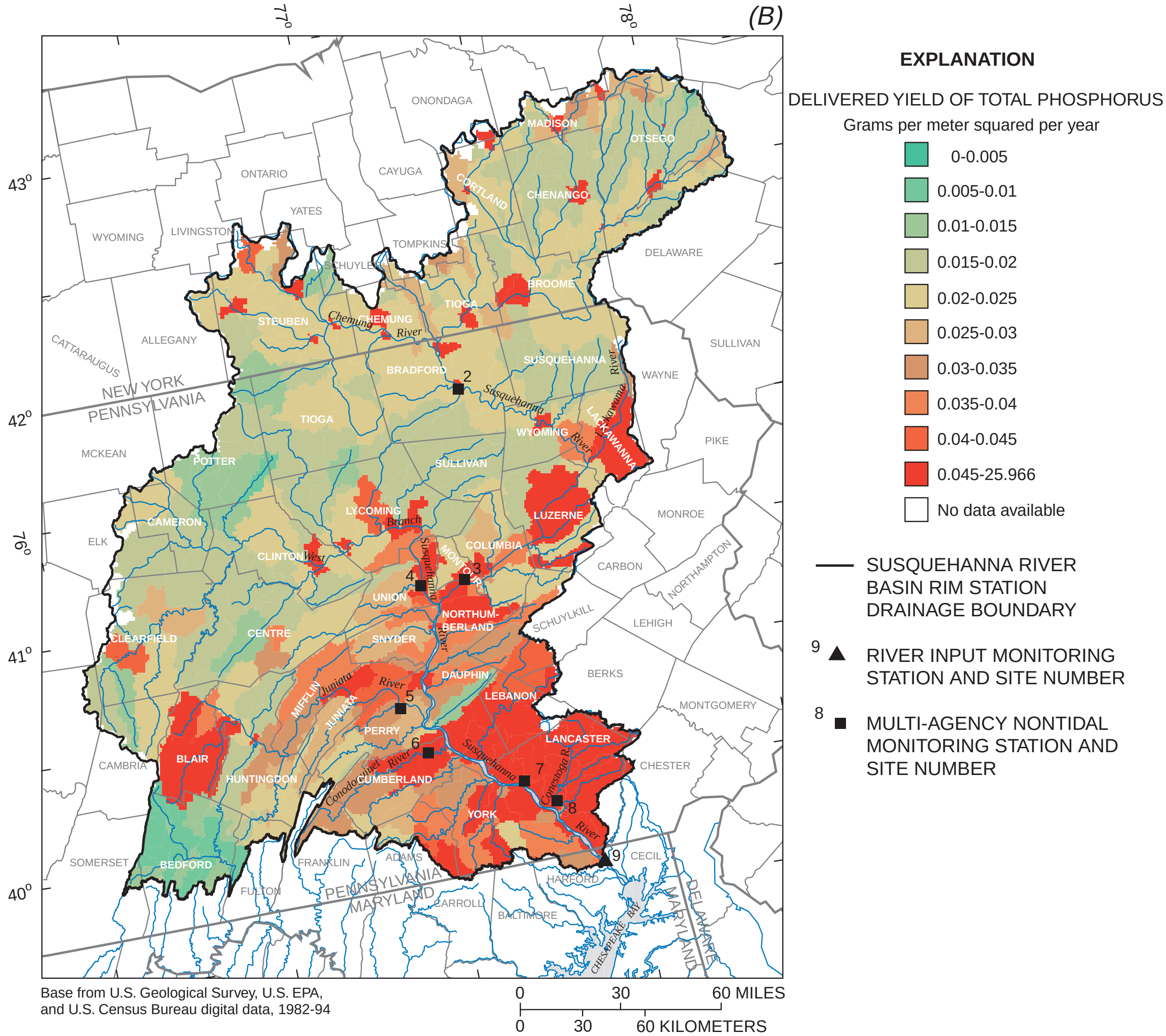


Figure 10. Map showing delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the Susquehanna River Basin in 1987, generated by the SPARROW model.

such as in Centre, Lycoming, and Northumberland Counties, Pa., increased substantially during this period.

Unlike nitrogen loads from fertilizer, nitrogen loads from manure applications decreased only 3 percent from 1985 to 1998 in the Susquehanna River Basin (table 7). U.S. Census of Agriculture data showed relatively constant manure generation between 1987 and 1992, followed by a slight increase through 1997 (fig. 12) (Puckett and others, 1998). The top three counties in terms of manure nitrogen generation were in the central and south-central parts of the Susquehanna River Basin. Lancaster, Franklin, and Lebanon Counties, Pa., increased manure generation of nitrogen by 2.5 percent, 51 percent, and 32 percent, respectively, resulting in a total increase of 5.5 million kilograms in these counties. The manure nitrogen generated in the northern Susquehanna River Basin decreased during the same period. The number of poultry and swine increased in the Susquehanna River Basin from 1987 to 1997, while the number of beef and dairy cows decreased slightly (fig. 13) (USDA National Agricultural Statistics Service, 1997).

Table 6. SPARROW model estimates of the percentage of total nitrogen and total phosphorus load generated in the watershed that is delivered to monitoring stations in the Susquehanna River Basin

Station number	Station name	Site number	Percent delivered to station	
			Total nitrogen	Total phosphorus
	Multi-Agency Nontidal Stations			
01531500	Susquehanna River at Towanda, Pa.	2	21	4.2
01540500	Susquehanna River at Danville, Pa.	3	22	5.3
01553500	West Branch Susquehanna River at Lewisburg, Pa.	4	24	7.7
01567000	Juniata River at Newport, Pa.	5	21	3.9
01570000	Conodoguinet Creek near Hogestown, Pa.	6	22	2.6
01576000	Susquehanna River at Marietta, Pa.	7	21	4.5
01576754	Conestoga River at Conestoga, Pa.	8	21	3.4
	River Input Monitoring Program Station			
01578310	Susquehanna River at Conowingo, Md.	9	18	3.4

Table 7. Watershed Model estimates of percent change in land use acreage, percent change in loads due to best management practice implementation, source loads, delivered loads, and percent change in loads between 1985 and 1998 for nitrogen and phosphorus in the Susquehanna River Basin

[BMP, best management practice; kg/yr, kilograms per year; <, less than; reported load values are either source (input) loads or delivered (output) loads from the Watershed Model]

	% Acreage change	% Load change from BMP implementation	Load (kg/yr)		
			1985	1998	% Change
Nitrogen					
Agriculture (Delivered)	-12	-8	2.94×10^7	2.56×10^7	-13
Fertilizer (Source)			6.44×10^7	5.44×10^7	-16
Manure (Source)			6.49×10^7	6.26×10^7	-3
Urban areas (Delivered)	+9	<-1	9.18×10^6	1.04×10^7	+13
Fertilizer (Source)			2.22×10^7	2.37×10^7	+7
Forested areas (Delivered)	+3	<-1	8.61×10^6	9.30×10^6	+8
Point sources (Delivered)			5.56×10^6	6.13×10^6	+10
Septic (Delivered)			1.70×10^6	1.87×10^6	+10
Atmospheric deposition (Delivered)			7.32×10^5	7.65×10^5	+5
Phosphorus					
Agriculture (Delivered)	-12	-12	1.37×10^6	1.20×10^6	-12
Fertilizer (Source)			2.81×10^7	2.34×10^7	-17
Manure (Source)			1.84×10^7	1.85×10^7	+1
Urban areas (Delivered)	+9	<-1	2.34×10^5	2.64×10^5	+13
Fertilizer (Source)			0	0	0
Forested areas (Delivered)	+3	<-1	5.59×10^4	5.96×10^4	+7
Point sources (Delivered)			6.19×10^5	3.67×10^5	-41
Septic (Delivered)			0	0	0
Atmospheric deposition (Delivered)			1.90×10^4	1.99×10^4	+5

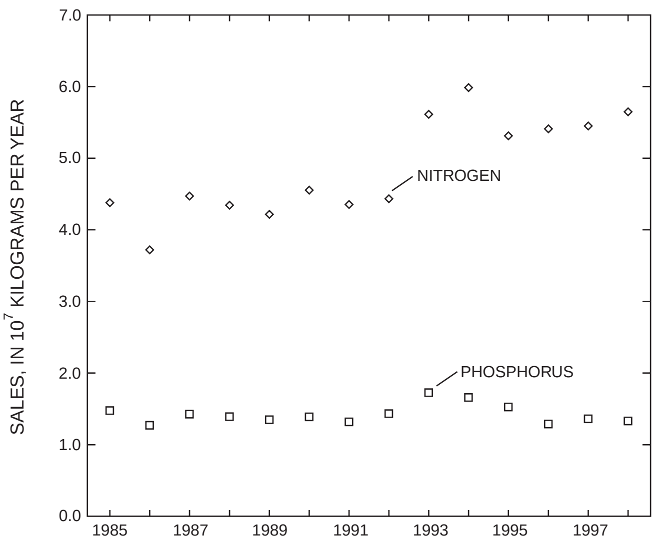


Figure 11. Annual sales of nitrogen and phosphorus fertilizer in the Susquehanna River Basin, 1985 to 1998.

The second largest nitrogen source in the basin is urban areas (fig. 9). From 1985 to 1998, there was a 13-percent increase in delivered load of nitrogen from urban areas, largely due to a 9-percent increase in urban acreage and a 7-percent increase in loads from urban nitrogen fertilizer use (table 7). The population of the Susquehanna River Basin grew 3.5 percent from 1985 to 1998, increasing mainly in the western and southern portions of the basin. The Conestoga River sub-basin experienced the greatest change in population, with an increase of 16 percent, and delivered nitrogen loads from urban areas in this sub-basin increased 28 percent during this period. The least amount of change occurred in the Juniata River sub-basin, where loads from urban areas increased 5 percent from 1985 to 1998. In the Susquehanna River sub-basin upstream of Danville, Pa., delivered nitrogen load from urban areas increased 15 percent even though the population in the sub-basin decreased 3 percent. During this same period, urban acreage in the sub-basin increased by 4 percent while agricultural acreage decreased 18 percent.

The third largest nitrogen source in the Susquehanna River Basin is forested areas (fig. 9). Inputs from forested areas increased by 8 percent from 1985 to 1998, with forested acreage increasing by 3 percent (table 7). Although forested areas are the third largest source overall in the basin, nitrogen loads from forested areas within the West Branch Susquehanna River sub-basin equal those from agricultural areas. This is primarily because forests make up 81 percent of the land area in this sub-basin (table 4).

Contributions of nitrogen from point sources were relatively small in the Susquehanna River Basin, constituting about 10 percent of the nitrogen budget (fig. 9). From 1985 to 1998, nitrogen loading from point sources increased 10 percent (table 7, fig. 14) (Wiedeman and Cosgrove, 1998), likely the result of increased point source flow offsetting decreasing concentrations during this period (fig. 15). For example, the annual mean concentration of nitrogen from point sources (for 165 wastewater treatment facilities in the basin) decreased steadily from 16 mg/L in 1985 to 14 mg/L in 1998. During the same period, annual mean discharge from all treatment facilities increased from 390 to 470 Mgd, peaking in 1996 at 520 Mgd.

The overall change in nitrogen loads from point sources varied throughout the Susquehanna River Basin. Increased nitrogen loading occurred primarily in parts of the southern basin, as well as in the West Branch Susquehanna River sub-basin. Decreased nitrogen loading occurred in the Juniata River sub-basin and the basin area between Danville and Towanda, Pa. The greatest change occurred in the Conestoga River sub-basin, with a 12 percent decrease in nitrogen loads from point sources.

Phosphorus

The dominant source of phosphorus in the Susquehanna River Basin is agriculture, which makes up approximately 60 percent of the phosphorus budget (fig. 9). From 1985 to 1998, there was a 12-percent decrease in delivered load of phosphorus from agriculture, similar to the 13-percent decrease in delivered load of nitrogen from agriculture. This decrease in part resulted from an approximately 12-percent decrease in agricultural acreage during this period (table 7). As with nitrogen, the greatest percent change in delivered phosphorus loads from agriculture occurred in the sub-basin upstream of the Towanda, Pa., monitoring station, where loads decreased 29 percent. The least amount of change occurred in the sub-basin upstream of the Juniata River monitoring station, where phosphorus loads from agriculture decreased 6 percent.

Implementation of structural BMPs resulted in an estimated 12-percent decrease in agricultural phosphorus loads in the Susquehanna River Basin (table 7). Implementation of nutrient management plans contributed to an estimated 17-percent decrease in loads from fertilizer application, though phosphorus fertilizer sales were relatively constant during this period (fig. 11).

Similar to nitrogen fertilizer sales, phosphorus fertilizer sales were higher in the southern part of the basin (when weighted by the percentage of the county in the basin), with Lancaster, York, and Franklin Counties, Pa., being the top three (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999).

While phosphorus loads from fertilizer application decreased substantially, loads from manure application were relatively constant in the Susquehanna River Basin from 1985 to 1998. U.S. Census of Agriculture data showed steady manure generation between 1987 and 1992, followed by an increase in 1997 (fig. 12) (Puckett and others, 1998). The greatest manure application of phosphorus (when weighted by the percentage of the county in the basin) occurs in the areas of highest agricultural activity, or the southern part of the basin. Manure phosphorus application increased substantially in Lancaster, Franklin, and Adams Counties, Pa., while increases were slight in surrounding counties. In the northern part of the basin, manure phosphorus application increased in only two counties and decreased in most of the counties in New York.

The second largest source of phosphorus in the Susquehanna River Basin is point sources, comprising about 27 percent of the budget (fig. 9). From 1985 to 1998, there was a 40-percent decrease in phosphorus loading from point sources above the RIM station at Conowingo (fig. 14). In the northern part of the Susquehanna River Basin, annual phosphorus loads from point sources remained constant from 1985 to 1993, when phosphorus loads peaked. Between 1993 and 1998, annual loads from point sources were highly variable, but generally declined overall (Wiedeman and Cosgrove, 1998). In the largest upstream sub-basin, the West Branch Susquehanna River sub-basin, point source phosphorus loads decreased 56 percent, and by 1998, phosphorus loads from forested areas exceeded those from point sources. In the Conestoga River sub-basin, the phosphorus load from point sources decreased 74 percent between 1985 to 1998. Both the phosphate detergent ban and an upgrade at the Lancaster Wastewater Facility in May 1988 probably are responsible for these reductions in phosphorus.

The third largest phosphorus source in the Susquehanna River Basin is urban areas, comprising about 10 percent of the phosphorus budget (fig. 9). Urban acreage increased by 9 percent from 1985 to 1998, contributing to an increase of about 13 percent in phosphorus loads from urban areas (table 7). Delivered loads from forested areas increased by 7 percent during this period.

Ground Water

On average, an estimated 42 percent of the total nitrogen load at the RIM station at Conowingo, Md., during the monitoring period was from ground-water inputs of nitrate (table 8). In the Susquehanna River Basin, the ground-water contribution varies by rock type and land use. The Conestoga River sub-basin, which is underlain by limestone and is intensely agricultural, contributes the highest amount of base flow (65 percent) and the highest percentage of ground-

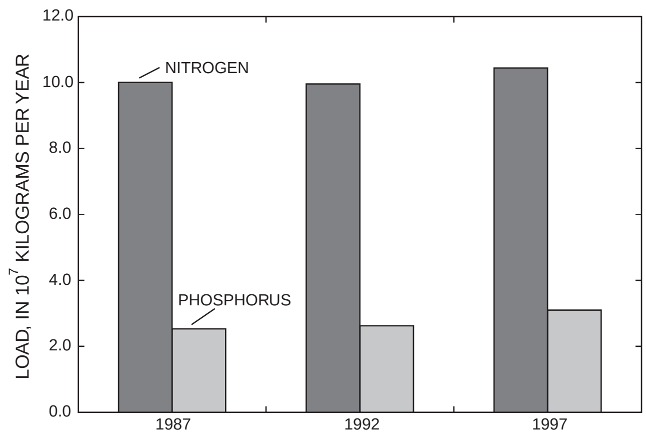


Figure 12. Annual load of nitrogen and phosphorus from manure generated in the Susquehanna River Basin in 1987, 1992, and 1997.

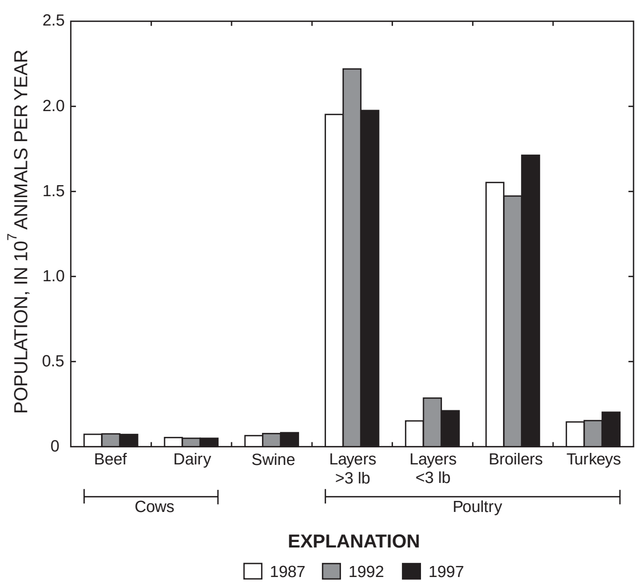


Figure 13. Population distribution of agricultural animals in the Susquehanna River Basin in 1987, 1992, and 1997.

water nitrate load to surface water (65 percent) (table 8). In contrast, the West Branch Susquehanna River sub-basin, which has a large percentage of forested land, contributes the least amount of base flow (29 percent) and a lesser amount of ground-water nitrate load to surface water (52 percent).

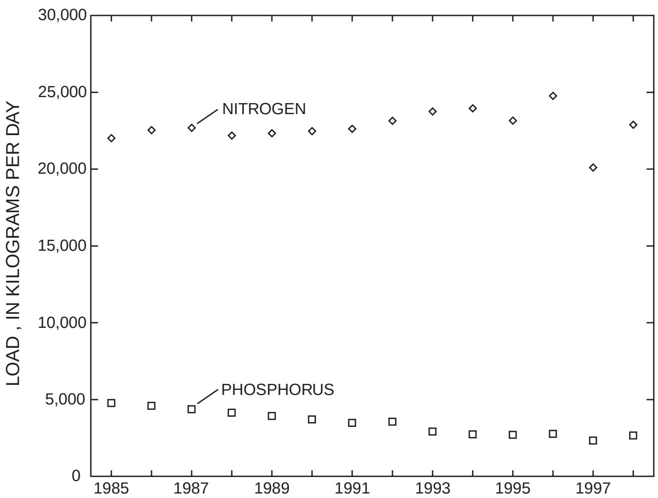


Figure 14. Annual mean point source load of total nitrogen and total phosphorus discharged in the Susquehanna River Basin, 1985 to 1998.

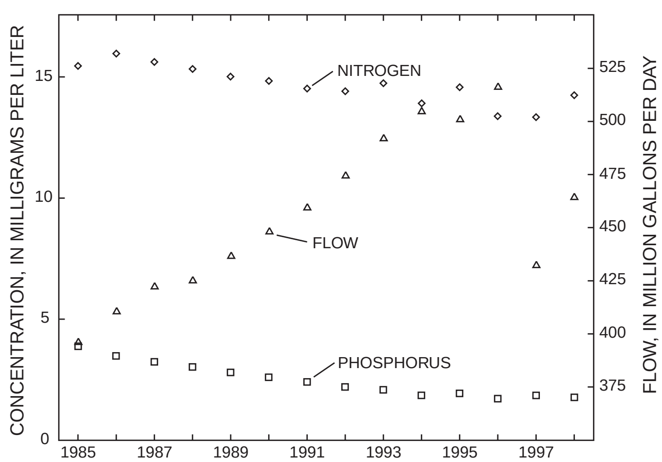


Figure 15. Annual mean point source flow and concentrations of total nitrogen and total phosphorus discharged in the Susquehanna River Basin, 1985 to 1998.

Summary

Wet years later in the monitoring period led to higher loads relative to those early in the monitoring period, likely preventing a significant overall downward trend in nitrogen loads at the RIM station at Conowingo, Md. When flow effects were removed, however, a significant downward trend occurred in flow-adjusted total nitrogen concentrations. For phosphorus, significant downward trends were detected in both loads and flow-adjusted concentrations.

In the Susquehanna River Basin, agriculture is the dominant nutrient source, contributing more than half of the nitrogen and phosphorus budgets. A reduction of agricultural nitrogen loads through decreasing agricultural acreage and loads from fertilizer application, in combination with the implementation of BMPs, is primarily responsible for the reduction in flow-adjusted total nitrogen concentrations in the Susquehanna River Basin. These agricultural reductions offset increasing loads from urban areas, the second largest nitrogen source in the basin. Nitrogen contributions from point sources were relatively small in the basin, and therefore had minimal impact on the nitrogen trend.

Similar to nitrogen, a reduction of agricultural phosphorus loads through decreasing agricultural acreage and loads from fertilizer application, along with the implementation of BMPs, is primarily responsible for the reduction in flow-adjusted total phosphorus concentrations in the Susquehanna River Basin. Agricultural reductions were supplemented by reductions in loads from point sources, the second largest source of phosphorus in the basin. Unlike nitrogen, these combined phosphorus reductions were apparently large enough to overcome any increases in streamflow during the monitoring period, as both flow-adjusted concentrations and loads of total phosphorus decreased in the basin.

Conowingo Reservoir on the lower Susquehanna River is currently trapping about 2 percent of the nitrogen, 40 percent of the phosphorus, and 50 to 70 percent of the suspended-sediment loads that otherwise would be discharged to Chesapeake Bay (Langland and Hainly, 1997). When the reservoir reaches its capacity to trap and store nutrients and sediment, which is estimated to occur in 20 to 25 years, significant increases are expected in phosphorus and sediment loads at the downstream RIM station.

Table 8. Trends in dissolved nitrate load in base flow, percent base-flow nitrate load to surface-water total nitrogen load, and percent base flow to total streamflow in the Susquehanna River Basin

[Trends expressed as percent change; percent change reported if significant at the 95-percent confidence level; NS, non-significant; --, not applicable or insufficient data]

Station number	Station name	Site number	Time period of trend	Trend in base-flow nitrate load	Percent base-flow nitrate load to surface-water total nitrogen load	Percent base flow to total streamflow
	Multi-Agency Nontidal Stations					
01531500	Susquehanna River at Towanda, Pa.	2	1989-98	-14 to -49	49	40
01540500	Susquehanna River at Danville, Pa.	3	1985-98	NS	54	35
01553500	West Branch Susquehanna River at Lewisburg, Pa.	4	1985-98	-1 to -23	52	29
01567000	Juniata River at Newport, Pa.	5	1985-98	NS	51	51
01570000	Conodoguinet Creek near Hogestown, Pa.	6	1985-98	NS	--	59
01576000	Susquehanna River at Marietta, Pa.	7	1985-98	+3 to +77	56	56
01576754	Conestoga River at Conestoga, Pa.	8	1985-98	NS	65	65
	River Input Monitoring Program Station					
01578310	Susquehanna River at Conowingo, Md.	9	1985-98	NS	42	49

FACTORS AFFECTING TRENDS IN THE POTOMAC RIVER BASIN

Basin Description

The Potomac River Basin, at 15,570 mi^2, is the second largest tributary basin in the Chesapeake Bay Watershed. The Potomac River drains a watershed composed of diverse physical settings and land use. The RIM station on the Potomac River (01646580) is located at the Fall Line near the northern Washington, D.C., boundary at Chain Bridge Road, about 1 mi upstream from where the Potomac River widens and becomes tidally influenced (fig. 16); streamflow is measured 1 mi. upstream at Little Falls, Md. The RIM station receives drainage from 75 percent of the Potomac River Basin. Land use in the basin is about 61 percent forest, 35 percent agriculture, and 3 percent urban (table 3). Land use patterns are closely tied to the physical makeup of the basin, and land use differs significantly in the basins of the major tributaries to the Potomac River.

The westernmost tributaries, including the North and South Branch Potomac Rivers, drain the primarily forested Appalachian Plateau and the Valley and Ridge Provinces where farmland and small towns are located in the narrow river valleys. The Appalachian Plateau, the only coal-bearing region, is drained by the uppermost tributaries of the North Branch Potomac River.

The Great Valley extends across the center of the basin from near Waynesboro, Va., to Chambersburg, Pa. The Shenandoah River and Opequan Creek drain the Great Valley from the south, and Conococheague Creek and Antietam Creek drain the Great Valley from the north. Land use in the Great Valley is dominated by agriculture; however, the region has sizable urban areas and is experiencing significant urban and suburban development. Downstream from Harpers Ferry, W.Va., the Potomac River crosses the Blue Ridge Province, a pronounced ridge bounding the eastern edge of the Great Valley. This forested region contains many smaller streams that provide headwater drainage to Potomac River tributaries in the Great Valley and Piedmont Provinces.

The Piedmont Province is characterized by gently rolling hills and has more varied land use than other parts of the basin, with agricultural land dominating the northeastern portion and mixed forest, farmland, urban, and suburban land throughout Virginia and Maryland. The density of urban and suburban development increases closer to Washington, D.C. The Monocacy River is the principal Potomac River tributary in the Piedmont, and many smaller streams drain directly to the Potomac River.

The Coastal Plain Province and portions of the Piedmont drain to the tidal Potomac River downstream from the RIM station. Major tributaries include the Anacostia River in Maryland and the District of Columbia, and Occoquan River in Virginia. This region contains the most urbanized portion of the Potomac River Basin. Most major municipal wastewater treatment facilities in the metropolitan Washington, D.C., area discharge to the Potomac River downstream from the RIM station. Therefore, trends observed in water quality at the RIM station are not indicative of changes in wastewater discharges from the largest facilities in this basin.

Of the nine Chesapeake Bay tributaries monitored, the Potomac River contributes about 20 percent of the streamflow, 28 percent of the total nitrogen load, and 33 percent of the total phosphorus load from the non-tidal portion of the Chesapeake Bay Watershed, making it the second largest streamflow and nutrient source to the Bay (Belval and Sprague, 1999).

Trends

The stream discharge and observed concentrations of total nitrogen and total phosphorus at the Potomac River RIM station from 1985 to 1998 are shown in figure 17. Total nitrogen concentrations ranged from 0.35 to 11.4 mg/L, with a median of 1.8. Total phosphorus concentrations ranged from 0.01 to 3.29 mg/L, with a median of 0.06 mg/L. In 1996, nitrogen and phosphorus concentrations remained above average for a prolonged period. This may have been due to higher-than-normal streamflow and associated lower relative rates of instream nutrient uptake.

During the period from 1985 to 1998, there were no significant trends in loads of total nitrogen or total phosphorus at the RIM station (table 9). Only two of the upstream monitoring stations showed significant trends in phosphorus or nitrogen loads. There was a

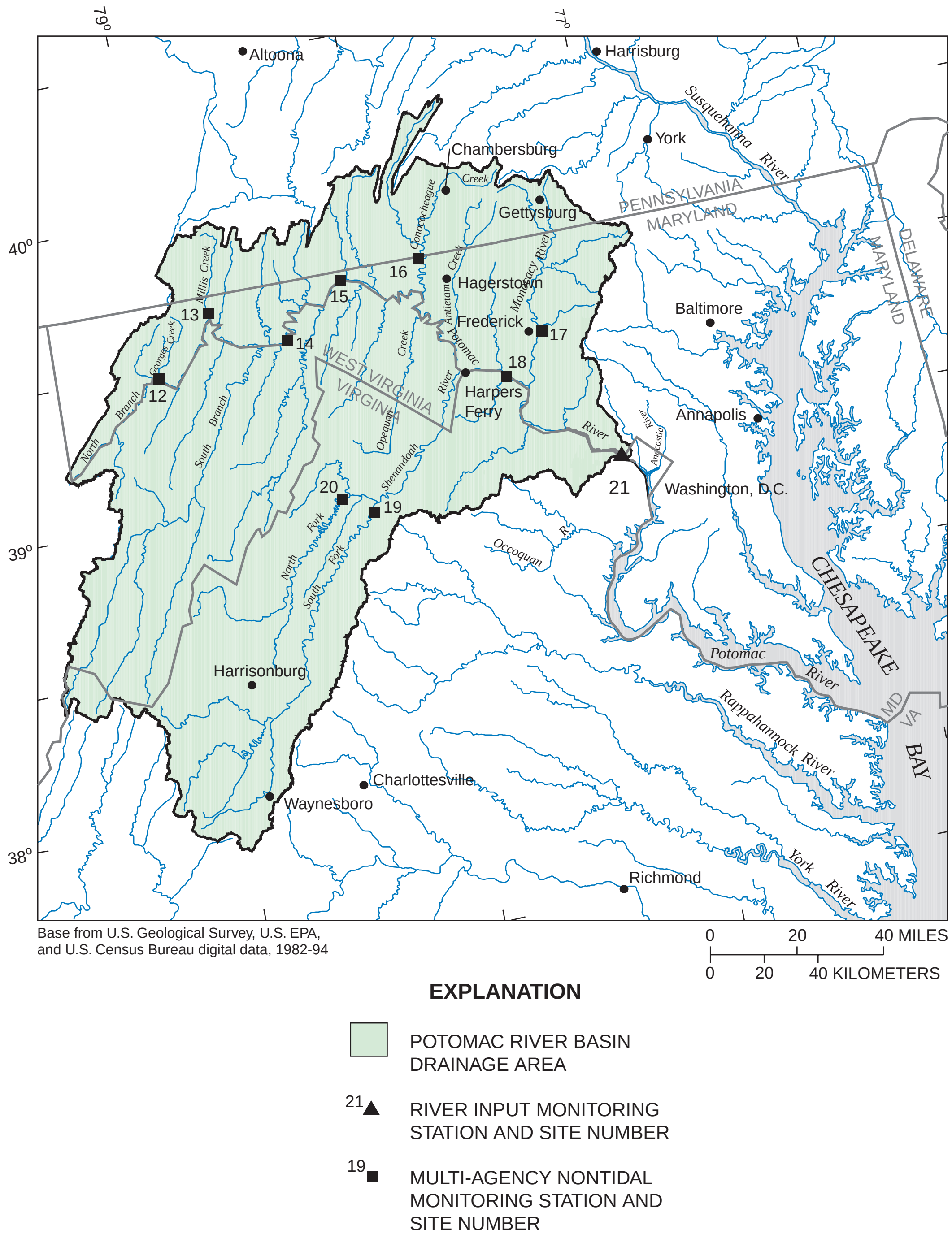


Figure 16. Location of the monitoring stations in the Potomac River Basin.

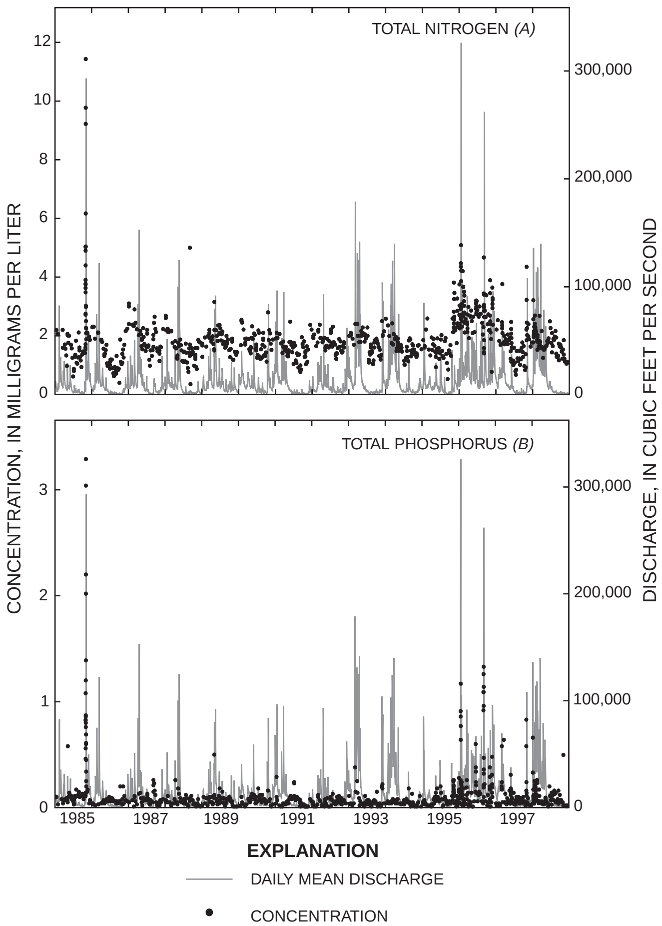


Figure 17. Observed total nitrogen *(A)* and total phosphorus *(B)* concentrations and daily mean discharge at the Potomac River Basin RIM station, 1985 through 1998.

significant increase in total nitrogen loads at the Conococheague Creek station, and an increase in loads of both nitrogen and phosphorus at the North Fork Shenandoah River station.

Streamflow increased significantly during the monitoring period at the Potomac River near Washington, D.C., with relatively wet years occurring in 1993, 1994, and 1996 (fig. 17, table 9). In fact, 1996 was one of the wettest years on record for the Potomac River, with daily mean streamflow exceeding 200,000 ft^3/s in both January and September. Monitoring stations in the middle part of the basin also showed significant increases in streamflow, while those on upper tributaries and the Monocacy River showed no significant trend in streamflow. The two stations that showed increases in nutrient loads also showed increases in streamflow; thus, increases in loadings may be, in large part, due to increases in flow.

Trends in flow-adjusted concentrations indicate the change in nutrient concentrations after the effects of streamflow have been removed. Flow-adjusted concentration trends at all stations in the Potomac River Basin were either downward or not significant (table 9). Flow-adjusted nitrogen concentrations decreased at seven upstream monitoring stations; however, there was no significant trend at the RIM station. Flow-adjusted total phosphorus concentrations also decreased at six of the upstream monitoring stations having sufficient data. Flow-adjusted phosphorus concentrations decreased by 40 to 60 percent over the monitoring period at the RIM station.

Nutrient Budgets and Yield Distribution

Nutrient Budgets

Nitrogen and phosphorus budgets were calculated for the Potomac River Basin upstream from the Potomac River RIM station (fig. 18). These budgets are Chesapeake Bay WSM estimates of the nutrient load delivered from six source categories, and are simulated for 1985 and 1998 using average hydrology in the basin.

Nitrogen

Results of WSM simulations indicate that agriculture is the primary source of nitrogen in the Potomac River Basin and, in 1985, accounted for about 60 percent of the total nitrogen budget (fig. 18). Although forest is the predominant land cover, forested areas contributed only about 11 percent of the nitrogen budget in the Potomac River Basin. Urban sources contributed about 15 percent of the nitrogen budget, while point sources contributed about 9 percent. Septic systems accounted for less than 4 percent of the nitrogen budget. Direct atmospheric deposition to water bodies was estimated at less than 1 percent of the budget for 1985. From 1985 to 1998, the contribution of agriculture to the nitrogen budget declined to 52 percent. However, population growth in the basin led to an increase in the contribution from urban areas and septic inputs, to 19 and 5 percent of the nitrogen budget, respectively.

Table 9. Trends in monthly mean flow, monthly load of total nitrogen (TN) and total phosphorus (TP), and flow-adjusted concentrations of TN and TP for stations in the Potomac River Basin

[TN, total nitrogen; TP, total phosphorus; NS, non-significant; --, not applicable or insufficient data; trends expressed as percent change; percent change is reported if significant at the 95-percent confidence level]

Station number	Station name	Site number	Time period of trend	Monthly mean flow trend	Monthly load trend		Flow-adjusted concentration trend	
					TN	TP	TN	TP
	Multi-Agency Nontidal Stations							
01599000	Georges Creek near Franklin, Md.	12	1985-98	NS	NS	NS	-31 to -35	-73 to -75
01601500	Wills Creek near Cumberland, Md.	13	1985-98	NS	NS	NS	-43 to -47	NS
01610000	Potomac River at Paw Paw, W.Va.	14	1985-98	NS	NS	NS	-19 to -23	-50 to -57
01613000	Potomac River at Hancock, Md.	15	1985-98	NS	NS	NS	-33 to -126	-53 to -58
01614500	Conococheague Creek at Fairview, Md.	16	1985-98	+44 to +194	+22 to +141	--	-15 to -18	-53 to -4
01643000	Monocacy River at Reels Mill Road, Md.	17	1985-98	NS	NS	NS	-49 to -53	-56 to -62
01638500	Potomac River at Point of Rocks, Md.	18	1985-98	+14 to +128	NS	NS	-17 to -20	-57 to -62
01631000	South Fork Shenandoah River at Front Royal, Va.	19	1985-98	+32 to +163	NS	NS	--	NS
01634000	North Fork Shenandoah River at Strasburg, Va.	20	1985-98	+43 to +220	+96 to +414	+169 to +497	NS	--
	River Input Monitoring Program Station							
01646580	Potomac River at Chain Bridge, Washington, D.C.	21	1985-98	+16 to +154	NS	NS	NS	-60 to -40

Phosphorus

Results of WSM simulations indicate that agricultural sources accounted for about 63 percent of the phosphorus budget in this basin in 1985 (fig. 18). Point-source discharges were the second largest contributor, accounting for about 26 percent of the phosphorus budget. Urban sources accounted for about 8 percent of the budget, while forested areas and atmospheric deposition to water were relatively minor contributors. Between 1985 and 1998, the contribution of point sources to the phosphorus budget decreased to about 20 percent, a change coincident with improvements in wastewater treatment facilities and the phosphate detergent ban. However, increased development led to increases in the contribution from urban areas, to about 10 percent of the phosphorus budget. The contribution of agriculture also increased to about 67 percent.

Nutrient Yield Distributions

The amount of nitrogen and phosphorus delivered to the Potomac River RIM station from individual small reaches within the Potomac River Basin was estimated using the SPARROW model for 1987 conditions. The yields shown in figure 19 are less than the yields generated within the basin because of on-land and in-stream losses that occur between the point of generation and the monitoring station.

Nitrogen

According to the SPARROW model results, only 15 percent of the nitrogen generated in the Potomac River Basin reaches the RIM station (table 10). The watershed segments that delivered the highest nitrogen yield to Chesapeake Bay include those with high agricultural land use and those that are closest to the Potomac River RIM station. In general, delivered yields from forested areas were low. The areas with the greatest delivered yields are located along Conococheague Creek, Antietam Creek, Monocacy River, the South Fork Shenandoah River and its tributaries, and tributaries along the lower mainstem of Potomac River. Instream uptake is apparently a significant process in the Potomac River Basin, as Conococheague Creek, Monocacy River, and the most distant tributaries of the Shenandoah River deliver much lower yields than closer tributaries, yet the land use patterns in these areas are not substantially different. Instream uptake is particularly important in small streams, where instream nitrogen losses are as much as 10 times greater than in large streams (Preston and Brakebill, 1999).

Phosphorus

According to the SPARROW model results, only 3.4 percent of the phosphorus generated in the Potomac River Basin reaches the RIM station (table 10). The

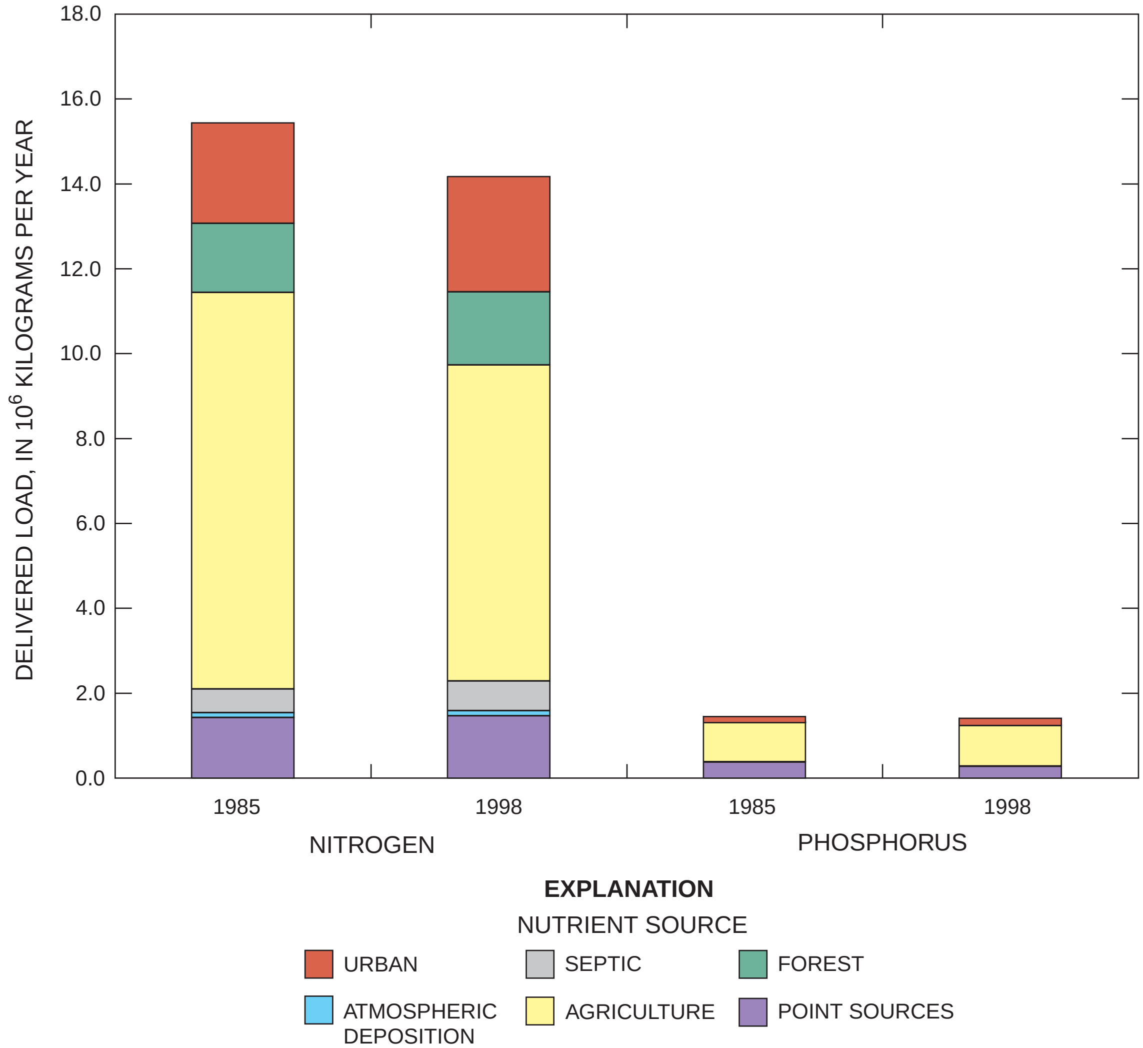


Figure 18. Contribution of major nutrient sources to the nitrogen and phosphorus budgets in the Potomac River Basin during 1985 and 1998, generated by the Chesapeake Bay Watershed Model.

spatial pattern of delivered yields for phosphorus is similar to nitrogen, with high delivered yields from agricultural and developed regions. Relative to nitrogen, areas with high delivered yields of phosphorus show a stronger correspondence with municipal wastewater dischargers. For example, high phosphorus yields occur on the stream segments that include wastewater discharges from Gettysburg and Chambersburg, Pa., Frederick and Hagerstown, Md., and several cities along the Shenandoah River in Virginia and West Virginia.

Trends in Nutrient Sources

Estimates of changes in nutrient source loads, land use, and management practices during the study period were provided by WSM simulations. These WSM estimates are described in the following section. Data on manure generation, animal numbers, and fertilizer sales derived from the U.S. Census of Agriculture and data on point source discharges from the USEPA are presented for comparison with model data.

Nitrogen

Throughout the Potomac River Basin, BMPs and nutrient management plans have been implemented to curb the amount of nitrogen reaching streams from agricultural sources. Partly as a result of these efforts, the nitrogen load from agricultural sources within the Potomac River Basin declined by 20 percent from 1985 to 1998. The amount of agricultural acreage in the Potomac River Basin declined 8 percent, and an estimated 9 percent reduction was attributable to BMP implementation (table 11). Nitrogen loads from fertilizer application decreased by 33 percent, while loads from manure application increased by 19 percent.

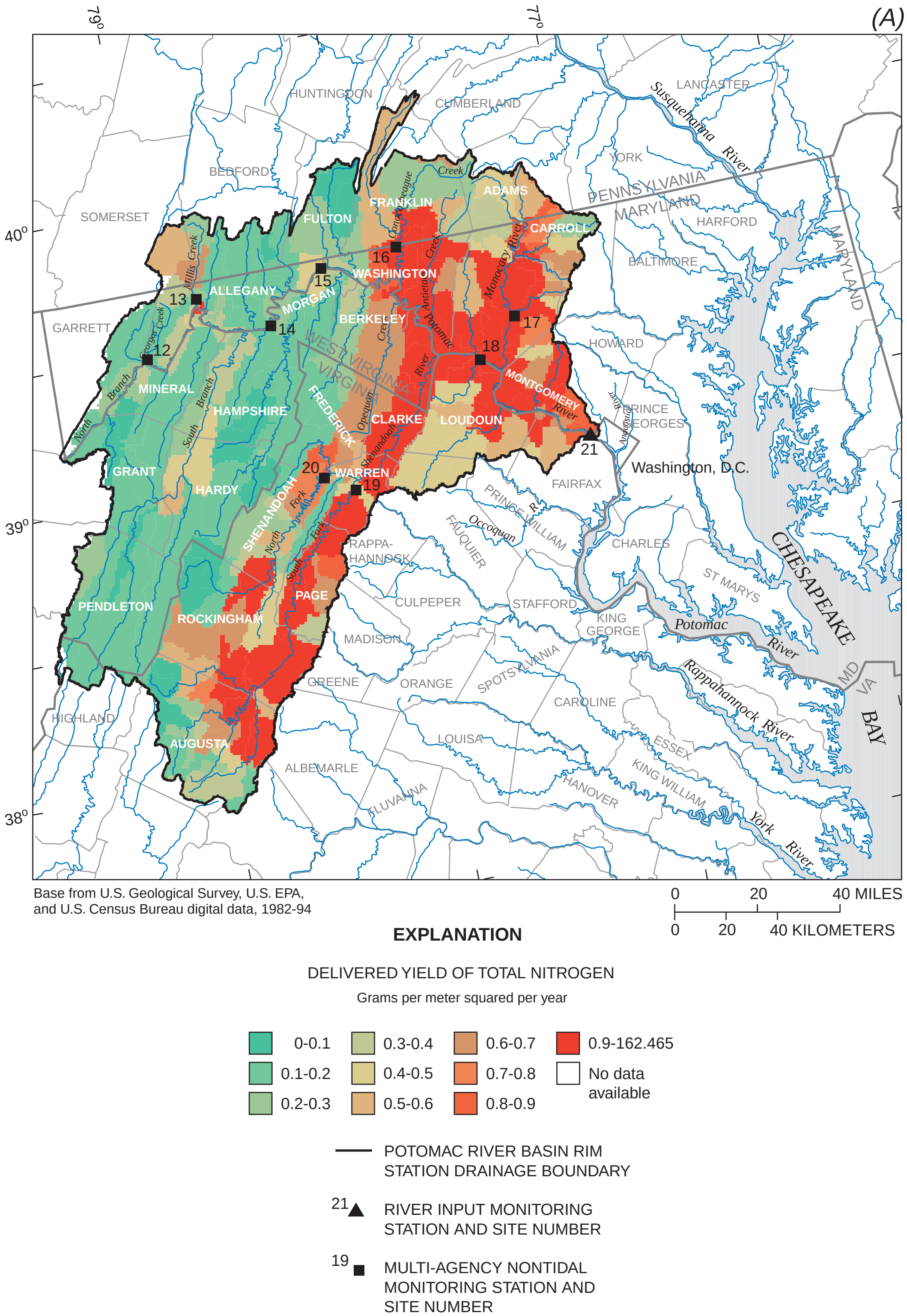


Figure 19. Delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the Potomac River Basin in 1987, generated by the SPARROW model.

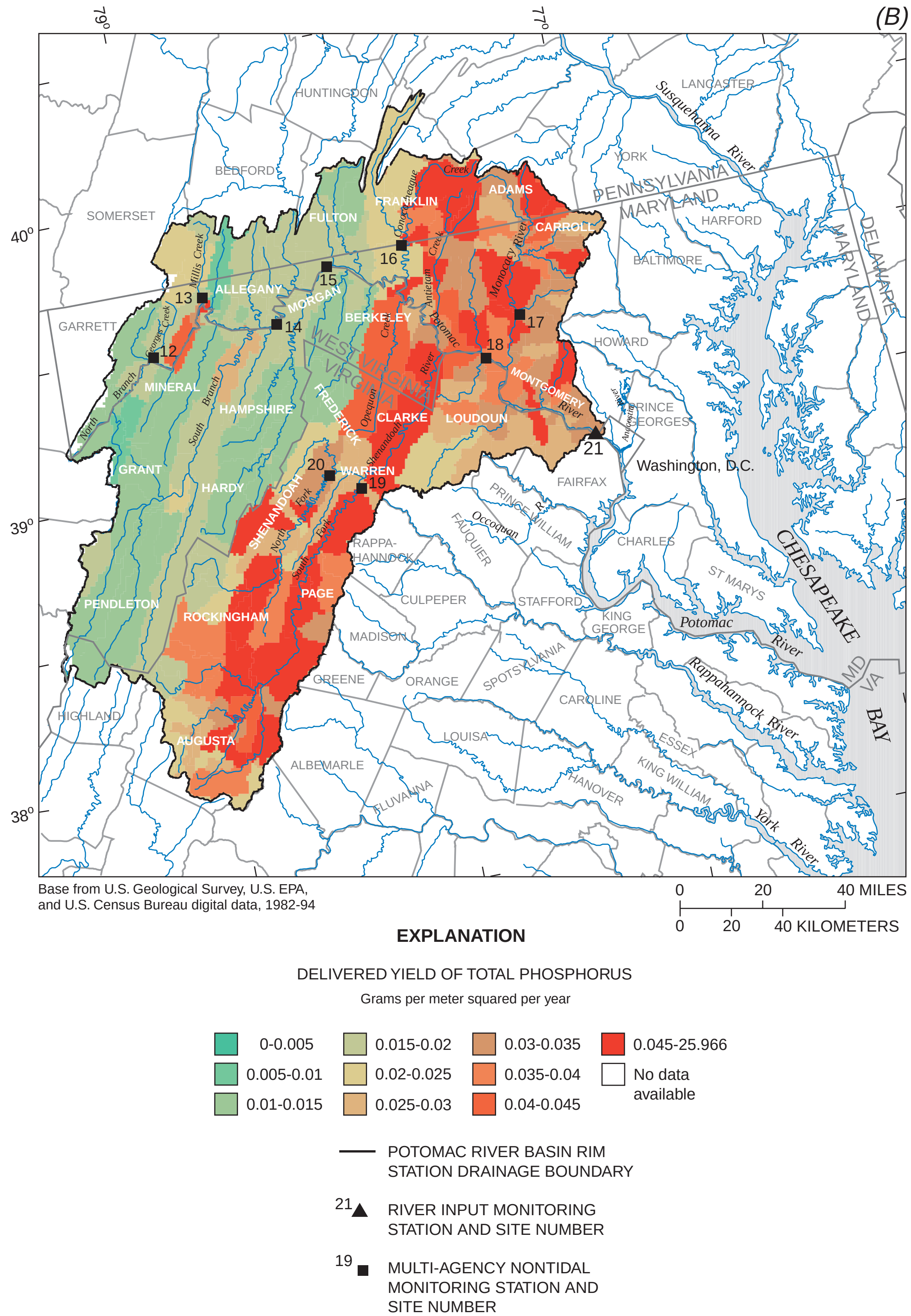


Figure 19. Delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the Potomac River Basin in 1987, generated by the SPARROW model.

Table 10. SPARROW model estimates of the percentage of total nitrogen and total phosphorus load generated in the watershed that is delivered to monitoring stations in the Potomac River Basin

Station number	Station name	Site Number	Percent delivered to station	
			Total nitrogen	Total phosphorus
	Multi-Agency Nontidal Stations			
01599000	Georges Creek near Franklin, Md.	12	32	9.0
01601500	Wills Creek near Cumberland, Md.	13	17	3.0
01610000	Potomac River at Paw Paw, W.Va.	14	20	5.0
01613000	Potomac River at Hancock, Md.	15	17	4.9
01614500	Conococheague Creek at Fairview, Md.	16	14	3.2
01643000	Monocacy River at Reels Mill Road, Md.	17	14	3.1
01638500	Potomac River at Point of Rocks, Md.	18	16	3.4
01631000	South Fork Shenandoah River at Front Royal, Va.	19	22	4.8
01634000	North Fork Shenandoah River at Strasburg, Va.	20	11	2.5
	River Input Monitoring Program Station			
01646580	Potomac River at Chain Bridge, Washington, D.C.	21	15	3.4

Table 11. Watershed Model estimates of percent change in land use acreage, percent change in loads due to best management practice implementation, source loads, delivered loads, and percent change in loads between 1985 and 1998 for nitrogen and phosphorus in the Potomac River Basin

[BMP, best management practice; kg/yr, kilograms per year; <, less than; reported load values are either source (input) loads or delivered (output) loads from the Watershed Model]

	% Acreage change	% Load change from BMP implementation	Load (kg/yr)		
			1985	1998	% Change
		Nitrogen			
Agriculture (Delivered)	-8	-9	8.97×10^6	7.15×10^6	-20
Fertilizer (Source)			3.96×10^7	2.65×10^7	-33
Manure (Source)			3.62×10^7	4.29×10^7	+19
Urban areas (Delivered)	+11	-1	2.27×10^6	2.61×10^6	+15
Fertilizer (Source)			9.77×10^6	1.12×10^7	+15
Forested areas (Delivered)	+2	<-1	1.57×10^6	1.65×10^6	+5
Point sources (Delivered)			1.37×10^6	1.41×10^6	+3
Septic (Delivered)			5.40×10^5	6.76×10^5	+25
Atmospheric deposition (Delivered)			1.09×10^5	1.12×10^5	+2
		Phosphorus			
Agriculture (Delivered)	-8	-12	8.80×10^5	9.15×10^5	+4
Fertilizer (Source)			1.22×10^7	9.12×10^6	-25
Manure (Source)			1.08×10^7	1.36×10^7	+26
Urban areas (Delivered)	+11	-1	1.14×10^5	1.36×10^5	+19
Fertilizer (Source)			0	0	0
Forested areas (Delivered)	+2	<-1	3.08×10^4	3.33×10^4	+8
Point sources (Delivered)			3.64×10^5	2.67×10^5	-27
Septic (Delivered)			0	0	0
Atmospheric deposition (Delivered)			1.09×10^5	1.12×10^5	+2

Nitrogen fertilizer sales in the basin remained essentially unchanged from 1985 to 1998 (fig. 20) (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999). The fertilizer sales data presented here should be interpreted with caution. U.S. Census of Agriculture data showed generally increasing nitrogen manure generation between 1987 and 1997 (fig. 21) (Puckett and others, 1998). The increase in manure loads and the decrease in fertilizer loads may have had a significant effect on nitrogen transport processes and loadings in the basin, as fertilizer sources are generally more soluble and mobile in soils and more rapidly transported to ground water and streams than organically bound nitrogen in manure.

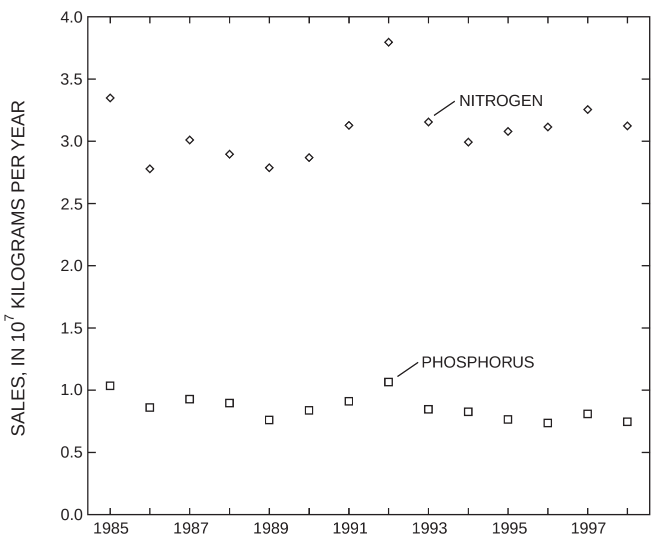


Figure 20. Annual sales of nitrogen and phosphorus fertilizer in the Potomac River Basin, 1985 to 1998.

The shift in the major source of agricultural nitrogen from fertilizer to manure is due largely to increases in poultry production in the basin (fig. 22). Rockingham County, Va., is one of the leading poultry-producing counties in the United States; poultry flocks increased by 60 percent in this county from 1987 to 1997 (USDA National Agricultural Statistics Service, 1997). Poultry flocks have also increased dramatically in many other counties throughout the basin, including Franklin County, Pa. (42 percent); Frederick County, Md. (168 percent); Grant (83 percent), Hardy (119 percent), Hampshire (462 percent), and Pendleton (102 percent) Counties, W.Va.; and Augusta (128 percent), Shenandoah (99 percent), and Page (106 percent) Counties, Va. In comparison, increases in

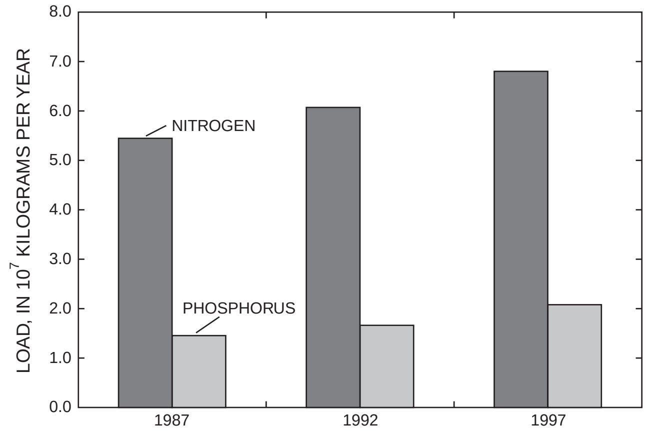


Figure 21. Annual load of nitrogen and phosphorus from manure generated in the Potomac River Basin in 1987, 1992, and 1997.

beef production have been small and somewhat offset by declines in dairy and swine production (USDA National Agricultural Statistics Service, 1997).

Nitrogen loads from urban areas, the second largest source of nitrogen in the Potomac River Basin, increased 15 percent between 1985 and 1998 (table 11). This is due largely to an 11-percent increase in urban acreage during this period. Loads from urban nitrogen fertilizer use also increased 15 percent. In addition, point-source nitrogen loads increased slightly from 1985 to 1998 (Wiedeman and Cosgrove, 1998) (fig. 23); however, these increases appear to have been slower than the rate of population growth in the basin.

Phosphorus

The two largest sources of phosphorus in the Potomac River Basin, agriculture and point sources, made up nearly 90 percent of the phosphorus budget (fig. 18). The phosphorus load delivered from agricultural sources within the basin increased slightly from 1985 to 1998 (table 11). This increase was due in large part to the 26-percent increase in loads from manure application during this period. U.S. Census of Agriculture data showed generally increasing phosphorus manure generation between 1987 and 1997 (fig. 21) (Puckett and others, 1998). The large increase in poultry production in the basin had a significant effect on phosphorus manure loadings, as poultry waste contains much more phosphorus than other animal manure. Phosphorus loads from fertilizer application decreased 25 percent (table 11), in part due to the implementation of nutrient management plans, though sales in the basin remained essentially unchanged from 1985 to 1998 (fig. 20) (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999). The decreases in fertilizer load and the estimated 12-percent decrease resulting from BMP implementation, however, were not enough to offset the increases in manure load.

Loads from point sources, the second largest source of phosphorus in the Potomac River Basin, decreased 27 percent between 1985 and 1998 (Wiedeman and Cosgrove, 1998) (table 11, fig. 23). Loads from urban areas, which made up less than 10 percent of the phosphorus budget, increased an estimated 19 percent.

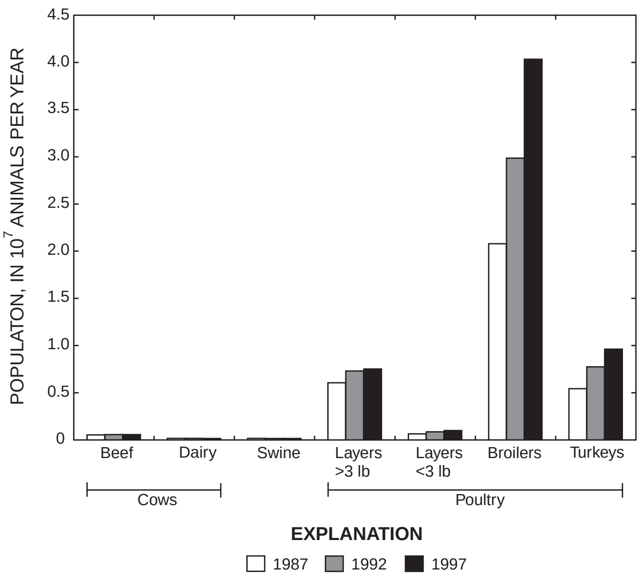


Figure 22. Population distribution of agricultural animals in the Potomac River Basin in 1987, 1992, and 1997.

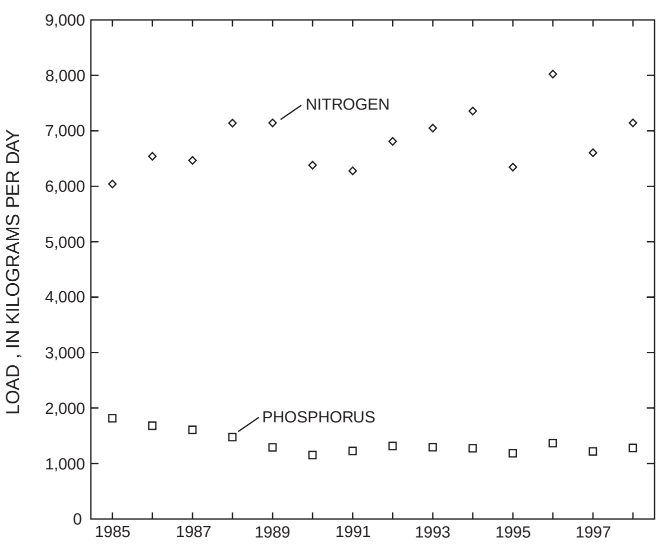


Figure 23. Annual mean point source load of total nitrogen and total phosphorus discharged in the Potomac River Basin, 1985 to 1998.

Ground Water

Between 1985 and 1998 at the RIM station, an average of 33 percent of the total nitrogen load in the Potomac River came from ground-water inputs of nitrate (table 12). However, there was no significant trend in the contribution of nitrate from ground water during this period (table 12). It is unlikely that ground water impacted the nitrogen trends at the RIM station.

Summary

Nitrogen trends at the Potomac River RIM station are largely controlled by agricultural sources in the watershed, as agriculture made up over half of the nitrogen budget in the basin. Reductions in nitrogen loads from BMP implementation and nutrient management were somewhat offset by substantial increases in manure load resulting, in part, from an increasing poultry population. In addition, nitrogen loads from urban areas and point sources also increased during the monitoring period. As a result, there was no significant trend in either total nitrogen load or flow-adjusted concentrations at the RIM station.

Combined loads from agriculture and point sources made up nearly 90 percent of the phosphorus budget in the Potomac River Basin. Large increases in manure loads offset reductions from BMP implementation and nutrient management of fertilizer application, resulting in a slight increase in loads from agriculture. However, a substantial reduction in point source loads offset this small increase, leading to a 40 to 60 percent decrease in flow-adjusted total phosphorus concentrations in the basin. Natural increases in streamflow during the monitoring period prevented a similar decreasing trend in total phosphorus loads.

Table 12. Trends in dissolved nitrate load in base flow, percent base-flow nitrate load to surface-water total nitrogen load, and percent base flow to total streamflow in the Potomac River Basin

[Trends expressed as percent change; percent change reported if significant at the 95-percent confidence level; NS, non-significant; --, not applicable or insufficient data]

Station number	Station name	Site number	Time period of trend	Trend in base-flow nitrate load	Percent base-flow nitrate load to surface-water total nitrogen load	Percent base flow to total streamflow
	Multi-Agency Nontidal Stations					
01599000	Georges Creek near Franklin, Md.	12	1985-98	NS	--	58
01601500	Wills Creek near Cumberland, Md.	13	1985-98	NS	--	50
01610000	Potomac River at Paw Paw, W.Va.	14	1985-98	NS	--	53
01613000	Potomac River at Hancock, Md.	15	1985-98	NS	40	48
01614500	Conococheague Creek at Fairview, Md.	16	1985-98	0 to 32	58	59
01643000	Monocacy River at Reels Mill Road, Md.	17	1985-98	NS	41	49
01638500	Potomac River at Point of Rocks, Md.	18	1985-98	-45 to -69	50	53
01631000	South Fork Shenandoah River at Front Royal, Va.	19	1985-98	NS	--	59
01634000	North Fork Shenandoah River at Strasburg, Va.	20	1985-98	NS	--	38
	River Input Monitoring Program Station					
01646580	Potomac River at Chain Bridge, Washington, D.C.	21	1985-98	NS	33	51

Basin Description

The James River Basin, at 10,200 mi^2, is the third largest tributary basin in the Chesapeake Bay Watershed. The James River originates in the Appalachian Mountains near the Virginia-West Virginia border, flows through the Valley and Ridge, the Blue Ridge, the Piedmont, and the Coastal Plain Physiographic Provinces, and joins Chesapeake Bay near the city of Norfolk in southeastern Virginia. Two RIM stations, James River at Cartersville (02035000) and Appomattox River at Matoaca (02041650), are located in the James River Basin. The RIM station in the James River sub-basin is located approximately 40 mi upstream from the Fall Line in Cartersville, Va. (fig. 24). This station was selected based on the availability of a long-term discharge record; no major streams enter the river between Cartersville and the Fall Line. This monitoring station receives drainage from about 60 percent of the James River Basin.

The Appomattox River, located in another sub-basin of the James River Basin, flows through a small area of the Coastal Plain Physiographic Province, then joins the James River downstream from Richmond near the city of Hopewell. The RIM station is in Matoaca, Va. (fig. 24), and receives drainage from about 84 percent of the 1,600-mi^2 Appomattox River Basin. The Appomattox River RIM station is 2.8 mi downstream from the Lake Chesdin Dam, which serves to dampen and delay the hydrologic response of the Appomattox River at the RIM station during storm events.

Land use upstream of both RIM stations is dominated by forest, at 80 percent upstream from the James River station and 72 percent upstream from the Appomattox River station (table 3). Agriculture is the second largest land use, at 16 percent and 20 percent, respectively. The agricultural areas above the RIM stations are concentrated in the western part of the basin around Rockbridge, Botetourt, and Nelson Counties, and in the southeastern part of the basin around Amelia County.

Of the nine rivers monitored, the James River contributes about 12 percent of the streamflow, 5 percent of the total nitrogen load, and 20 percent of the total phosphorus load to Chesapeake Bay, making it the third largest streamflow and nutrient source to the Bay after the Susquehanna and the Potomac Rivers (Belval and Sprague, 1999). The contribution of the Appomattox River is much smaller, with 2 percent of the total streamflow and approximately 1 percent of both the total nitrogen and the total phosphorus load entering the Bay from this river.

Trends

The stream discharge and observed nitrogen and phosphorus concentrations at the James River sub-basin RIM station from 1988 through 1998 are shown in figure 25. Total nitrogen concentrations ranged from 0.03 to 3.3 mg/L, with a median of 0.68 mg/L. Total phosphorus concentrations ranged from 0.02 to 1.4 mg/L, with a median of 0.13 mg/L.

The stream discharge and observed nitrogen and phosphorus concentrations at the Appomattox River sub-basin RIM station from 1989 through 1998 are shown in figure 26. Total nitrogen concentrations ranged from 0.10 to 1.12 mg/L, with a median of 0.56 mg/L. Total phosphorus concentrations ranged from 0.01 to 0.20 mg/L, with a median of 0.05 mg/L.

There were no significant trends in either the total nitrogen or total phosphorus loads at the RIM station on these rivers between 1988 and 1998 (table 13). Although there was also no significant trend in streamflow, relatively wet years in 1996 and 1997 caused higher than normal flows and nutrient loads during those years. When streamflow was removed as a variable affecting in-stream concentrations of these nutrients, however, there were significant downward trends in flow-adjusted total nitrogen concentrations of 5 to 30 percent at the James River RIM station and 11 to 27 percent at the Appomattox River RIM station during the monitoring period. There was also a significant downward trend in flow-adjusted total phosphorus concentrations of 44 to 69 percent at the James River RIM station.

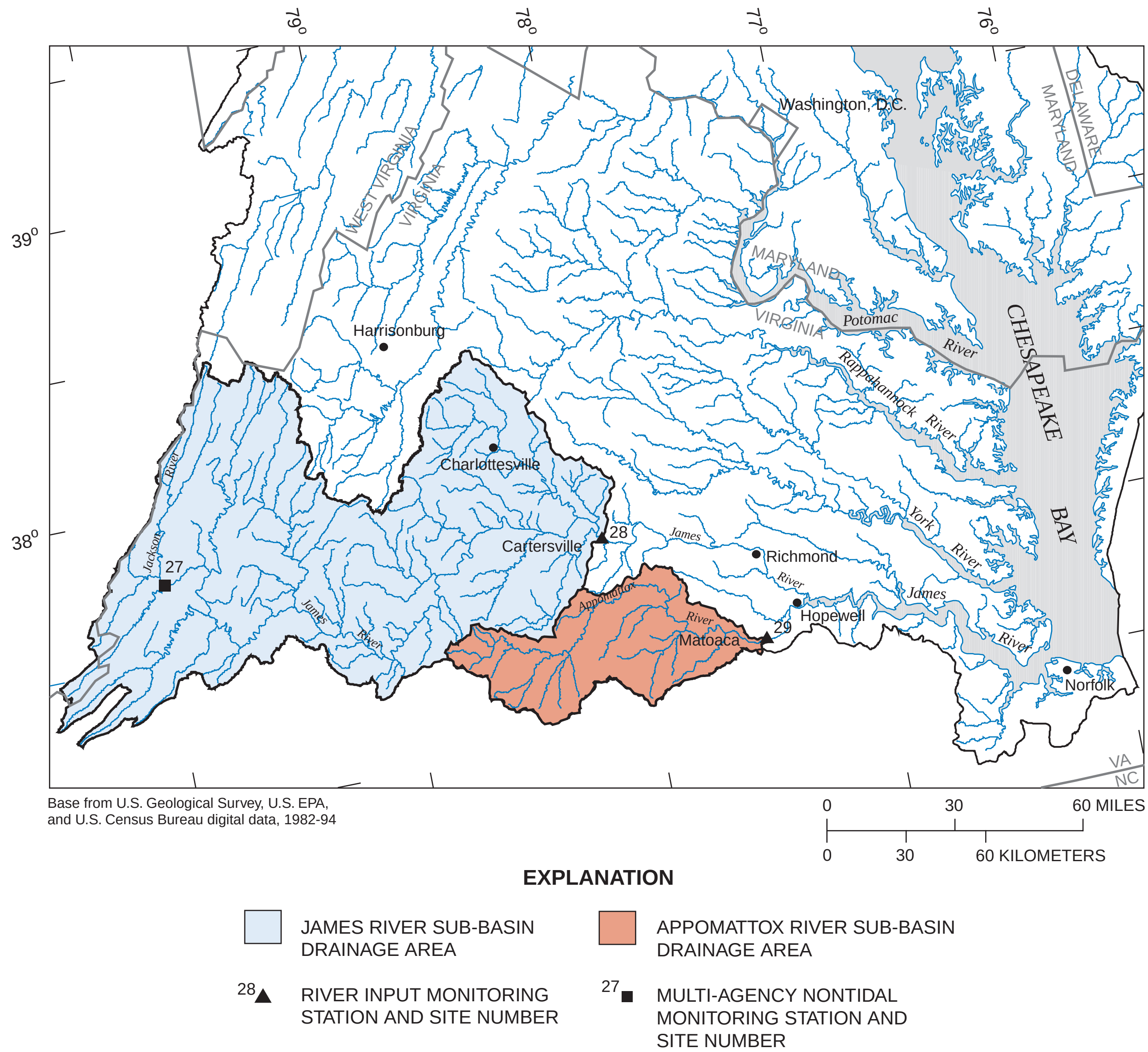


Figure 24. Location of the monitoring stations in the James River Basin.

Nutrient Budgets and Yield Distributions

Nutrient Budgets

Nitrogen and phosphorus budgets were calculated for the sub-basins upstream from the James River and Appomattox River RIM stations (figs. 27a and b). These budgets are Chesapeake Bay WSM estimates of the nutrient load delivered from six source categories, and are simulated for 1985 and 1998 using average hydrology in the basins.

Nitrogen

Results of WSM simulations indicate that in 1985, the two major contributors to the nitrogen budget in the James River sub-basin were agriculture (35 percent) and urban areas (26 percent) (fig. 27a). Forested areas contributed 21 percent of the total budget although they cover 80 percent of the watershed. Point sources contributed 13 percent of the nitrogen budget. Septic inputs and atmospheric deposition combined made up about 5 percent of the total nitrogen budget. In 1998, the contribution of urban and forested areas increased to 30

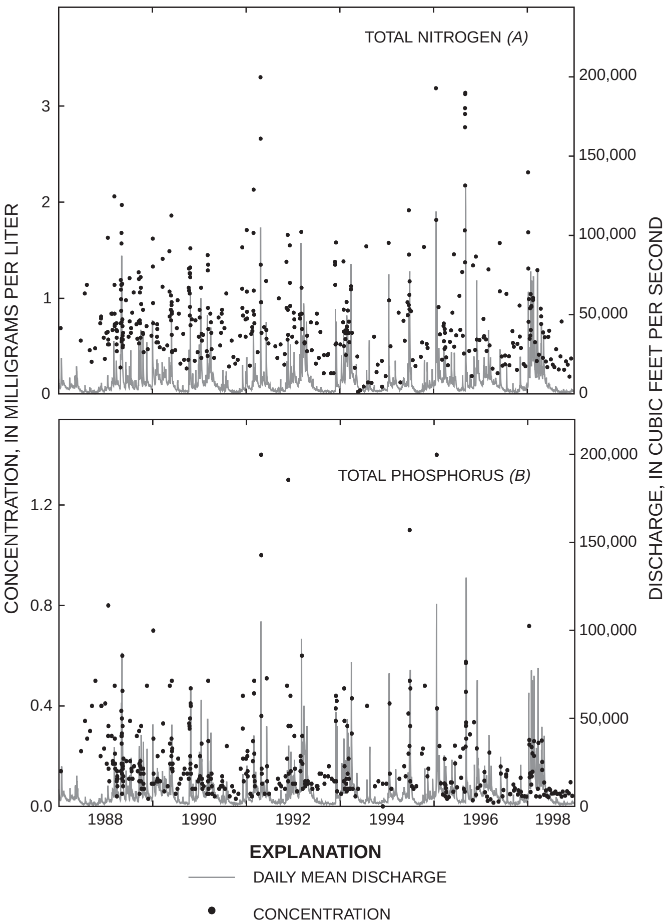


Figure 25. Observed total nitrogen *(A)* and total phosphorus *(B)* concentrations and daily mean discharge at the James River Basin RIM station, 1988 through 1998.

percent and 22 percent, respectively, whereas the contribution of agriculture and point sources decreased to 31 percent and 11 percent, respectively.

Similar to the James River sub-basin, the three major contributors to the nitrogen budget in the Appomattox River sub-basin in 1985 were agriculture (50 percent), urban areas (23 percent), and forested areas (21 percent) (fig. 27b). Septic inputs and atmospheric deposition together contributed about 5 percent of the nitrogen budget. There is only one small point source discharger in this basin, and contributions from point sources were negligible in 1985 and had increased by only about 1 percent in 1998. The remainder of the 1998 budget was similar to the 1985 budget. The relative contribution of urban areas increased to 26 percent, whereas the contribution of agriculture decreased to 42 percent.

Phosphorus

Results of WSM simulations indicate that in 1985, the three major contributors to the phosphorus budget in the James River sub-basin were agriculture (53 percent), forested areas (22 percent), and point sources (15 percent) (fig. 27a). Urban areas contributed approximately 10 percent. In 1998, the contribution of point sources had increased to 21 percent, whereas the contribution of agriculture had decreased to 48 percent. All other contributions remained consistent with 1985 levels.

In 1985, the three major contributors to the phosphorus budget in the Appomattox River sub-basin were agriculture (76 percent), urban areas (12 percent), and forested areas (9 percent) (fig. 27b). Contributions from all other sources were negligible. In 1998, the relative contributions of all sources had changed less than 1 percent.

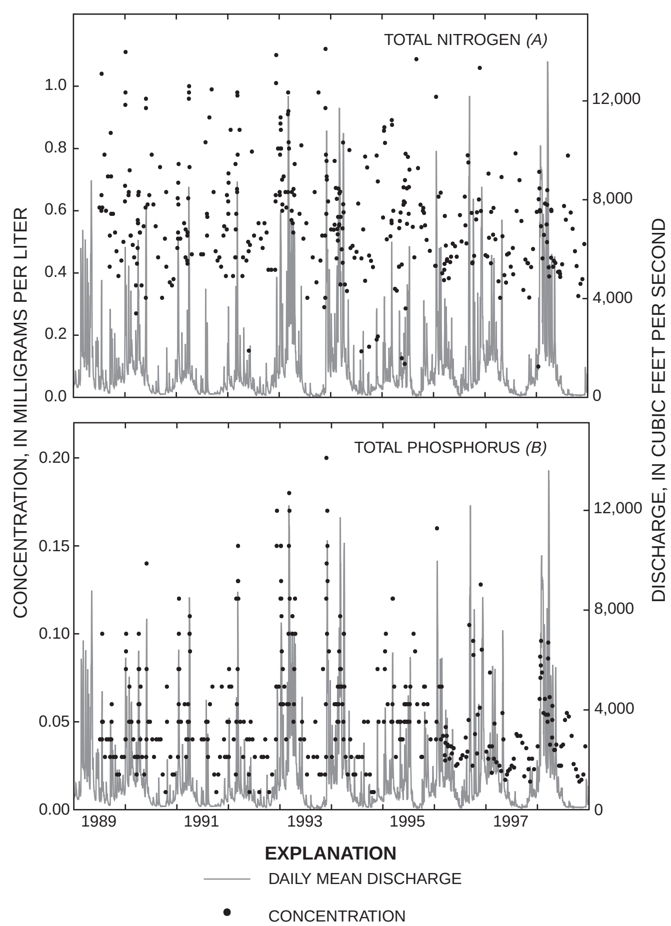


Figure 26. Observed total nitrogen *(A)* and total phosphorus *(B)* concentrations and discharge at the Appomattox River Basin RIM station, 1989 through 1998.

Table 13. Trends in monthly mean flow, monthly load of total nitrogen (TN) and total phosphorus (TP), and flow-adjusted concentrations of TN and TP for stations in the James River Basin

[TN, total nitrogen; TP, total phosphorus; NS, non-significant; --, not applicable or insufficient data; trends expressed as percent change; percent change is reported if significant at the 95-percent confidence level]

Station number	Station name	Site Number	Time period of trend	Monthly mean flow trend	Monthly load trend		Flow-adjusted concentration trend	
					TN	TP	TN	TP
Multi-Agency Nontidal Station								
02013100	Jackson River below Dunlap Creek at Covington, Va.	27	1985-98	NS	NS	-83 to -85	--	-119 to -124
River Input Monitoring Program Stations								
02035000	James River at Cartersville, Va.	28	1988-98	NS	NS	NS	-5 to -30	-44 to -69
02041650	Appomattox River at Matoaca, Va.	29	1989-98	NS	NS	NS	-11 to -27	NS

Nutrient Yield Distributions

The amount of nitrogen and phosphorus delivered to the James and Appomattox River RIM stations from individual small reaches within the James River Basin was estimated using the SPARROW model for 1987 conditions. The yields shown in figure 28 are less than the yields generated within the basin because of on-land and in-stream losses that occur between the point of generation and the monitoring station.

Nitrogen

According to the SPARROW model results, 20 percent of the nitrogen generated in the James River sub-basin and 13 percent of that generated in the Appomattox River sub-basin reach the RIM stations (table 14). Areas above the RIM stations in this basin that deliver high yields of nitrogen to the monitoring stations are in the southern part of the basin, near Campbell and Bedford Counties, and in the eastern part of the basin, in Dinwiddie and Chesterfield Counties. A small area of eastern Albemarle County, in the northern part of the basin, also delivers a high yield of total nitrogen.

Phosphorus

According to the SPARROW model results, 6.0 percent of the phosphorus generated in the James River sub-basin and 2.3 percent of that generated in the Appomattox River sub-basin reach the RIM stations (table 14). As with nitrogen, areas in the southern part of the basin, around Amherst and Campbell Counties, deliver high yields of total phosphorus to Chesapeake Bay. Eastern Albemarle and Alleghany Counties, in the northern part of the basin, also deliver high yields of total phosphorus.

With the exception of small portions of Albemarle and Rockbridge Counties, the counties with the highest rates of fertilizer and manure application do not deliver high yields of nitrogen and phosphorus to the RIM stations. This suggests that physical characteristics of these areas—such as low land-surface slope, high soil permeability, and proximity to smaller stream reaches in which greater in-stream losses can occur—decrease the delivery of nutrients from the land surface to the downstream monitoring stations.

Trends in Nutrient Sources

Estimates of changes in nutrient source loads, land use, and management practices during the study period were provided by WSM simulations. These WSM estimates are described in the following section. Data on manure generation, animal numbers, and fertilizer sales derived from the U.S. Census of Agriculture and data on point source discharges from the USEPA are presented for comparison with model data.

Nitrogen

James River Sub-Basin

The dominant nitrogen source in the James River sub-basin is agriculture, which made up approximately one-third of the nitrogen budget (fig. 27a). The WSM results indicate that from 1985 to 1998, delivered loads of nitrogen from agriculture decreased 17 percent. Most of this decrease resulted from an approximately

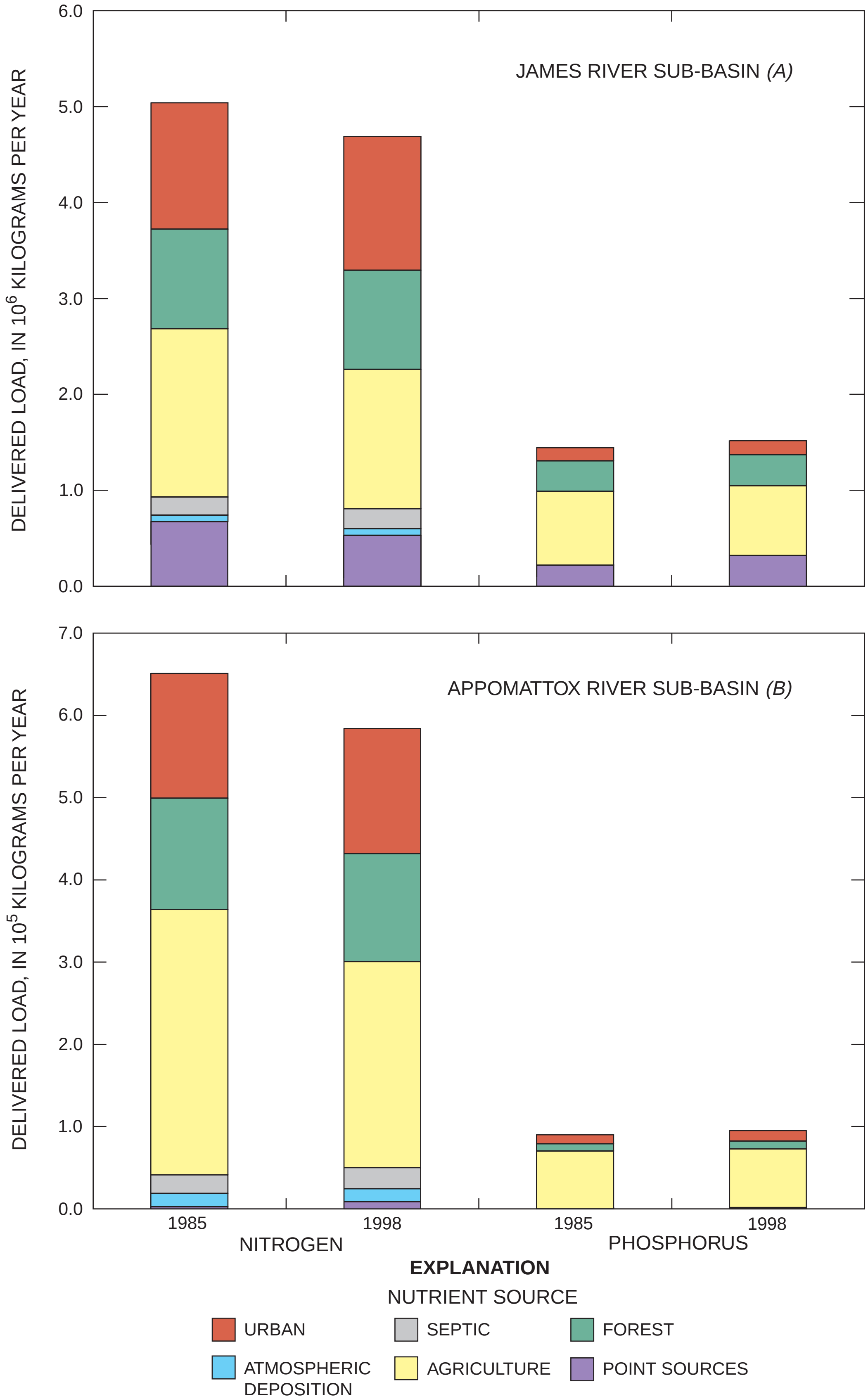


Figure 27. Contribution of major nutrient sources to the nitrogen and phosphorus budgets in the James River Basin *(A)* and the Appomattox River Basin *(B)* during 1985 and 1998, generated by the Chesapeake Bay Watershed Model.

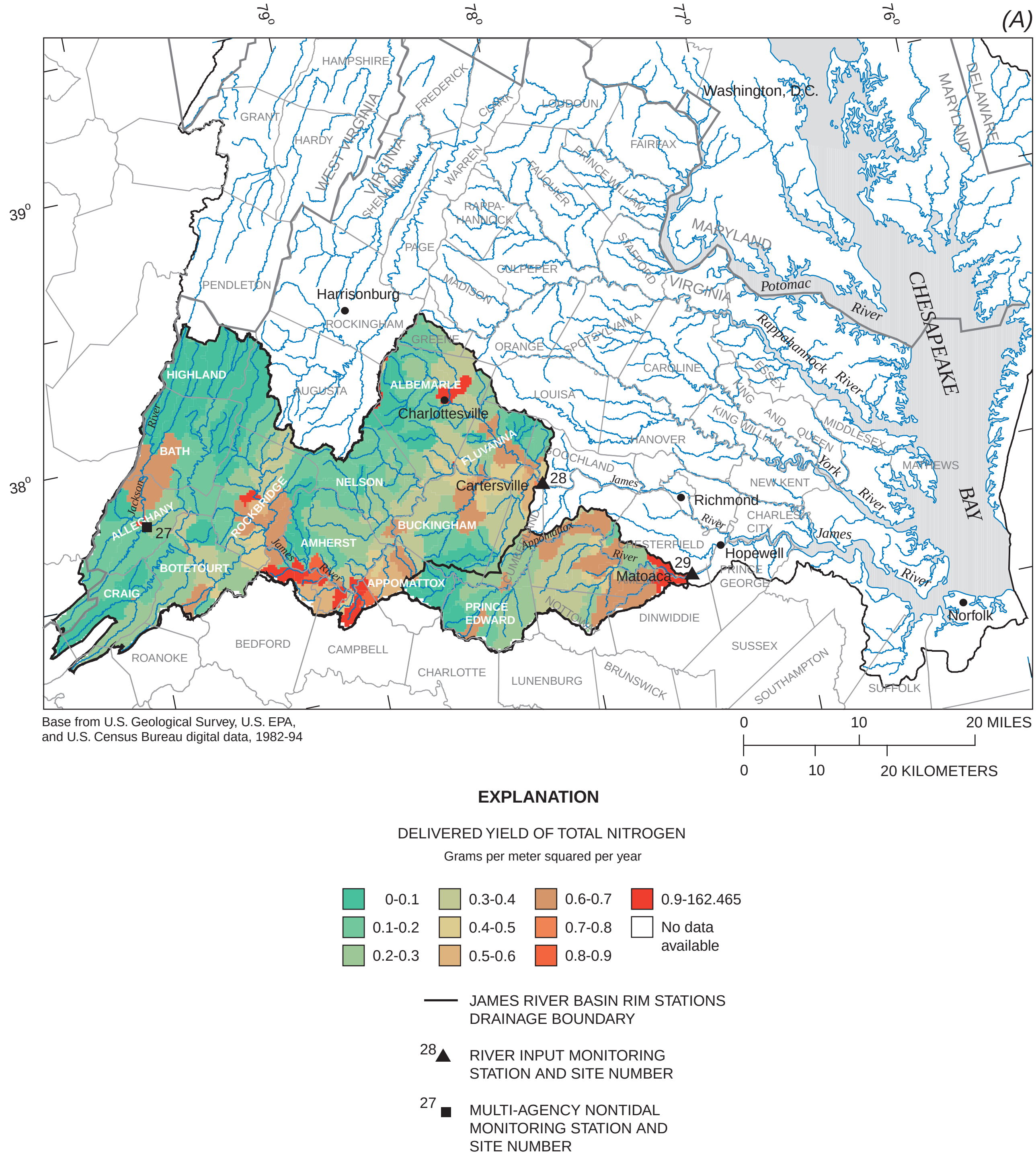


Figure 28. Map showing delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the James River Basin in 1987, generated by the SPARROW model.

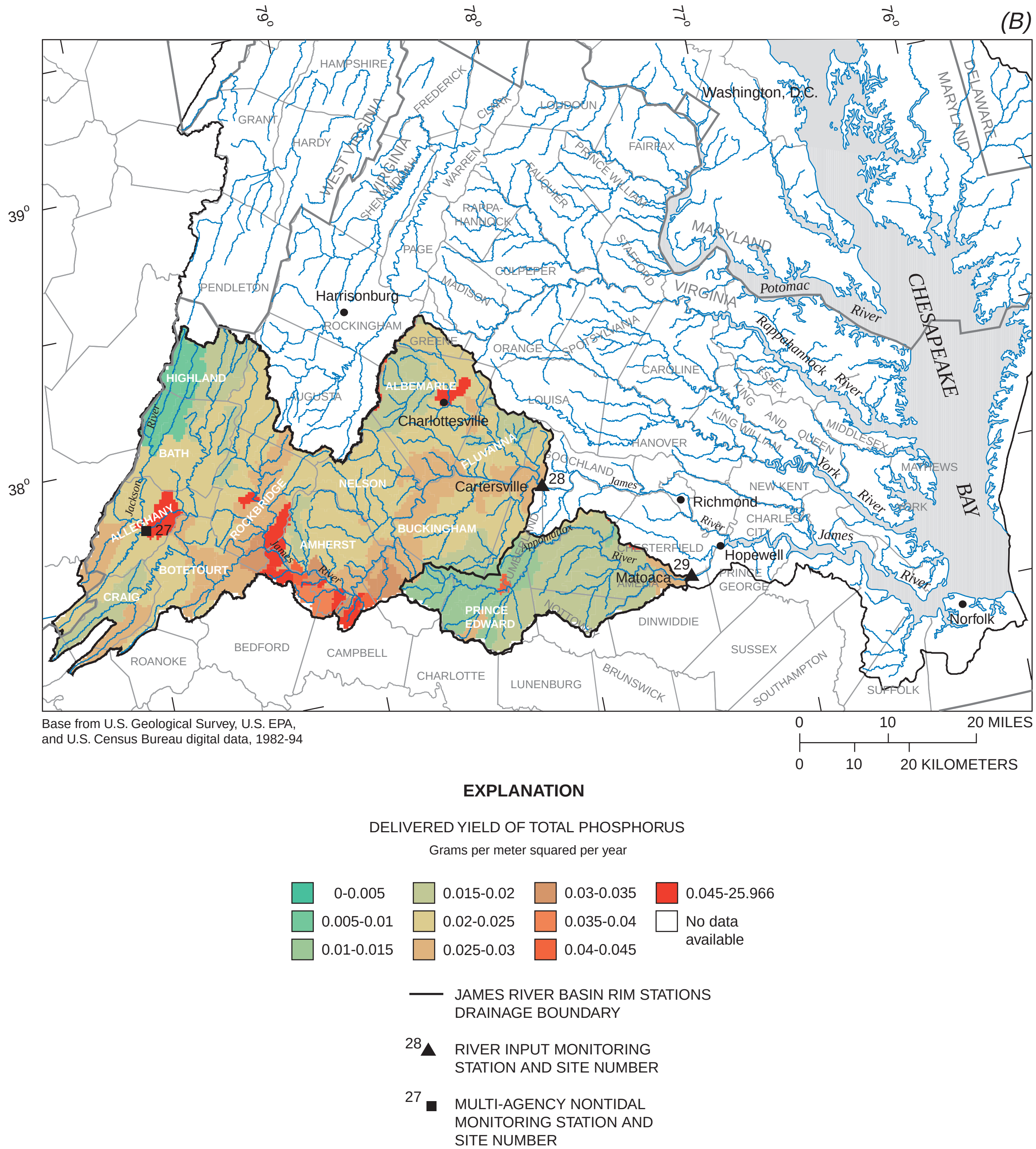


Figure 28. Map showing delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the James River Basin in 1987, generated by the SPARROW model.

Table 14. SPARROW model estimates of the percentage of total nitrogen and total phosphorus load generated in the watershed that is delivered to monitoring stations in the James River Basin

Station number	Station name	Site number	Percent delivered to station	
			Total nitrogen	Total phosphorus
	Multi-Agency Nontidal Station			
02013100	Jackson River below Dunlap Creek at Covington, Va.	27	33	7.3
	River Input Monitoring Program Stations			
02035000	James River at Cartersville, Va.	28	20	6.0
02041650	Appomattox River at Matoaca, Va.	29	13	2.3

11-percent decrease in agricultural acreage during this period (table 15). The implementation of BMPs resulted in an approximately 2-percent decrease in agricultural nitrogen loads.

The implementation of fertilizer nutrient management plans led to other reductions in agricultural nitrogen loads. Nitrogen loads from agricultural fertilizer application decreased an estimated 24 percent from 1985 to 1998, though sales fluctuated during this period (fig. 29a). The fertilizer sales data presented here should be interpreted with caution. The greatest amount of nitrogen fertilizer sold in the James River Basin (when weighted by the percentage of the county in the basin) was in Albemarle, Amelia, Rockbridge, and Augusta Counties (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999).

Nitrogen loads from manure application were greater than those from fertilizer application, and loads from manure application increased 5 percent in the sub-basin from 1985 to 1998 (table 15). U.S. Census of Agriculture data show increasing nitrogen manure generation between 1987 and 1992, then no substantial change between 1992 and 1997 (fig. 30a) (Puckett and others, 1998). The greatest manure generation of nitrogen (when weighted by the percentage of the county in the basin) occurs in Rockbridge, Albemarle, Amelia, Cumberland and Buckingham Counties, and manure generation increased in all of these counties from 1987 to 1992. Between 1992 and 1997, manure generation increased in Rockbridge and Amelia Counties, but decreased in Albemarle, Cumberland and Buckingham Counties. From 1987 to 1997 in these five counties, the numbers of poultry and beef cows generally increased, while the numbers of dairy cows and swine decreased (fig. 31) (USDA National Agricultural Statistics Service, 1997).

The second largest nitrogen source in this sub-basin is urban areas, which in 1998 contributed nearly as much nitrogen as agricultural areas (fig. 27a). From 1985 to 1998, there was a 6-percent increase in delivered load of nitrogen from urban areas (table 15). This was due in part to a 6-percent increase in urban acreage during this period. In addition, loads from urban nitrogen fertilizer application increased 10 percent.

The third largest nitrogen source is forested areas; input from these areas has remained relatively constant during the monitoring period (fig. 27a). Nitrogen contributions from point sources were relatively small in this basin, at about 12 percent of the nitrogen budget. From 1985 to 1998, there was an 11-percent decrease in nitrogen loading from point sources, likely from BNR upgrades at wastewater treatment plants (Wiedeman and Cosgrove, 1998) (fig. 32a). In contrast, septic inputs increased about 10 percent between 1985 and 1998 (table 15).

Appomattox River Sub-Basin

As in the James River sub-basin, agriculture is the largest contributor to the nitrogen budget in the Appomattox River sub-basin (fig. 27b). In this sub-basin, however, agriculture made up a greater percentage, at nearly half, of the budget. A 22-percent decrease in agricultural nitrogen loads from 1985 to 1998 resulted in large part from a 37-percent decrease in nitrogen loads from agricultural fertilizer application supplemented by an estimated 6 percent reduction from BMP implementation and a 3 percent reduction in agricultural acreage during the same time period (table 15). Nitrogen fertilizer sales remained relatively constant during this period (fig. 29b). The decrease in loads from fertilizer application was offset by a 29-percent increase in nitrogen loads from manure application.

Table 15. Watershed Model estimates of percent change in land use acreage, percent change in loads due to best management practice implementation, source loads, delivered loads, and percent change in loads between 1985 and 1998 for nitrogen and phosphorus in the James River Basin

[BMP, best management practice; kg/yr, kilograms per year; <, less than; reported load values are either source (input) loads or delivered (output) loads from the Watershed Model]

	% Acreage change	% Load change from BMP implementation	Load (kg/yr)		
			1985	1998	% Change
James River Sub-Basin—Nitrogen					
Agriculture (Delivered)	-11	-2	1.68×10^6	1.39×10^6	-17
Fertilizer (Source)			5.69×10^6	4.30×10^6	-24
Manure (Source)			6.30×10^6	6.60×10^6	+5
Urban areas (Delivered)	+6	<-1	1.27×10^6	1.34×10^6	+6
Fertilizer (Source)			4.67×10^6	5.12×10^6	+10
Forested areas (Delivered)	+2	<-1	9.98×10^5	9.93×10^5	<-1
Point sources (Delivered)			6.45×10^5	5.10×10^5	-21
Septic (Delivered)			1.82×10^5	2.00×10^5	+10
Atmospheric deposition (Delivered)			6.63×10^4	6.54×10^4	-1
James River Sub-Basin—Phosphorus					
Agriculture (Delivered)	-11	-3	7.31×10^5	6.99×10^5	-4
Fertilizer (Source)			2.69×10^6	2.30×10^6	-14
Manure (Source)			1.87×10^6	2.01×10^6	+8
Urban areas (Delivered)	+6	<-1	1.31×10^5	1.40×10^5	+7
Fertilizer (Source)			0	0	0
Forested areas (Delivered)	+2	<-1	3.05×10^5	3.10×10^5	+2
Point sources (Delivered)			2.13×10^5	3.02×10^5	+42
Septic (Delivered)			0	0	0
Atmospheric deposition (Delivered)			5.97×10^3	5.97×10^3	<+1
Appomattox River Sub-Basin—Nitrogen					
Agriculture (Delivered)	-3	-6	3.10×10^5	2.41×10^5	-22
Fertilizer (Source)			3.07×10^6	1.95×10^6	-37
Manure (Source)			2.21×10^6	2.84×10^6	+29
Urban areas (Delivered)	+3	<-1	1.46×10^5	1.46×10^5	<+1
Fertilizer (Source)			1.11×10^6	1.16×10^6	+5
Forested areas (Delivered)	<+1	<-1	1.30×10^5	1.26×10^5	-3
Point sources (Delivered)			2.47×10^3	8.29×10^3	+235
Septic (Delivered)			2.18×10^4	2.47×10^4	+13
Atmospheric deposition (Delivered)			1.54×10^4	1.51×10^4	-2
Appomattox River Sub-Basin—Phosphorus					
Agriculture (Delivered)	-3	-9	6.56×10^4	6.74×10^4	+3
Fertilizer (Source)			1.02×10^6	7.69×10^5	-25
Manure (Source)			6.77×10^5	9.25×10^5	+37
Urban areas (Delivered)	+3	<-1	1.08×10^4	1.24×10^4	+15
Fertilizer (Source)			0	0	0
Forested areas (Delivered)	<+1	<-1	8.22×10^3	9.10×10^3	+11
Point sources (Delivered)			1.13×10^3	1.69×10^3	+50
Septic (Delivered)			0	0	0
Atmospheric deposition (Delivered)			8.22×10^2	9.13×10^2	+11

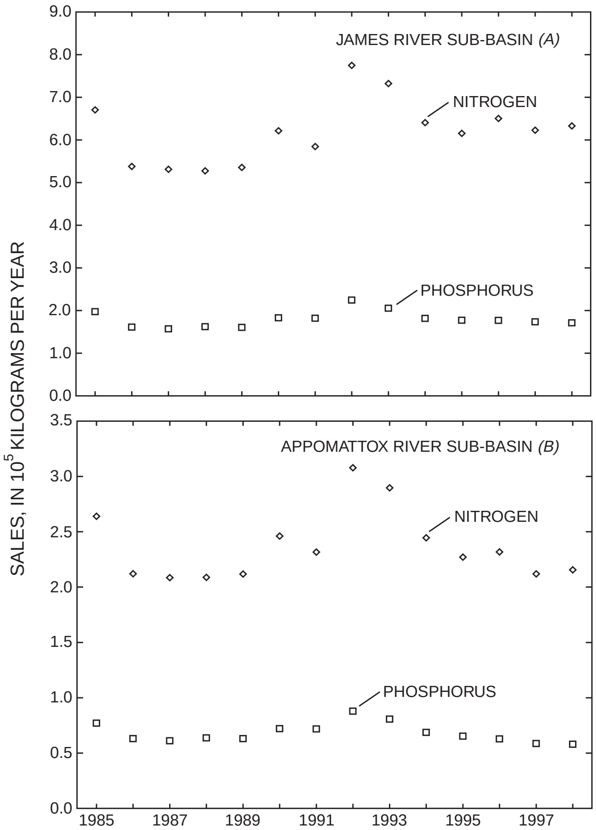


Figure 29. Annual sales of nitrogen and phosphorus fertilizer in the James River Basin *(A)* and the Appomattox River Basin *(B)*, 1985 to 1998.

U.S. Census of Agriculture data show generally increasing nitrogen manure generation between 1987 and 1997 (fig. 30b) (Puckett and others, 1998).

The second largest nitrogen source in the Appomattox River sub-basin is urban areas, which contribute approximately one-quarter of the nitrogen budget (fig. 27b). From 1985 to 1998, nitrogen loading from urban areas increased by less than 1 percent (table 15). Loads delivered from forested areas were only slightly smaller than those from urban areas. The contribution from forested areas also remained relatively constant from 1985 to 1998.

Other contributors, including point sources, septic inputs, and atmospheric deposition, together made up only about 5 percent of the nitrogen budget (fig. 27b). Although point source loads of nitrogen increased 235 percent during the monitoring period (fig. 32b), point sources made up less than 1 percent of the nitrogen budget, and this increase had little impact on the downward trend in flow-adjusted total nitrogen concentrations in this sub-basin.

Phosphorus

James River Sub-Basin

The dominant phosphorus source in the James River sub-basin is agriculture, which makes up approximately half of the phosphorus budget (fig. 27a). From 1985 to 1998, there was a 4-percent decrease in the delivered load of phosphorus from agriculture, much less than the 17-percent decrease in the delivered load of agricultural nitrogen. The decrease in agricultural phosphorus loads resulted partly from an approximately 11-percent decrease in agricultural acreage (table 15). In addition, the implementation of BMPs resulted in an approximately 3-percent decrease in delivered load of agricultural phosphorus.

Reductions in phosphorus achieved through the implementation of fertilizer nutrient management plans were smaller than those achieved for nitrogen (table 15). Agricultural phosphorus fertilizer loads decreased only an estimated 14 percent in this basin;

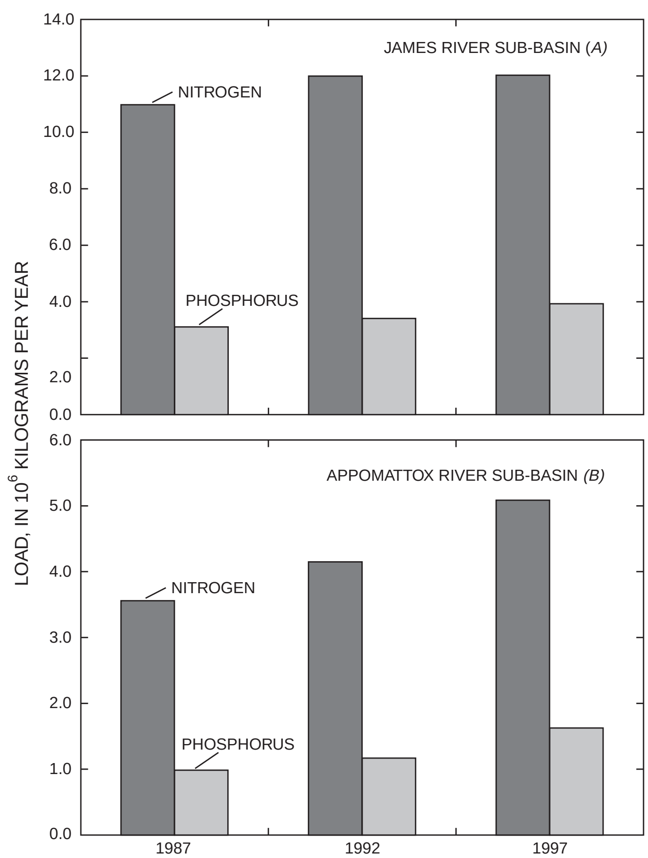


Figure 30. Annual load of nitrogen and phosphorus from manure generated in the James River Basin *(A)* and the Appomattox River Basin *(B)* in 1987, 1992, and 1997.

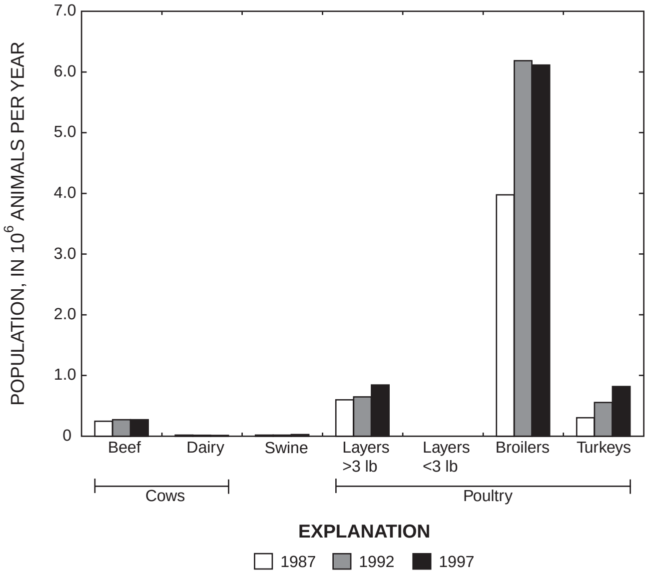


Figure 31. Population distribution of agricultural animals in the James River Basin (including the Appomattox River Basin) in 1987, 1992, and 1997.

sales were fairly steady (fig. 29a). The greatest amount of phosphorus fertilizer sold in the James River sub-basin (when weighted by the percentage of the county in the basin) was in Albemarle, Amelia, Rockbridge, and Augusta Counties (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999).

Although phosphorus loads from fertilizer application were slightly larger than those from manure application, phosphorus loads from manure application increased 8 percent in the basin from 1985 to 1998. U.S. Census of Agriculture data show generally increasing phosphorus manure generation between 1987 and 1997 (fig. 30a) (Puckett and others, 1998). The increase in loads from manure application somewhat offset the reductions achieved through fertilizer management. The largest generation of manure-derived phosphorus (when weighted by the percentage of the county in the basin) occurred in Rockbridge, Albemarle, Amelia, Cumberland and Buckingham Counties. Manure generation in these counties increased from 1987 to 1992, and continued to increase between 1992 and 1997 in all but Cumberland County.

The second largest phosphorus source in the James River sub-basin is forested areas, at about 20 percent (fig. 27a). The phosphorus loads delivered from these areas are high relative to the other basins in the Chesapeake Bay Watershed. This may be because of naturally high concentrations of phosphorus in the soil and rocks in localized areas of this basin (Herz and Force, 1987). Input from forested areas remained high but relatively constant during this period.

The third largest contribution of phosphorus was from point sources, at about 15 percent of the budget (fig. 27a). From 1985 to 1998, there was a 42-percent increase in phosphorus loading from point sources above the Fall Line (table 15). However, the RIM station at Cartersville is approximately 40 mi upstream from the Fall Line, and most of this 42-percent increase likely occurred downstream from the RIM station. Phosphorus loads from point sources above the monitoring station remained relatively constant during this period (Wiedeman and Cosgrove, 1998) (fig. 32a). Between 1985 and 1988, phosphorus loads dropped, likely a result of the phosphate detergent ban. After 1988, loads began to rise, due in part to increases in flow discharged from the point sources above the RIM station.

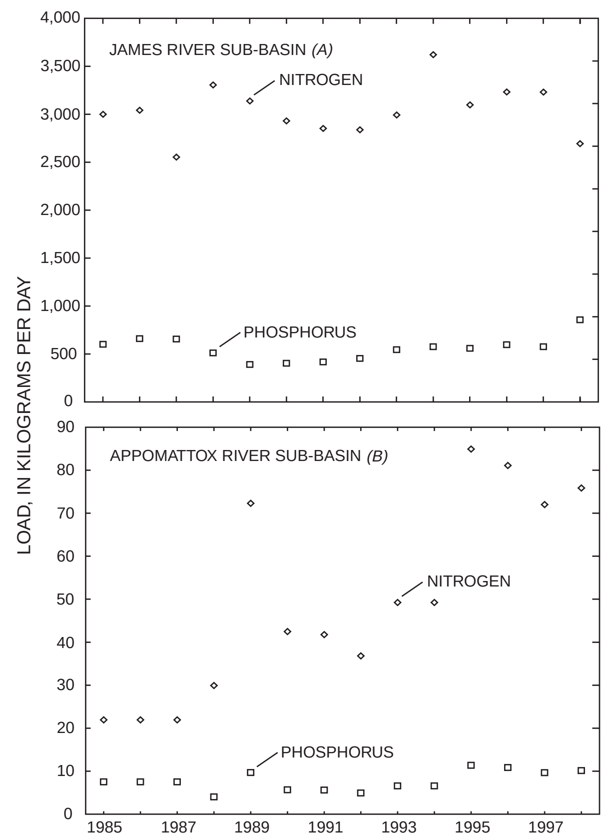


Figure 32. Annual mean point source load of total nitrogen and total phosphorus discharged in the James River Basin (A) and the Appomattox River Basin (B), 1985 to 1998.

Upstream of the RIM station, there was a significant decrease in loads and flow-adjusted concentrations of total phosphorus between 1985 and 1998 at the monitoring station on the Jackson River below Dunlap Creek at Covington, Va. (02013100), in the westernmost part of this sub-basin in Alleghany County (fig. 28b, table 13). According to the SPARROW model results, this area delivered a relatively high yield of total phosphorus to Chesapeake Bay in 1987 (fig. 28b). The trends at the Covington monitoring station suggest that management of phosphorus in this area have led to significant improvements. These downward trends likely contributed to the overall decrease in flow-adjusted total phosphorus concentrations observed downstream at the RIM station.

Appomattox River Sub-Basin

Agriculture is the largest source of phosphorus in the Appomattox River sub-basin as well, at nearly three-quarters of the budget (fig. 27b). The delivered load of phosphorus from agriculture remained relatively constant from 1985 to 1998, even though agricultural acreage decreased nearly 3 percent, BMP implementation led to an estimated 9-percent decrease, and phosphorus loads from fertilizer application decreased approximately 25 percent (table 15). Sales of phosphorus fertilizer fluctuated during this period (fig. 29b). In 1985, fertilizer was a larger source of phosphorus than manure, but by 1998, manure had become the larger source. U.S. Census of Agriculture data show generally increasing phosphorus manure generation between 1987 and 1997 (fig. 30b) (Puckett and others, 1998). Phosphorus loads from manure application increased 37 percent during this period, offsetting other reductions in agriculture (table 15).

There was a 3-percent increase in acreage of urban areas, the second largest source of phosphorus in this sub-basin (fig. 27b, table 15). Given that phosphorus loads from urban areas made up only 13 percent of the phosphorus budget, this change likely had little impact on the overall trend in flow-adjusted phosphorus concentrations in this sub-basin. Contributions from forested areas, the third largest source, remained relatively constant from 1985 to 1998. Contributions from all other sources, including point sources, were negligible.

Ground Water

Between 1985 and 1998 at the James River RIM station, an average of 21 percent of the total nitrogen load in the river came from ground-water inputs of nitrate (table 16). The load of nitrate from ground water decreased 43 to 74 percent from 1985 to 1998 (table 16), which contributed to the overall decrease in nitrogen in this sub-basin. At the RIM station on the Appomattox River, there was no significant change in nitrate loads entering the river from ground water during the study period (table 16), so ground-water contributions had a negligible impact on the downward trend in flow-adjusted total nitrogen concentrations in this sub-basin.

Summary

James River Sub-Basin

Flow-adjusted concentrations of both total nitrogen and total phosphorus decreased significantly in the James River sub-basin from 1988 to 1998, while loads of total nitrogen and total phosphorus did not change significantly. The lack of a corresponding decrease in loads cannot be explained by increasing streamflow, as there was no significant overall increase in streamflow during the monitoring period. It is possible that loads did not decrease significantly because of reduced efficiencies of BMPs during individual storm events.

Agriculture, the dominant source of nutrients in the James River sub-basin, contributed one-third of the nitrogen budget and half of the phosphorus budget. As a result, changes in agriculture contributed the most to the decreasing trend in flow-adjusted nutrient concentrations in this sub-basin. For nitrogen, an 11-percent decrease in agricultural acreage combined with an estimated 24-percent decrease in fertilizer loads offset the 5-percent increase in manure loads. These decreases in agriculture also offset a 6-percent increase in urban acreage. A substantial downward trend in nitrate entering the river from ground water also contributed to the downward trend in flow-adjusted total nitrogen concentrations.

For phosphorus, the 11-percent decrease in agricultural acreage combined with decreases achieved through nutrient management of fertilizer application and structural BMP implementation offset increases in loads from manure application. The other major, but smaller, contributors to the phosphorus budget, phosphorus-bearing soils and rocks and point sources, remained relatively constant. Significant reductions in phosphorus observed upstream from the RIM station in the western part of the basin also contributed to the downward trend in flow-adjusted total phosphorus concentrations observed near the Fall Line in the James River sub-basin.

Appomattox River Sub-Basin

The only significant trend in the Appomattox River sub-basin was a decrease in flow-adjusted total nitrogen concentrations. As in the James River sub-basin, agriculture is the dominant nutrient source, contributing half of the nitrogen budget and three-quarters of the phosphorus budget.

The downward trend in flow-adjusted total nitrogen concentrations resulted primarily from an estimated 37-percent decrease in nitrogen fertilizer loads and a 6-percent decrease from BMP implementation. These decreases offset the 29-percent increase in manure loads. Urban areas, the second largest contributor to the nitrogen budget, experienced only slight increases and contributed little to the overall trend.

There was no trend in flow-adjusted total phosphorus concentrations in this sub-basin. Reductions from nutrient management of fertilizer and BMP implementation were offset by a 37-percent increase in manure loads. Because agriculture made up three-quarters of the phosphorus budget, these factors minimized the impact of other changes in phosphorus sources in the sub-basin. Additionally, trapping of sediment and associated phosphorus behind the Lake Chesdin Dam likely maintained outflow phosphorus concentrations at a steady state throughout the monitoring period.

Table 16. Trends in dissolved nitrate load in base flow, percent base-flow nitrate load to surface-water total nitrogen load, and percent base flow to total streamflow in the James River Basin

[Trends expressed as percent change; percent change reported if significant at the 95-percent confidence level; NS, non-significant; --, not applicable or insufficient data]

Station number	Station name	Site number	Time period of trend	Trend in base-flow nitrate load	Percent base-flow nitrate load to surface-water total nitrogen load	Percent base flow to total stream-flow
	Multi-Agency Nontidal Station					
02013100	Jackson River below Dunlap Creek at Covington, Va.	27	1985-98	NS	--	57
	River Input Monitoring Program Stations					
02035000	James River at Cartersville, Va.	28	1988-98	-43 to -74	21	53
02041650	Appomattox River at Matoaca, Va.	29	1989-98	NS	15	47

Basin Description

The Rappahannock River Basin, at 2,800 mi^2, is the fourth largest tributary basin in the Chesapeake Bay Watershed. The Rappahannock River originates near the eastern edge of the Blue Ridge Physiographic Province and extends eastward through the Piedmont and Coastal Plain Physiographic Provinces. The RIM station (01668000) is located at the Fall Line just upstream of Fredericksburg, Va. (fig. 33). The monitoring station receives drainage from about 57 percent of the Rappahannock River Basin. Upstream from the monitoring station, the Rappahannock River Basin is of high relief, and the steep slopes cause the river to respond rapidly to storm events.

Land use upstream of the monitoring station is dominated by forest, at 61 percent, and agriculture, at 36 percent (table 3). The Rappahannock River Basin contains the highest percentage of agricultural land above the Fall Line of the five tributary basins in Virginia. The agricultural areas above the monitoring station are generally located in the central part of the basin, in Fauquier, Culpeper, Madison, and Orange Counties. Of the nine rivers monitored in the RIM Program, the Rappahannock River contributes about 3 percent of the streamflow, 2 percent of the total nitrogen load, and 8 percent of the total phosphorus load delivered annually from the nontidal part of the Chesapeake Bay Watershed (Belval and Sprague, 1999).

Trends

The stream discharge and observed nitrogen and phosphorus concentrations at the Rappahannock River RIM station from 1988 to 1998 are shown in figure 34. Total nitrogen concentrations ranged from 0.12 to 4.21 mg/L, with a median of 0.93 mg/L. Total phosphorus concentrations ranged from 0.008 to 1.50 mg/L, with a median of 0.06 mg/L.

There were no significant trends in total nitrogen and total phosphorus loads at the RIM station on the Rappahannock River between 1988 and 1998 (table 17). Although flows were higher during the latter half of this period, there was no overall trend in streamflow. However, when streamflow was removed as a variable affecting in-stream concentrations of these nutrients, there was a significant downward trend in flow-adjusted concentrations of total nitrogen and total phosphorus (21 to 41 percent and 41 to 76 percent, respectively) during the monitoring period. Upstream from the RIM station, total phosphorus loads increased significantly on the Robinson River near Locust Dale, Va.

Nutrient Budgets and Yield Distributions

Nutrient Budgets

Nitrogen and phosphorus budgets were calculated for the Rappahannock River Basin upstream from the RIM station (fig. 35). These budgets are Chesapeake Bay WSM estimates of the nutrient load delivered from six source categories, and are simulated for 1985 and 1998 using average hydrology in the basin.

Nitrogen

Results of WSM simulations indicate that in 1985, the major contributors to the nitrogen budget in the Rappahannock River Basin were agriculture (59 percent) and urban areas (21 percent) (fig. 35). Forested areas contributed 14 percent of the total nitrogen budget although they cover 61 percent of the watershed. Point sources and septic inputs combined to make up about 5 percent of the total budget. In 1998, the contribution of urban areas increased to 26 percent, whereas the contribution of agriculture decreased to 50 percent.

Phosphorus

Results of WSM simulations indicate that in 1985, the major contributor to the phosphorus budget in the Rappahannock River Basin was agriculture (76 percent) (fig. 35). Urban areas and point sources, the other substantial contributors, made up 14 percent and 9 percent of the budget, respectively. In 1998, the contribution of point sources had decreased to 4 percent of the budget, while the contribution of urban areas increased to about 18 percent. The contribution of agriculture remained consistent with 1985 levels.

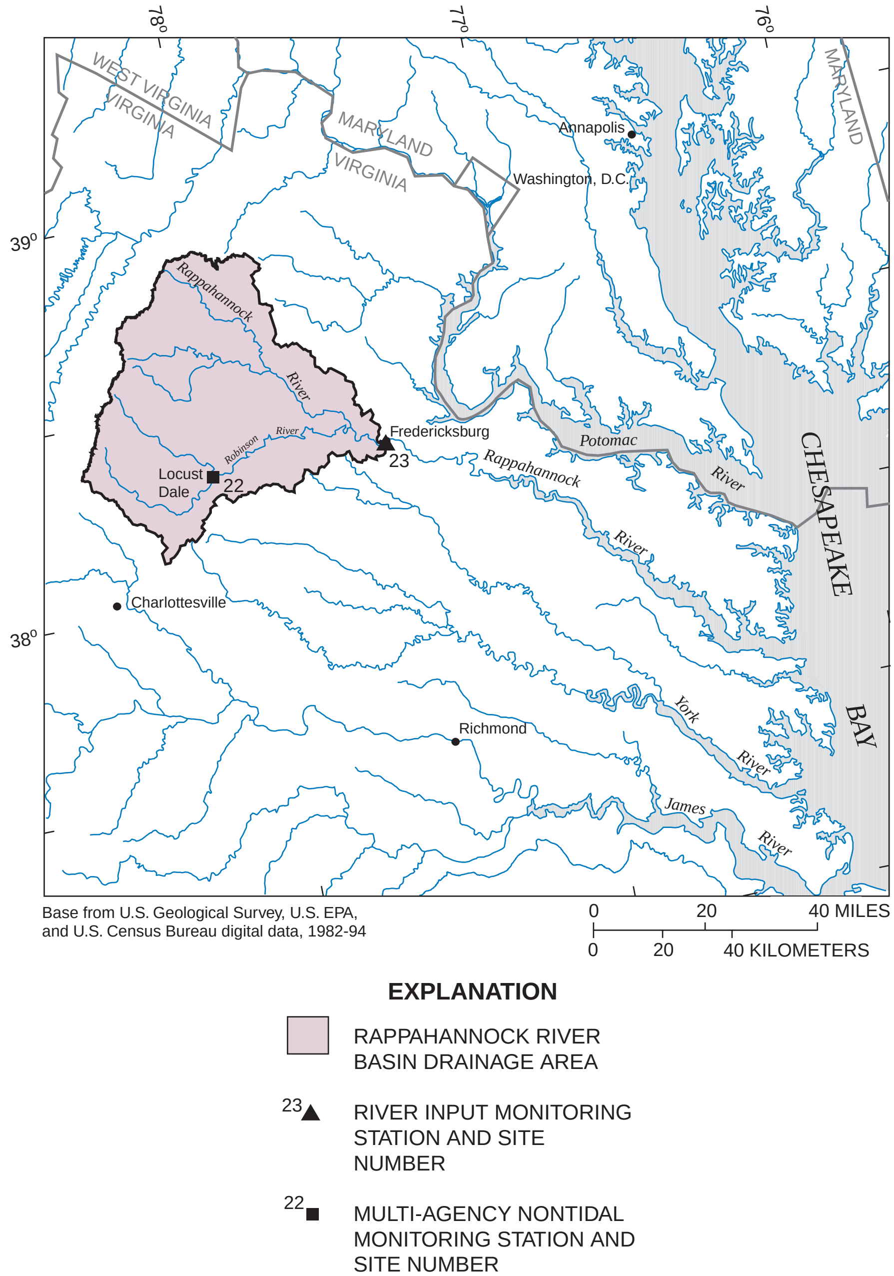


Figure 33. Location of the monitoring stations in the Rappahannock River Basin.

Nutrient Yield Distributions

The amount of nitrogen and phosphorus delivered to the Rappahannock River RIM station from individual small reaches within the Rappahannock River Basin was estimated using the SPARROW model for 1987 conditions. The yields shown in figure 36 are less than the yields generated within the basin because of on-land and in-stream losses that occur between the point of generation and the monitoring station.

Nitrogen

According to the SPARROW model results, only 14 percent of the nitrogen generated in the basin reaches the RIM station (table 18). Areas above the RIM station that deliver high yields of nitrogen to the monitoring station are in northern Orange County, southeastern Culpeper County, eastern Madison County, and small areas in southwestern Fauquier County and northeastern Culpeper County.

Phosphorus

According to the SPARROW model, only 3.2 percent of the phosphorus generated in the basin reaches the RIM station (table 18). Areas above the RIM station that deliver high yields of phosphorus to the monitoring station are in central Culpeper County, extending into southwestern Fauquier County, and a smaller area in northern Orange County, extending into southern Madison County.

The counties with the highest fertilizer and manure application in this basin are generally areas that deliver high yields of nitrogen and phosphorus to the RIM station. Because these areas are near the Fall Line and the nutrients have relatively short travel times to the RIM station, there is less opportunity for in-stream losses to occur.

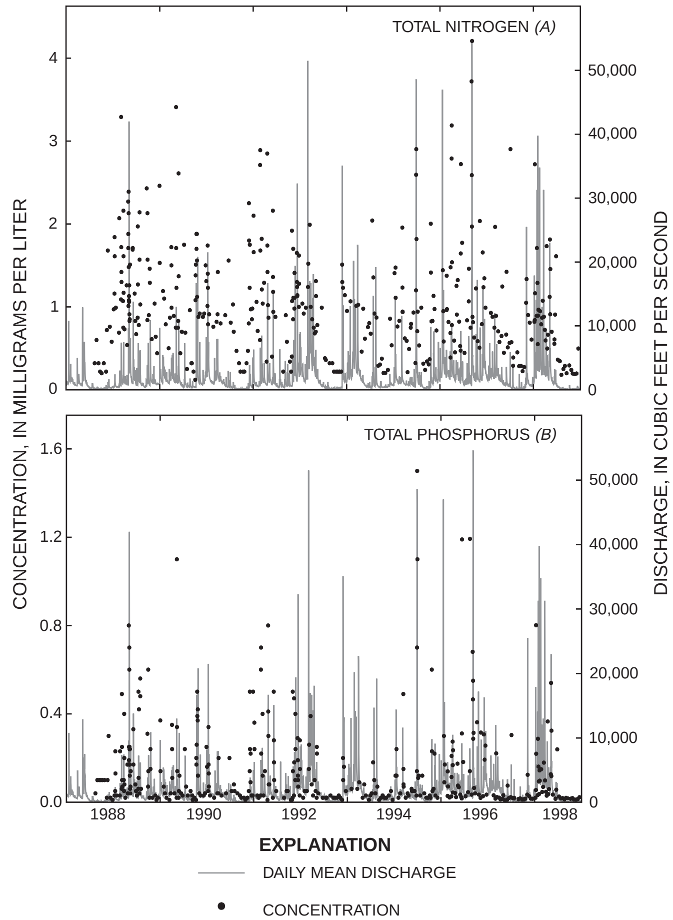


Figure 34. Observed total nitrogen (A) and total phosphorus (B) concentrations and daily mean discharge at the Rappahannock River Basin RIM station, 1988 through 1998.

Trends in Nutrient Sources

Estimates of changes in nutrient source loads, land use, and management practices during the study period were provided by WSM simulations. These WSM estimates are described in the following section. Data on manure generation, animal numbers, and fertilizer sales derived from the U.S. Census of Agriculture and data on point source discharges from the USEPA are presented for comparison with model data.

Nitrogen

The dominant nitrogen source in the basin is agriculture, which made up approximately half of the nitrogen budget (fig. 35). From 1985 to 1998, there was a 24-percent decrease in delivered load of nitrogen

Table 17. Trends in monthly mean flow, monthly load of total nitrogen (TN) and total phosphorus (TP), and flow-adjusted concentrations of TN and TP for stations in the Rappahannock River Basin

[TN, total nitrogen; TP, total phosphorus; NS, non-significant; --, not applicable or insufficient data; trends expressed as percent change; percent change is reported if significant at the 95-percent confidence level]

Station number	Station name	Site number	Time period of trend	Monthly mean flow trend	Monthly load trend		Flow-adjusted concentration trend	
					TN	TP	TN	TP
	Multi-Agency Nontidal Station							
01666500	Robinson River near Locust Dale, Va.	22	1985-98	+40 to +202	NS	+39 to +283	--	--
	River Input Monitoring Program Station							
01668000	Rappahannock River near Fredericksburg, Va.	23	1988-98	NS	NS	NS	-21 to -41	-41 to -76

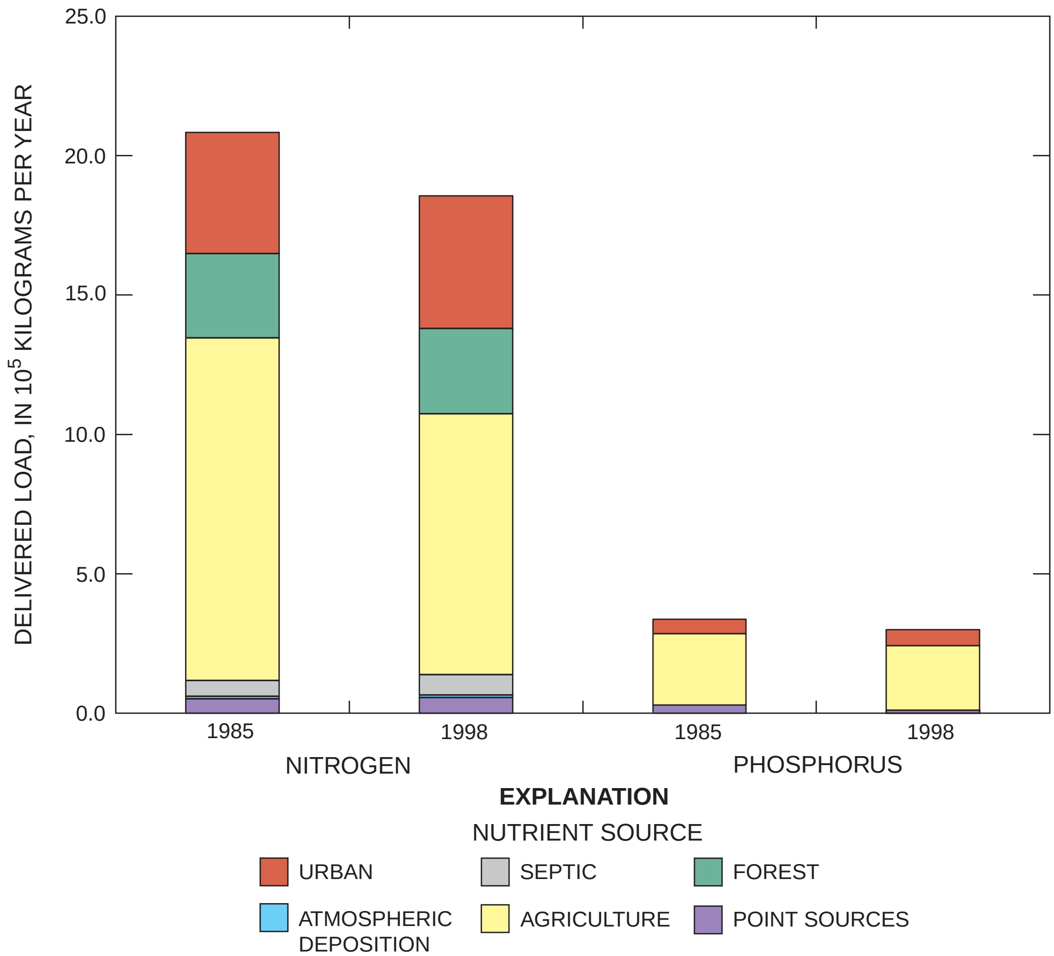


Figure 35. Contribution of major nutrient sources to the nitrogen and phosphorus budgets in the Rappahannock River Basin during 1985 and 1998, generated by the Chesapeake Bay Watershed Model.

from agriculture. This decrease resulted in part from an approximately 7-percent decrease in agricultural acreage during this period (table 19). In addition, the implementation of BMPs led to an estimated 6-percent decrease in agricultural nitrogen loads.

Other reductions in agricultural nitrogen were achieved through the implementation of fertilizer nutrient management plans. Agricultural nitrogen loads from fertilizer decreased an estimated 20 percent from 1985 to 1998, though sales fluctuated throughout this period (fig. 37). The fertilizer sales data presented here should be interpreted with caution. Half of the nitrogen fertilizer sales in this basin (when weighted by the percentage of the county in the basin) occurred in Madison and Culpeper Counties (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999).

Nitrogen loads from manure decreased about 2 percent in the basin from 1985 to 1998. U.S. Census of Agriculture data showed generally increasing nitrogen manure generation between 1987 and 1992, followed by a decrease through 1997 (fig. 38) (Puckett and others, 1998). As with nitrogen loads from fertilizer, nearly half of the nitrogen load from manure generation (when weighted by the percentage of the county in the basin) occurred in Madison and Culpeper Counties. Manure application in Culpeper County increased between 1987 and 1992, then began to decrease. In Madison County, manure application steadily increased between 1987 and 1997. From 1987 to 1997 in the Rappahannock River Basin, the numbers of poultry generally increased, while the numbers of swine decreased (fig. 39) (USDA National Agricultural Statistics Service, 1997).

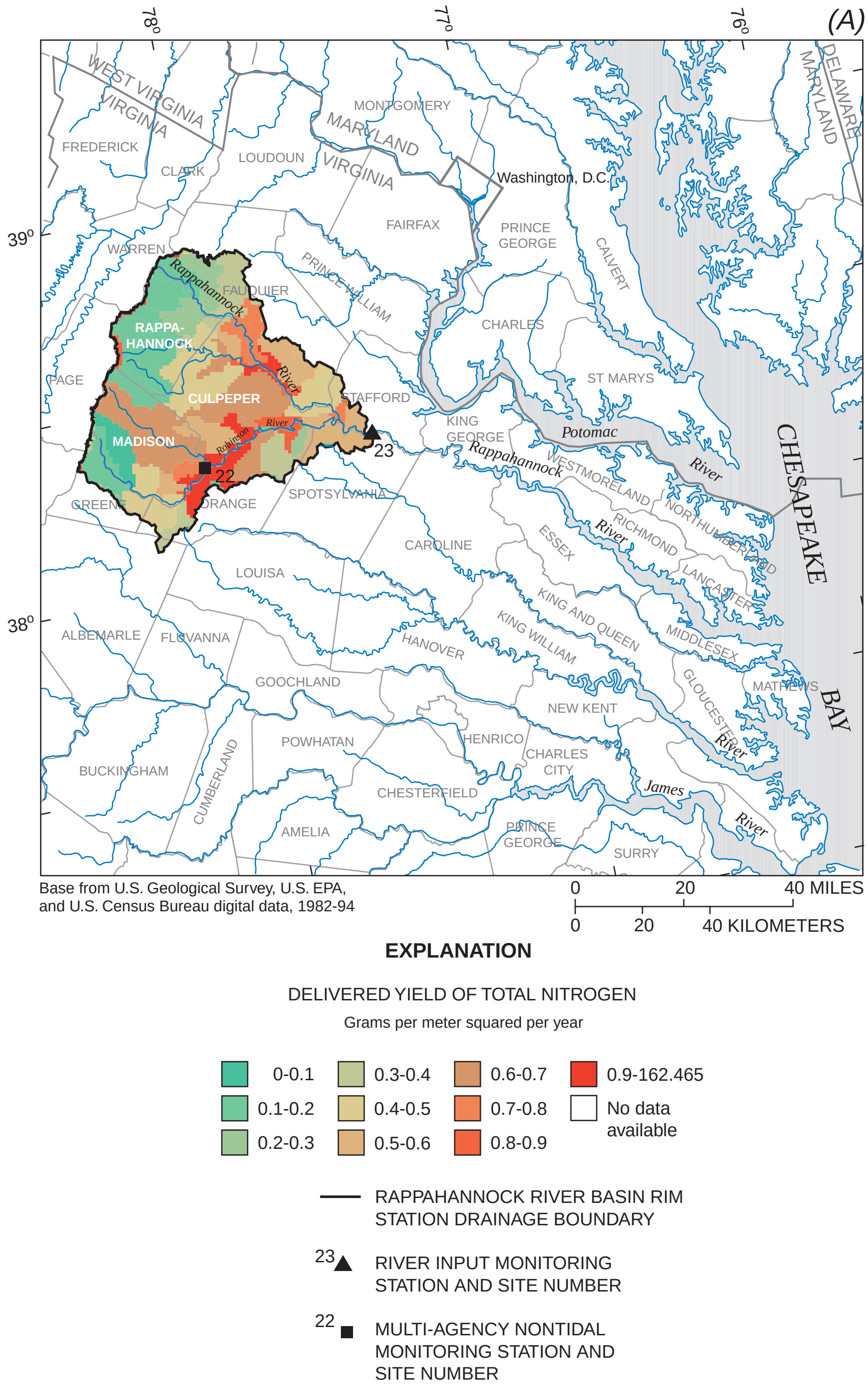
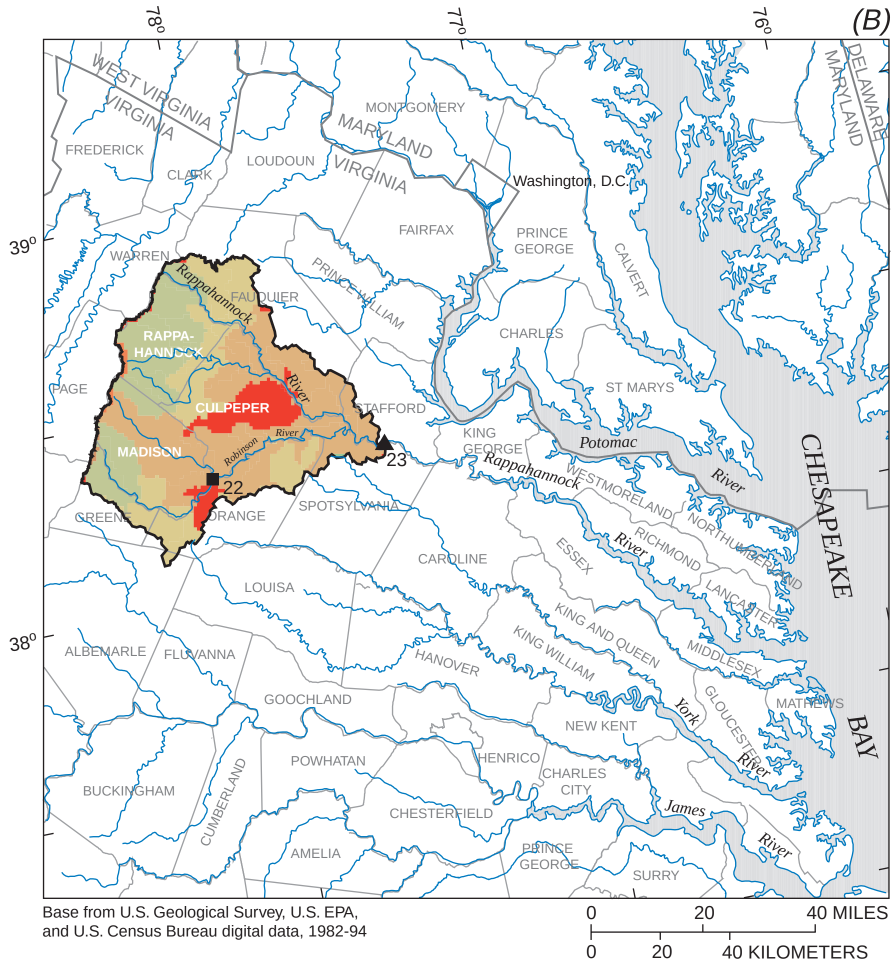


Figure 36. Delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the Rappahannock River Basin in 1987, generated by the SPARROW model.



EXPLANATION

DELIVERED YIELD OF TOTAL PHOSPHORUS

Grams per meter squared per year

- 0-0.005
- 0.005-0.01
- 0.01-0.015
- 0.015-0.02
- 0.02-0.025
- 0.025-0.03
- 0.03-0.035
- 0.035-0.04
- 0.04-0.045
- 0.045-25.966
- No data available

RAPPAHANNOCK RIVER BASIN RIM STATIONDRAINAGE BOUNDARY

23 ▲ RIVER INPUT MONITORING STATION AND SITE NUMBER

22 ■ MULTI-AGENCY NONTIDAL MONITORING STATION AND SITE NUMBER

Figure 36. Delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the Rappahannock River Basin in 1987, generated by the SPARROW model.

Table 18. SPARROW model estimates of the percentage of total nitrogen and total phosphorus load generated in the watershed that is delivered to monitoring stations in the Rappahannock River Basin

Station number	Station name	Site number	Percent delivered to station	
			Total nitrogen	Total phosphorus
	Multi-Agency Nontidal Station			
01666500	Robinson River near Locust Dale, Va.	22	24	3.0
	River Input Monitoring Program Station			
01668000	Rappahannock River near Fredericksburg, Va.	23	14	3.2

Table 19. Watershed Model estimates of percent change in land use acreage, percent change in loads due to best management practice implementation, source loads, delivered loads, and percent change in loads between 1985 and 1998 for nitrogen and phosphorus in the Rappahannock River Basin

[BMP, best management practice; kg/yr, kilograms per year; <, less than; reported load values are either source (input) loads or delivered (output) loads from the Watershed Model]

	% Acreage change	% Load change from BMP implementation	Load (kg/yr)		
			1985	1998	% Change
Nitrogen					
Agriculture (Delivered)	-7	-6	1.18×10^6	8.99×10^5	-24
Fertilizer (Source)			6.81×10^6	5.47×10^6	-20
Manure (Source)			3.91×10^6	3.83×10^6	-2
Urban areas (Delivered)	+10	<-1	4.17×10^5	4.57×10^5	+9
Fertilizer (Source)			1.46×10^6	1.70×10^6	+17
Forested areas (Delivered)	+2	<-1	2.91×10^5	2.94×10^5	+1
Point sources (Delivered)			4.92×10^4	5.34×10^4	+9
Septic (Delivered)			5.42×10^4	7.04×10^4	+30
Atmospheric deposition (Delivered)			8.65×10^3	8.57×10^3	-1
Phosphorus					
Agriculture (Delivered)	-7	-9	2.45×10^5	2.20×10^5	-10
Fertilizer (Source)			1.48×10^6	1.01×10^6	-32
Manure (Source)			1.10×10^6	1.08×10^6	-1
Urban areas (Delivered)	+10	<-1	4.49×10^4	5.12×10^4	+14
Fertilizer (Source)			0	0	0
Forested areas (Delivered)	+2	<-1	5.27×10^3	5.55×10^3	+5
Point sources (Delivered)			2.81×10^4	1.05×10^4	-63
Septic (Delivered)			0	0	0
Atmospheric deposition (Delivered)			7.06×10^2	7.29×10^2	+3

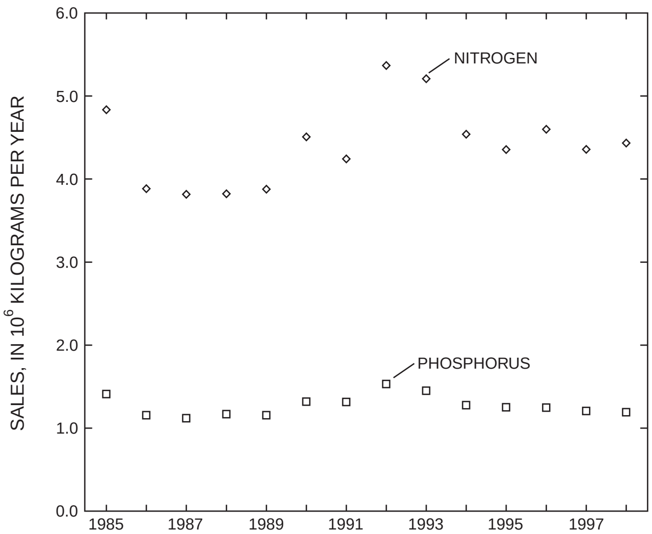


Figure 37. Annual sales of nitrogen and phosphorus fertilizer in the Rappahannock River Basin, 1985 to 1998.

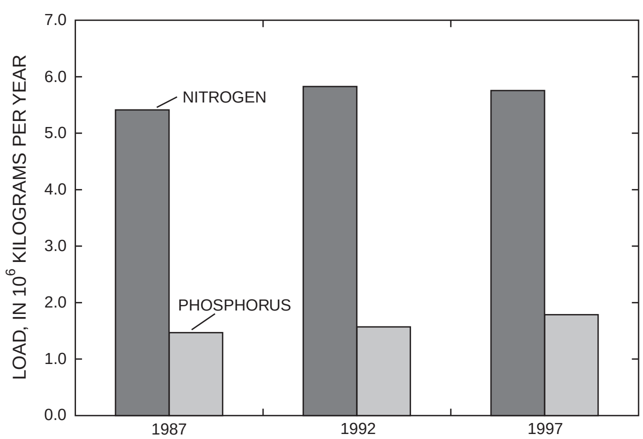


Figure 38. Annual load of nitrogen and phosphorus from manure generated in the Rappahannock River Basin in 1987, 1992, and 1997.

The second largest nitrogen source in this basin is urban areas, which in 1998 contributed about half as much nitrogen as agricultural areas (fig. 35). From 1985 to 1998, there was a 9-percent increase in delivered load of nitrogen from urban areas (table 19). This increase was largely due to a 10-percent increase in urban acreage during this period. The nitrogen load from urban fertilizer use also increased about 17 percent.

The third largest nitrogen source is forested areas; input from these areas remained relatively constant during the study period (fig. 35, table 19). Nitrogen contributions from point sources were small in this basin, and were approximately equal to septic inputs, at about 3 percent of the nitrogen budget. There was a 9-percent increase in nitrogen loading from point sources upstream of the RIM station from 1985 to 1998, likely a product of the 37-percent increase in population in the Rappahannock River Basin during this period. Additional point source data indicate a large increase in loads of nitrogen, especially from 1988 to 1997 (Wiedeman and Cosgrove, 1998) (fig. 40). BNR upgrades have taken place at only one point source facility above the RIM station; upgrades at other facilities are anticipated by 2010 as part of the Rappahannock River Tributary Strategy process (Virginia Department of Environmental Quality, 1999).

Phosphorus

The dominant phosphorus source in the basin is agriculture, which made up over three-quarters of the phosphorus budget (fig. 35). From 1985 to 1998, there was a 10-percent decrease in delivered load of phosphorus from agriculture (table 19). Most of this decrease resulted from an estimated 32-percent decrease in phosphorus loads from fertilizer application as a result of the implementation of nutrient management plans, combined with an estimated 9-percent decrease from the implementation of BMPs in the basin. Sales of phosphorus fertilizer fluctuated throughout this period (fig. 37). Most of the phosphorus fertilizer sales in this basin (when weighted by the percentage of the county in the basin) occurred in Madison, Culpeper, and Fauquier Counties (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999).

Phosphorus loads from manure application remained fairly steady during this period (table 19). U.S. Census of Agriculture data showed slightly increasing phosphorus manure generation between 1987 and 1997 (fig. 38) (Puckett and others, 1998). The greatest manure generation of phosphorus (when weighted by the percentage of the county in the basin) occurred in Madison, Culpeper, and Fauquier Counties. From 1987 to 1997, manure generation in these counties generally increased.

The second largest phosphorus source in this basin is urban areas, at about 15 percent (fig. 35). Phosphorus loads from urban areas increased 14 percent from 1985 to 1998, largely the result of a 10-percent increase in urban acreage. The other substantial contributor to the phosphorus budget in this basin was

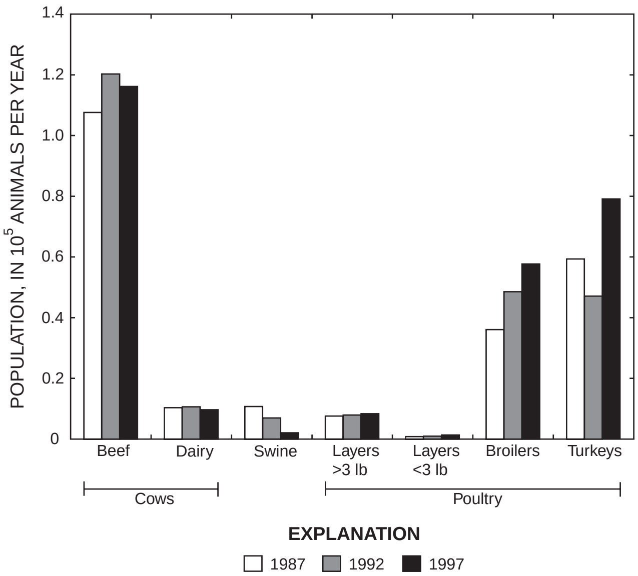


Figure 39. Population distribution of agricultural animals in the Rappahannock River Basin in 1987, 1992, and 1997.

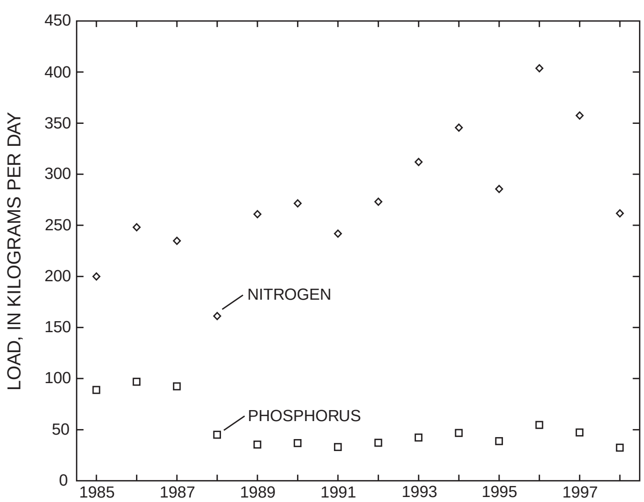


Figure 40. Annual mean point source load of total nitrogen and total phosphorus discharged in the Rappahannock River Basin, 1985 to 1998.

point sources, and loads from these point sources decreased 63 percent during this period (Wiedeman and Cosgrove, 1998). Phosphorus loads dropped significantly between 1987 and 1988 (fig. 40), probably due in large part to the phosphate detergent ban.

At the one upstream monitoring station in this basin with data sufficient to be included in this study—on the Robinson River near Locust Dale, Va. (01666500), at the confluence of the Rapidan River and the Robinson River in the southern part of the basin—there was a significant increase of between 39 and 283 percent in total phosphorus loads from 1985 to 1998 (fig. 33, table 17). According to the SPARROW model, part of the area draining to this station delivered a high yield of total phosphorus to Chesapeake Bay in 1987 (fig. 36).

Ground Water

Between 1988 and 1998 at the Fredericksburg RIM station, an average of 26 percent of the total nitrogen load in the river came from ground-water inputs of nitrate (table 20), more than at any of the other RIM stations in Virginia. The load of nitrate from ground water decreased 38 to 69 percent from 1985 to 1998 (table 20), in part reflecting the reduction in nitrogen loads from fertilizer application, as nitrogen in fertilizer is more readily transported in ground water than the organic nitrogen in manure.

Summary

Flow-adjusted concentrations of both total nitrogen and total phosphorus decreased significantly at the Rappahannock River RIM station. There were no trends, however, in loads of total nitrogen and phosphorus. The lack of a corresponding decrease in loads cannot be explained with increasing streamflow, as there was no significant overall increase in streamflow during the monitoring period. This suggests that the lack of decreasing loads may be due to the reduced efficiencies of BMPs during individual storm events.

Agriculture is the dominant nutrient source, contributing about half of the nitrogen budget and three-quarters of the phosphorus budget. As a result, changes in agriculture contributed the most to the downward trends in flow-adjusted nutrient concentrations in this basin. Nitrogen loads from fertilizer decreased an estimated 20 percent due largely to the implementation of nutrient management plans; in addition, BMP implementation led to an estimated 6-percent decrease in nitrogen loads. These decreases in agricultural nitrogen loads were enough to offset increasing nitrogen loads from urban areas, the second largest contributor to the nitrogen budget.

The implementation of nutrient management plans and BMPs appears to have been even more successful in reducing phosphorus. Phosphorus loads from fertilizer decreased an estimated 32 percent, while BMP implementation led to another estimated 9-percent decrease. Because contributions from agriculture overwhelmed all other sources, increases in loads from urban areas, the second largest contributor, did not offset decreases in agriculture. Phosphorus loads from point sources, though a relatively small contributor to the budget, decreased 63 percent.

Table 20. Trends in dissolved nitrate load in base flow, percent base-flow nitrate load to surface-water total nitrogen load, and percent base flow to total streamflow in the Rappahannock River Basin

[Trends expressed as percent change; percent change reported if significant at the 95-percent confidence level; NS, non-significant; --, not applicable or insufficient data]

Station number	Station name	Site number	Time period of trend	Trend in base-flow nitrate load	Percent base-flow nitrate load to surface-water total nitrogen load	Percent base flow to total stream flow
	Multi-Agency Nontidal Station					
01666500	Robinson River near Locust Dale, Va.	22	1985-98	NS	--	58
	River Input Monitoring Program Station					
01668000	Rappahannock River near Fredericksburg, Va.	23	1988-98	-38 to -69	26	48

Basin Description

The York River Basin, at 2,400 mi^2, is the fifth largest tributary basin to Chesapeake Bay. The York River is formed by the confluence of the Pamunkey and Mattaponi Rivers near West Point, Va. Because these two sub-basins have distinct hydrogeologic characteristics, they are monitored separately. The Pamunkey River begins in the eastern part of the Piedmont Physiographic Province and flows into the Coastal Plain Physiographic Province. The Pamunkey River RIM station (01673000) near Hanover, Va., receives drainage from about 45 percent of the York River Basin (fig. 41). The Pamunkey River sub-basin is of relatively low relief and contains Lake Anna approximately 60 miles upstream from the monitoring station. Lake Anna serves to dampen and delay the hydrologic response of the Pamunkey River at the RIM station during storm events.

The Mattaponi River sub-basin is located north of the Pamunkey River sub-basin, in the Piedmont and Coastal Plain Physiographic Provinces. Because a relatively large percentage of the sub-basin is in the Coastal Plain, is of low relief, and contains expanses of wetlands, the Mattaponi River typically experiences lower streamflows and lower concentrations and yields of nutrients relative to the Pamunkey River and the other rivers draining to Chesapeake Bay. The Mattaponi River RIM station (01674500) near Beulahville, Va., receives drainage from about 25 percent of the York River Basin (fig. 41).

As with the other tributary basins in Virginia, land use in both sub-basins is dominated by forest. Forest makes up 68 percent of the land use upstream of the Pamunkey River RIM station and 69 percent upstream of the Mattaponi River RIM station (table 3). Agriculture, the second largest land use at 24 percent and 19 percent, respectively, is distributed sporadically throughout the sub-basins.

Of the nine rivers monitored, the Pamunkey River contributes about 2 percent of the streamflow, less than 1 percent of the total nitrogen load, and 2 percent of the total phosphorus load delivered annually from the nontidal part of the Chesapeake Bay Watershed (Belval and Sprague, 1999). The Mattaponi River contributes less than 1 percent of the total streamflow, the total nitrogen load, and the total phosphorus load entering the Bay.

Trends

The stream discharge and observed total nitrogen and phosphorus concentrations at the Pamunkey River RIM station from 1989 to 1998 are shown in figure 42. Total nitrogen concentrations ranged from 0.16 to 2.23 mg/L, with a median of 0.67 mg/L. Total phosphorus concentrations ranged from 0.02 to 0.50 mg/L, with a median of 0.06 mg/L. The stream discharge and observed total nitrogen and phosphorus concentrations at the Mattaponi River RIM station from 1989 to 1998 are shown in figure 43. Total nitrogen concentrations ranged from 0.03 to 1.57 mg/L, with a median of 0.54 mg/L. Total phosphorus concentrations ranged from 0.005 to 0.26 mg/L, with a median of 0.05 mg/L.

There were no significant trends in total nitrogen and total phosphorus loads at either the Pamunkey or Mattaponi River RIM stations between 1989 and 1998 (table 21). There were also no significant trends in streamflow during this period. When streamflow was removed as a variable affecting in-stream concentrations of these nutrients, there were significant downward trends in flow-adjusted concentrations of total nitrogen and total phosphorus of 21 to 37 percent and 25 to 42 percent, respectively, at the Mattaponi River RIM station. In contrast, there were no significant trends in flow-adjusted concentrations of total nitrogen and phosphorus during the monitoring period at the Pamunkey River RIM station.

Nutrient Budgets and Yield Distributions

Nutrient Budgets

Nitrogen and phosphorus budgets were calculated for the York River Basin upstream from the Pamunkey River and Mattaponi River RIM stations (fig. 44). These budgets are Chesapeake Bay WSM

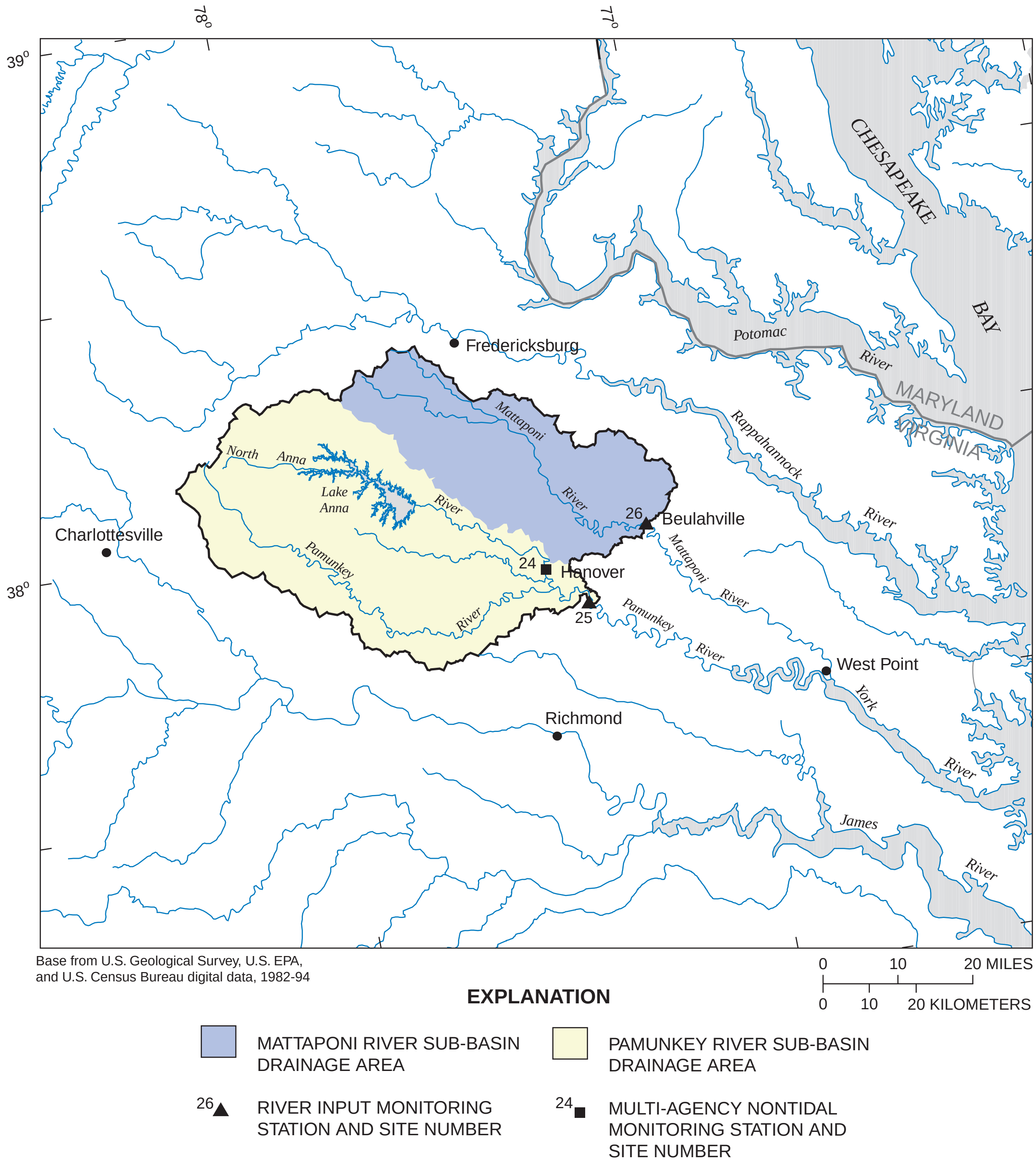


Figure 41. Location of the monitoring stations in the York River Basin.

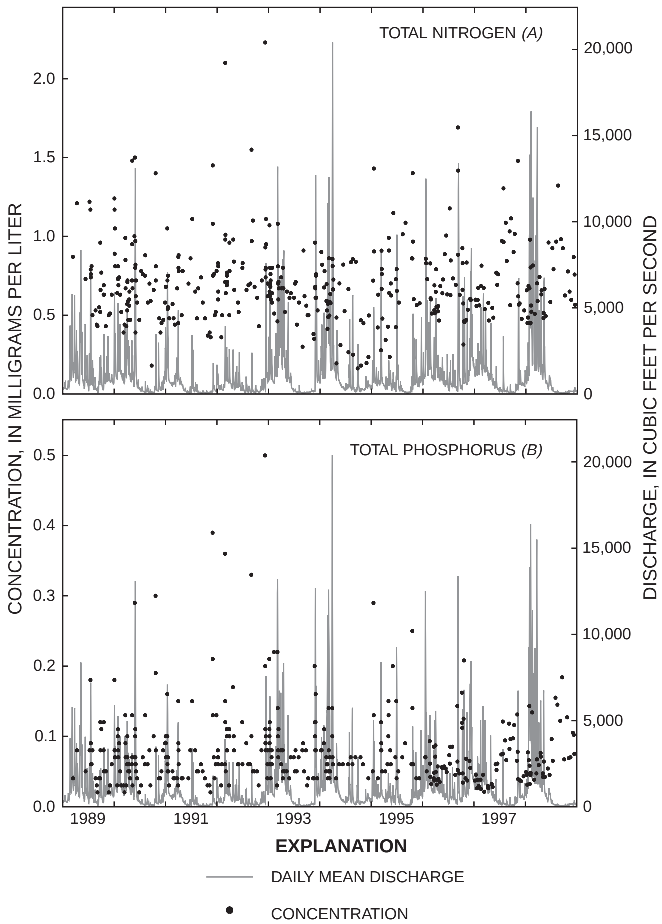


Figure 42. Observed total nitrogen *(A)* and total phosphorus *(B)* concentrations and daily mean discharge at the Pamunkey River Basin RIM station, 1989 through 1998.

estimates of the nutrient load delivered from six source categories, and are simulated for 1985 and 1998 using average hydrology in the basins.

Nitrogen

Results of WSM simulations indicate that in 1985, the two major contributors to the nitrogen budget in the Pamunkey River sub-basin were agriculture (46 percent) and urban areas (32 percent) (fig. 44a). Forested areas contributed 16 percent of the total budget although they comprise nearly 70 percent of the watershed. Point sources made up 2 percent of the nitrogen budget in 1985, and septic inputs and atmospheric deposition combined made up about 4 percent of the total budget. In 1998, the contribution of agriculture decreased to 38 percent of the budget, while the contribution of point sources increased to nearly 10 percent of the budget. The relative contributions from urban and forested areas were similar to 1985 levels.

Similar to the Pamunkey River sub-basin, the three major contributors to the nitrogen budget in the Mattaponi River sub-basin in 1985 were agriculture (42 percent), urban areas (31 percent), and forested areas (20 percent) (fig. 44b). Septic inputs contributed about 5 percent of the budget. There were no point-source dischargers in this basin in 1985. The Caroline County treatment facility came on-line in 1990, but discharged nitrogen loads have been small (Wiedeman and Cosgrove, 1998), and point-source contributions increased less than 1 percent between 1985 and 1998. In 1998, the relative contribution of urban areas and forested areas, at 32 percent and 20 percent, respectively, were similar to 1985 levels. Contributions from agriculture decreased slightly to 39 percent, while septic inputs rose to 7 percent.

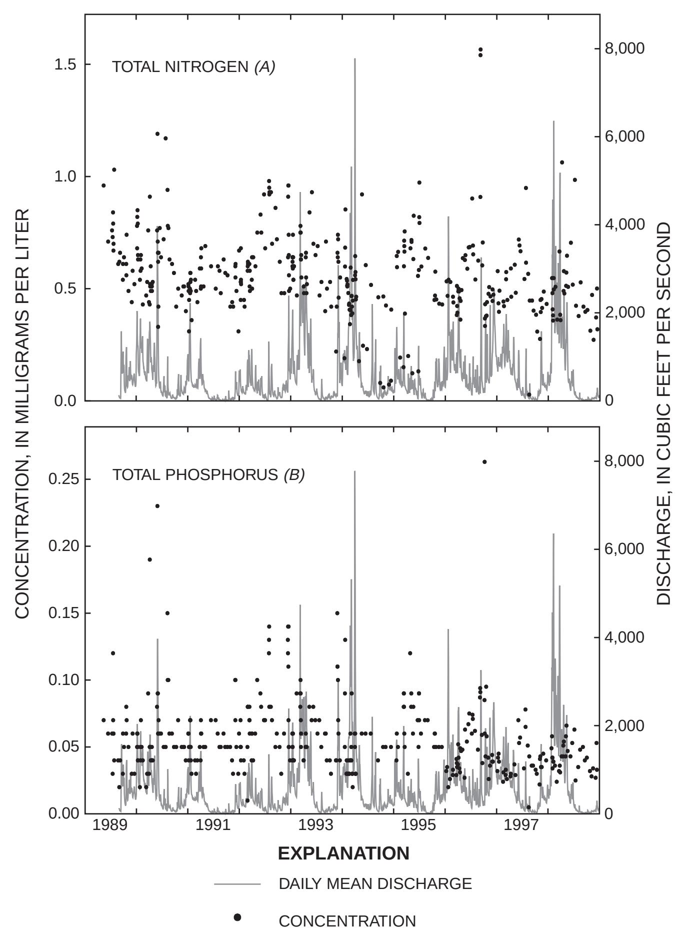


Figure 43. Observed total nitrogen *(A)* and total phosphorus *(B)* concentrations and daily mean discharge at the Mattaponi River Basin RIM station, 1989 through 1998.

Table 21. Trends in monthly mean flow, monthly load of total nitrogen (TN) and total phosphorus (TP), and flow-adjusted concentrations of TN and TP for stations in the York River Basin

[TN, total nitrogen; TP, total phosphorus; NS, non-significant; --, not applicable or insufficient data; trends expressed as percent change; percent change is reported if significant at the 95-percent confidence level]

Station number	Station name	Site number	Time period of trend	Monthly mean flow trend	Monthly load trend		Flow-adjusted concentration trend	
					TN	TP	TN	TP
	Multi-Agency Nontidal Station							
01671020	North Anna River at Hart Corner near Doswell, Va.	24	1985-98	NS	NS	NS	--	--
	River Input Monitoring Program Stations							
01673000	Pamunkey River near Hanover, Va.	25	1989-98	NS	NS	NS	NS	NS
01674500	Mattaponi River near Beulahville, Va.	26	1989-98	NS	NS	NS	-21 to -37	-25 to -42

Phosphorus

Results of WSM simulations indicate that in 1985, the three major contributors to the phosphorus budget in the Pamunkey River sub-basin were agriculture (66 percent), urban areas (19 percent), and forested areas (8 percent) (fig. 44a). The only other significant contributor was point sources, at about 5 percent. In 1998, the contribution of point sources had risen to nearly 9 percent, while the contribution of agriculture had decreased to 61 percent. All other contributions remained consistent with 1985 levels.

In 1985, the two significant contributors to the phosphorus budget in the Mattaponi River sub-basin were agriculture (76 percent) and urban areas (19 percent) (fig. 44b). Forested areas contributed less than 5 percent. In 1998, contributions from point sources had increased to 5 percent, whereas agriculture contributions had decreased to 67 percent.

Nutrient Yield Distributions

The amount of nitrogen and phosphorus delivered to the York River Basin RIM stations from individual small reaches within the basin was estimated using the SPARROW model for 1987 conditions. The yields shown in figure 45 are less than the yields generated within the basin because of on-land and in-stream losses that occur between the point of generation and the monitoring stations.

Nitrogen

Delivered nitrogen yields in the York River Basin are small relative to the other Chesapeake Bay basins monitored in this study. Areas with high delivered nitrogen yields are located in southeastern Caroline County, extending into northeastern Hanover County, and in northern Orange County. According to the SPARROW model results, 18 percent of the nitrogen generated in the Pamunkey River sub-basin and 14 percent of that generated in the Mattaponi River sub-basin reach the respective RIM stations (table 22).

Phosphorus

According to the SPARROW model results, 3.9 percent of the phosphorus generated in the Pamunkey River sub-basin and 4.6 percent of that generated in the Mattaponi River sub-basin reach the respective RIM stations (table 22). As with nitrogen, an area in southeastern Caroline County and northeastern Hanover County delivers relatively high yields of phosphorus. Western Orange County also delivers a relatively high yield of phosphorus.

The area that delivers the highest yields of nitrogen and phosphorus to the Bay in this basin is in Hanover County, where some of the highest manure and fertilizer application occurs. This high yield is likely due to the close proximity of Hanover County to the RIM stations, which leaves little travel time for in-stream losses to occur.

Trends in Nutrient Sources

Estimates of changes in nutrient source loads, land use, and management practices during the study period were provided by WSM simulations. These WSM estimates are described in the following section. Data on manure generation, animal numbers, and

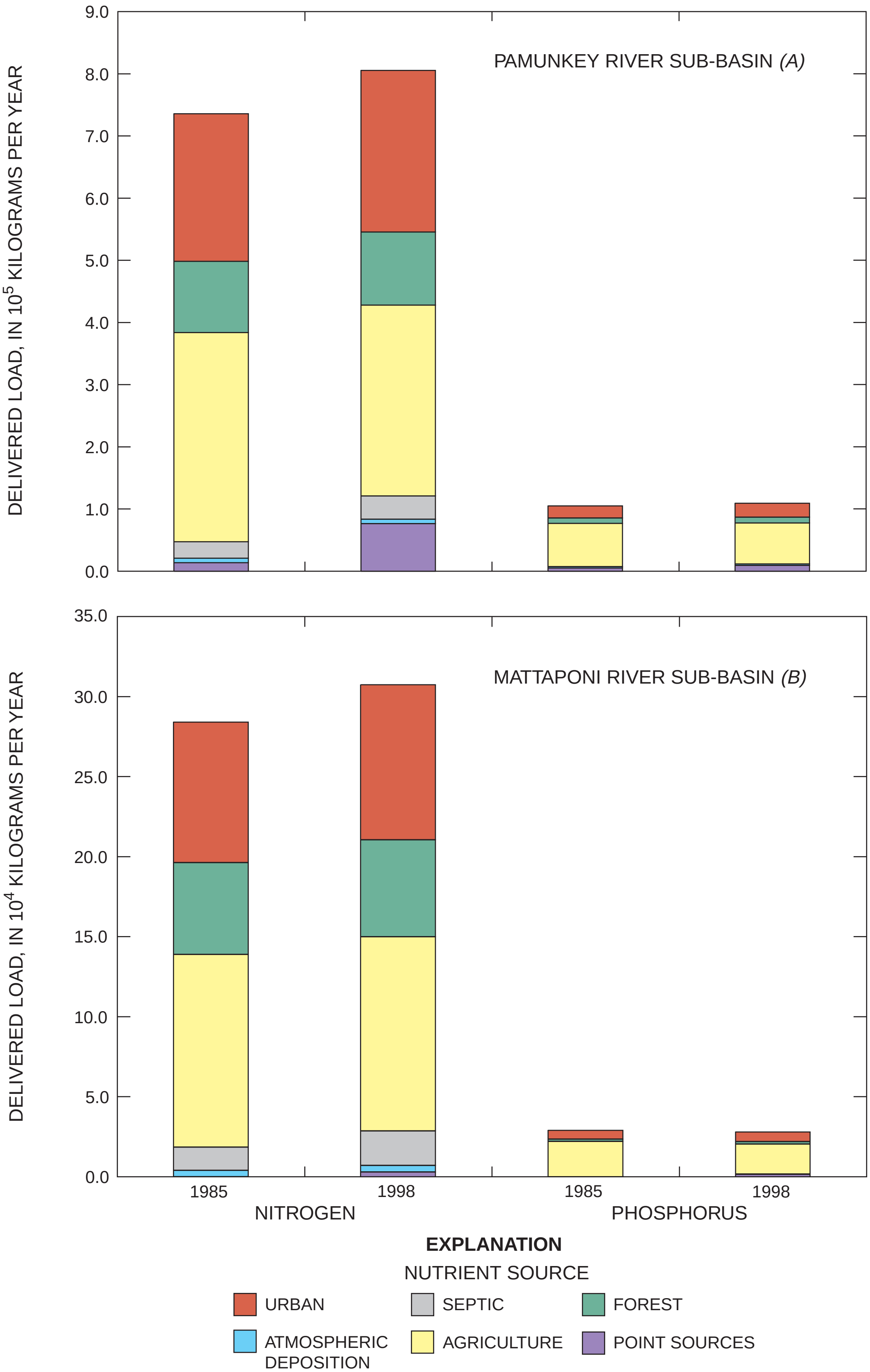


Figure 44. Contribution of major nutrient sources to the nitrogen and phosphorus budgets in the Pamunkey River Basin *(A)* and the Mattaponi River Basin *(B)* during 1985 and 1998, generated by the Chesapeake Bay Watershed Model.

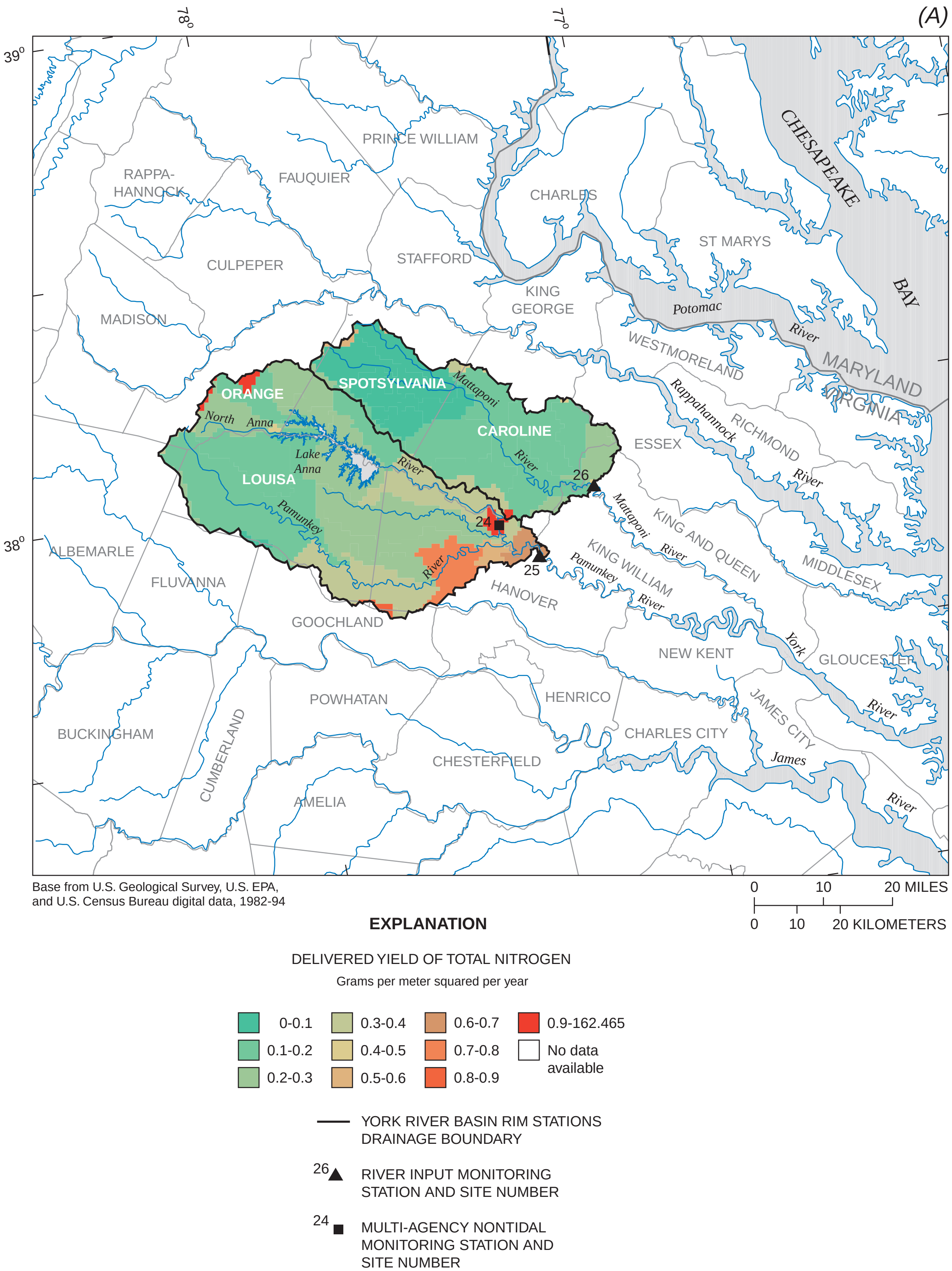


Figure 45. Delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the York River Basin in 1987, generated by the SPARROW model.

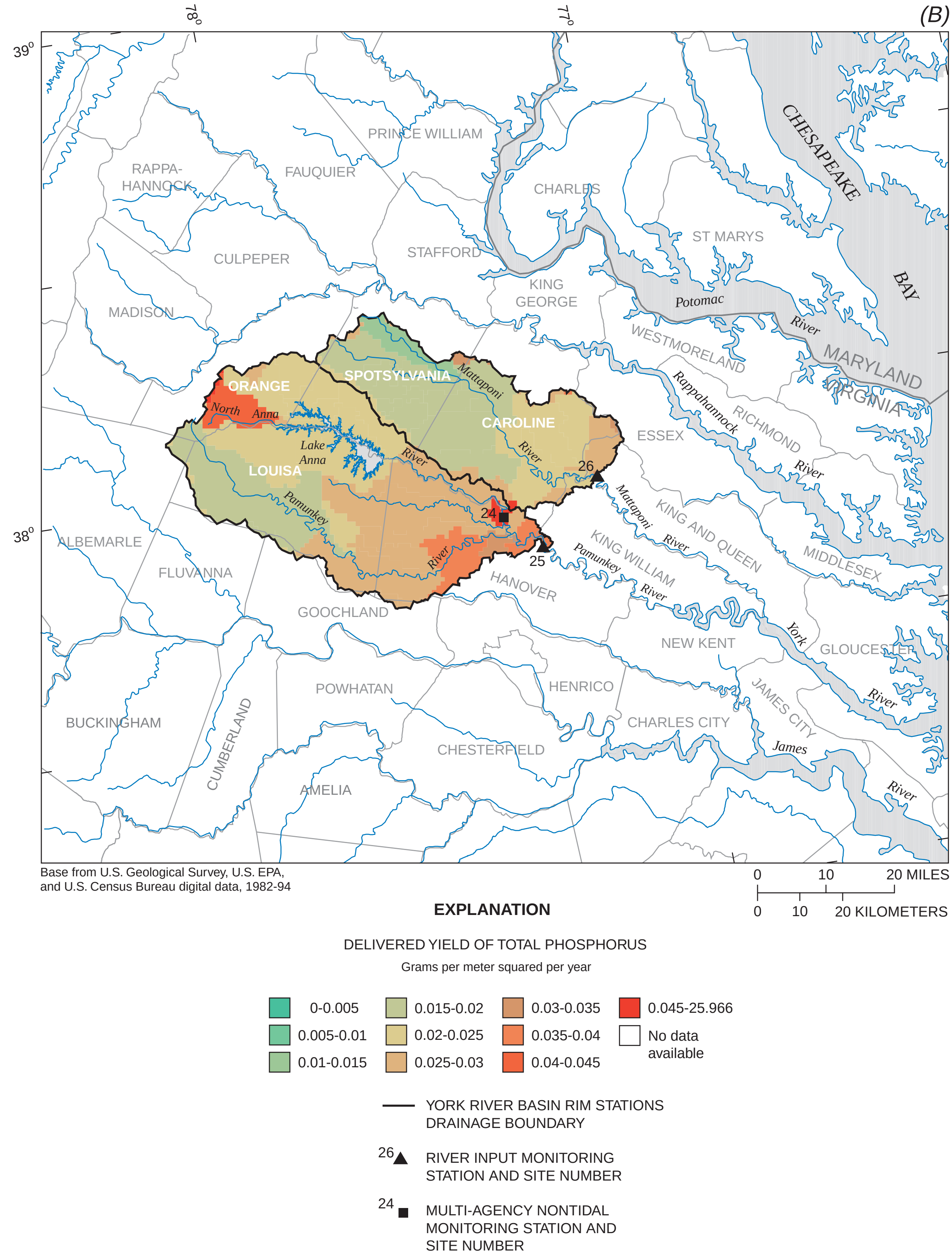


Figure 45. Delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the York River Basin in 1987, generated by the SPARROW model.

Table 22. SPARROW model estimates of the percentage of total nitrogen and total phosphorus load generated in the watershed that is delivered to monitoring stations in the York River Basin

Station number	Station name	Site number	Percent delivered to station	
			Total nitrogen	Total phosphorus
	Multi-Agency Nontidal Station			
01671020	North Anna River at Hart Corner near Doswell, Va.	24	14	3.5
	River Input Monitoring Program Stations			
01673000	Pamunkey River near Hanover, Va.	25	18	3.9
01674500	Mattaponi River near Beulahville, Va.	26	14	4.6

fertilizer sales derived from the U.S. Census of Agriculture and data on point source discharges from the USEPA are presented for comparison with model data.

Nitrogen

Pamunkey River Sub-Basin

The dominant nitrogen source in the Pamunkey River sub-basin is agriculture (fig. 44a). From 1985 to 1998, there was a 9-percent decrease in delivered load of nitrogen from agriculture (table 23). During this period, agricultural acreage decreased approximately 9 percent. Implementation of BMPs led to an approximately 5-percent decrease in agricultural nitrogen loads.

Other reductions in agricultural nitrogen loads were achieved through the implementation of fertilizer nutrient management plans. Agricultural nitrogen fertilizer loads decreased an estimated 17 percent from 1985 to 1998, though sales remained fairly constant (fig. 46a). The greatest amounts of nitrogen fertilizer sold in the sub-basin (when weighted by the percentage of the county in the sub-basin) were in Hanover, Caroline, and Louisa Counties (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999). The fertilizer sales data presented here should be interpreted with caution.

Nitrogen loads from manure application increased 4 percent in the sub-basin from 1985 to 1998. U.S. Census of Agriculture data showed a slight decrease in nitrogen manure generation between 1987 and 1992, followed by an increase through 1997 (fig. 47a) (Puckett and others, 1998). The greatest manure application of nitrogen (when weighted by the percentage of the county in the sub-basin) occurred in Louisa, Orange, and Hanover Counties. From 1987 to 1997 in these counties, the number of broilers and turkeys generally increased, while the number of dairy cows and swine decreased (fig. 48) (USDA National Agricultural Statistics Service, 1997).

The second largest nitrogen source in this sub-basin is urban areas (fig. 44a). From 1985 to 1998, there was a 10-percent increase in delivered load of nitrogen from urban areas (table 23). During this period there was a 7-percent increase in urban acreage. Nitrogen loads from urban fertilizer application also increased about 14 percent. Loads from the third largest nitrogen source, forested areas, remained relatively constant during this period.

The load of nitrogen from point sources, though relatively small in this sub-basin, increased more than 450 percent from 1985 to 1998 (Wiedeman and Cosgrove, 1998) (fig. 49a). Of the point source facilities in this sub-basin, the Doswell combined outfall is the most significant contributor to this increase. Total nitrogen loads at the Doswell combined outfall, including output from both the Doswell Wastewater Treatment Plant and a local paper company, increased over 1,000 percent between 1985 and 1998 (Wiedeman and Cosgrove, 1998). These load increases were due to increases in effluent discharge during this period, as nutrient concentration levels remained nearly constant. In 1985, annual mean discharge at the combined outfall was 0.293 Mgal/day; in 1998, it had risen to 3.99 Mgal/day, an increase of 1,260 percent. The Hanover County Department of Public Utilities attributes a large increase in discharge in 1994 to the creation of a paper recycling facility at the paper company; earlier smaller increases in discharge are likely due to process changes at the company (William Weber, Hanover County Department of Public Utilities, personal commun.,

Table 23. Watershed Model estimates of percent change in land use acreage, percent change in loads due to best management practice implementation, source loads, delivered loads, and percent change in loads between 1985 and 1998 for nitrogen and phosphorus in the York River Basin

[BMP, best management practice; kg/yr, kilograms per year; <, less than; reported load values are either source (input) loads or delivered (output) loads from the Watershed Model]

	% Acreage change	% Load change from BMP implementation	Load (kg/yr)		
			1985	1998	% Change
Pamunkey River Sub-Basin—Nitrogen					
Agriculture (Delivered)	-9	-5	3.23×10^5	2.95×10^5	-9
Fertilizer (Source)			2.59×10^6	2.14×10^6	-17
Manure (Source)			1.40×10^6	1.46×10^6	+4
Urban areas (Delivered)	+7	<-1	2.28×10^5	2.50×10^5	+10
Fertilizer (Source)			9.35×10^5	1.07×10^6	+14
Forested areas (Delivered)	+1	<-1	1.10×10^5	1.13×10^5	+2
Point sources (Delivered)			1.32×10^4	7.37×10^4	+457
Septic (Delivered)			2.58×10^4	3.60×10^4	+40
Atmospheric deposition (Delivered)			6.42×10^3	6.50×10^3	+1
Pamunkey River Sub-Basin—Phosphorus					
Agriculture (Delivered)	-9	-10	6.67×10^4	6.37×10^4	-4
Fertilizer (Source)			1.02×10^6	9.34×10^5	-8
Manure (Source)			4.04×10^5	4.41×10^5	+9
Urban areas (Delivered)	+7	<-1	1.89×10^4	2.14×10^4	+14
Fertilizer (Source)			0	0	0
Forested areas (Delivered)	+1	<-1	8.16×10^3	8.79×10^3	+8
Point sources (Delivered)			11,866	20,611	+74
Septic (Delivered)			0	0	0
Atmospheric deposition (Delivered)			1.83×10^3	1.94×10^3	+6
Mattaponi River Sub-Basin—Nitrogen					
Agriculture (Delivered)	-13	-8	1.16×10^5	1.17×10^5	+1
Fertilizer (Source)			1.13×10^6	1.12×10^6	-1
Manure (Source)			5.08×10^5	4.48×10^5	-12
Urban areas (Delivered)	+6	<-1	8.43×10^4	9.31×10^4	+10
Fertilizer (Source)			4.82×10^5	5.43×10^5	+13
Forested areas (Delivered)	+1	<-1	5.50×10^4	5.81×10^4	+6
Point sources (Delivered)			0	2.78×10^3	2780
Septic (Delivered)			1.40×10^4	2.07×10^4	+48
Atmospheric deposition (Delivered)			3.77×10^3	3.97×10^3	+5
Mattaponi River Sub-Basin—Phosphorus					
Agriculture (Delivered)	-13	-20	2.10×10^4	1.80×10^4	-15
Fertilizer (Source)			3.81×10^5	3.35×10^5	-12
Manure (Source)			1.39×10^5	1.25×10^5	-10
Urban areas (Delivered)	+6	<-1	5.24×10^3	5.78×10^3	+10
Fertilizer (Source)			0	0	0
Forested areas (Delivered)	+1	<-1	1.35×10^3	1.42×10^3	+5
Point sources (Delivered)			0	1.43×10^3	1430
Septic (Delivered)			0	0	0
Atmospheric deposition (Delivered)			2.05×10^2	2.13×10^2	+4

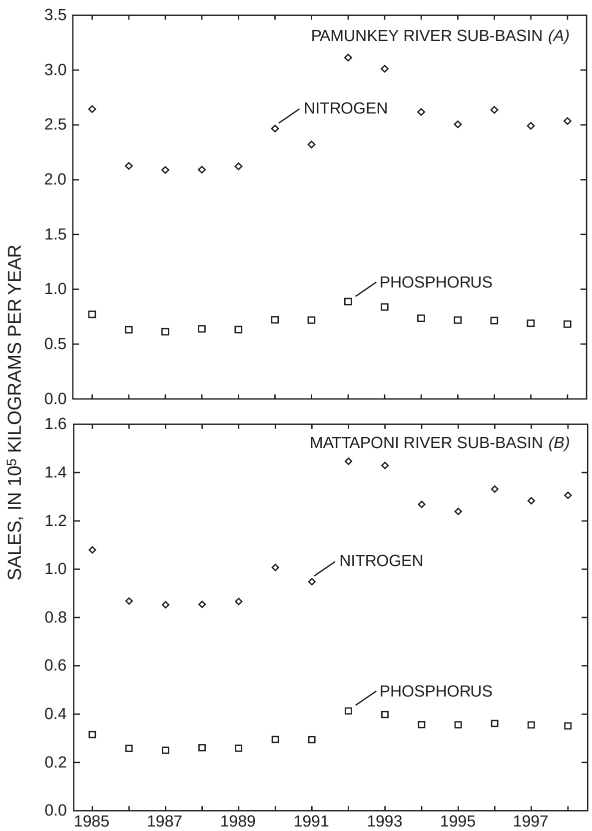


Figure 46. Annual sales of nitrogen and phosphorus fertilizer in the Pamunkey River Basin *(A)* and the Mattaponi River Basin *(B)*, 1985 to 1998.

2000). Even with these increases at the combined outfall, point sources made up only 10 percent of the nitrogen budget in this sub-basin by 1998.

Mattaponi River Sub-Basin

As in the Pamunkey River sub-basin, agriculture is the largest contributor to the nitrogen budget in the Mattaponi River sub-basin (fig. 44b). Unlike the Pamunkey River sub-basin, where nitrogen loads from agriculture decreased 9 percent, nitrogen loads from agriculture remained relatively constant in the Mattaponi River sub-basin from 1985 to 1998. Agricultural acreage decreased 13 percent and BMP implementation resulted in an estimated 8-percent decrease in nitrogen loads during this period (table 23). Nitrogen loads from manure application decreased 12 percent, while loads from fertilizer application remained relatively constant. Though loads from fertilizer application were steady from 1985 to 1998, the rate of fertilizer application increased about 13 percent, driven largely by the conversion of hayland to cropland in the sub-basin (USDA National Agricultural Statistics Service, 1997). Sales of nitrogen fertilizer remained fairly constant during this period (fig. 46b). The greatest nitrogen fertilizer sales were in Caroline County, where total harvested cropland increased from 28,026 acres in 1987 to 33,655 acres in 1997 (USDA National Agricultural Statistics Service, 1997). U.S. Census of Agriculture data showed generally increasing nitrogen manure generation between 1987 and 1997 (fig. 47b) (Puckett and others, 1998).

The second largest nitrogen source in this sub-basin is urban areas, which contributed approximately 30 percent of the nitrogen budget (fig. 44b). From 1985 to 1998, there was a 10-percent increase in nitrogen loading from this source, caused by a 6-percent increase in urban acreage and a 13-percent increase in loads from urban nitrogen fertilizer use (table 23). The acreage of forested areas, the third largest source, remained relatively constant from 1985 to 1998.

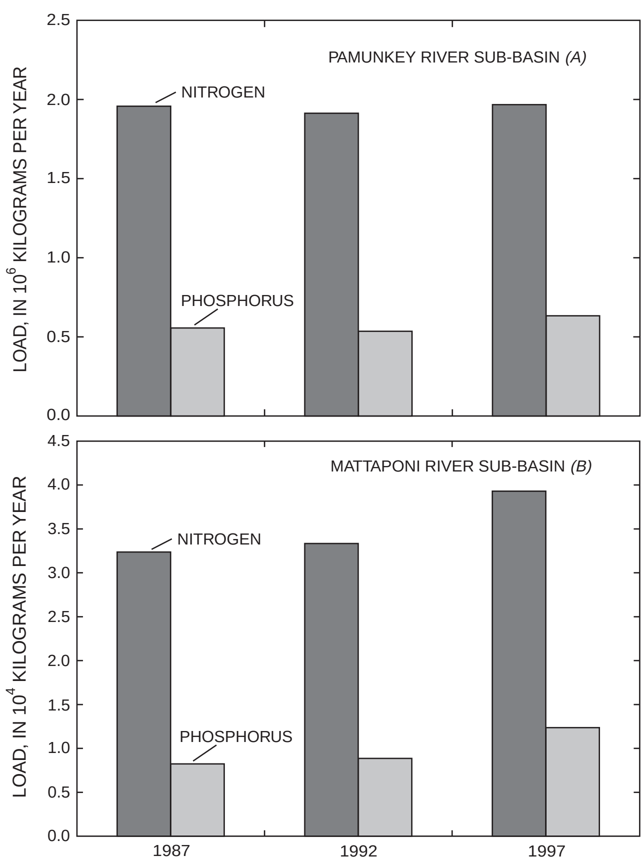


Figure 47. Annual load of nitrogen and phosphorus from manure generated in the Pamunkey River Basin *(A)* and the Mattaponi River Basin *(B)* in 1987, 1992, and 1997.

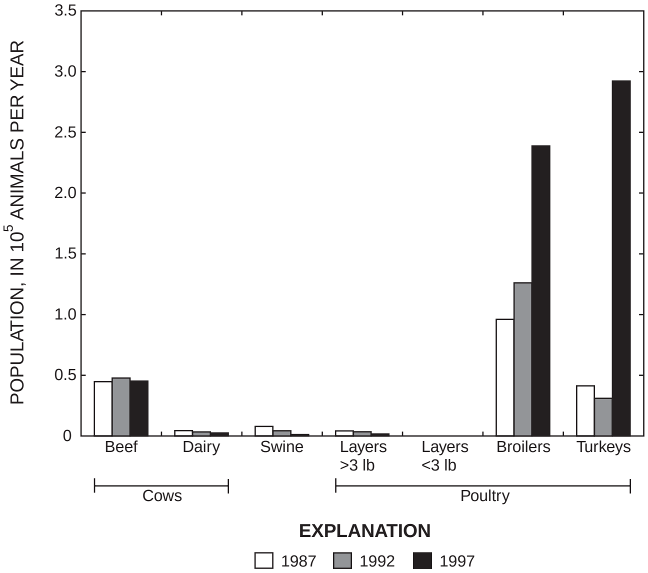


Figure 48. Population distribution of agricultural animals in the York River Basin in 1987, 1992, and 1997.

Increases in the other measurable contributors to the nitrogen budget in this sub-basin, point sources and septic inputs, can be tied to the 62-percent increase in population in the Mattaponi River sub-basin from 1985 to 1998. Septic inputs increased approximately 48 percent during this period. However, because septic inputs contribute only about 5 percent of the total nitrogen budget, this increase had a negligible impact on the overall nitrogen trend in this sub-basin. The contribution from point sources is smaller still; even with the Caroline County treatment facility coming on-line in 1990, point source contributions of nitrogen were less than 1 percent of the nitrogen budget between 1985 and 1998.

Phosphorus

Pamunkey River Sub-Basin

The dominant phosphorus source in the Pamunkey River sub-basin is agriculture, which made up over 60 percent of the phosphorus budget (fig. 44a). From 1985 to 1998, there was a 4-percent decrease in delivered load of phosphorus from agriculture (table 23). There was an estimated 9-percent decrease in agricultural acreage during this period. Implementation of BMPs led to an estimated 10-percent decrease.

Fertilizer nutrient management plans implemented for phosphorus were not as successful as those for nitrogen. Agricultural phosphorus fertilizer loads decreased only 8 percent in this basin from 1985 to 1998. Sales of phosphorus fertilizer fluctuated throughout this period (fig. 46a). The greatest amounts of phosphorus fertilizer sold in this sub-basin (when weighted by the percentage of the county in the sub-basin) were in Hanover, Caroline, and Louisa Counties (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999).

Phosphorus loads from manure application increased 9 percent in the sub-basin from 1985 to 1998. U.S. Census of Agriculture data showed a decrease in phosphorus manure generation between 1987 and 1992, followed by an increase through 1997 (fig. 47a) (Puckett and others, 1998). The greatest manure generation of phosphorus (when weighted by the percentage of the county in the sub-basin) occurred in Louisa,

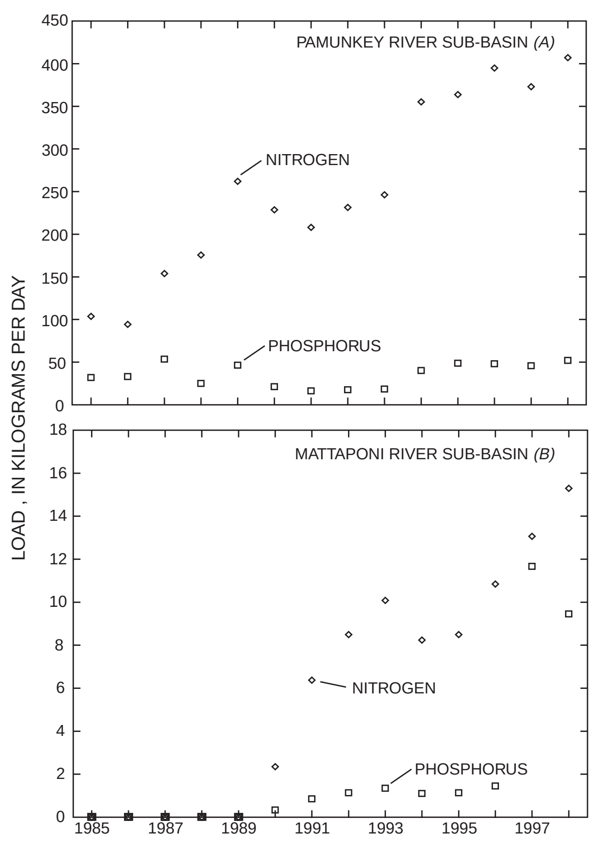


Figure 49. Annual mean point source load of total nitrogen and total phosphorus discharged in the Pamunkey River Basin *(A)* and the Mattaponi River Basin *(B)*, 1985 to 1998.

Orange, and Hanover Counties. Manure generation generally decreased from 1987 to 1992 in these counties, then increased between 1992 and 1997.

The second largest phosphorus source in the Pamunkey River sub-basin is urban areas, at about 20 percent of the phosphorus budget (fig. 44a). Input of phosphorus from urban areas increased 14 percent during this period, largely as a result of a 7-percent increase in urban acreage (table 23). The third largest source of phosphorus in 1985 was forested areas. By 1998, the contribution of point sources had exceeded that of forested areas slightly. From 1985 through 1998, there was a 74-percent increase in phosphorus loading from point sources above the RIM station, even though loads decreased from 1985 through 1993, probably as a result of the phosphate detergent ban (fig. 49a) (Wiedeman and Cosgrove, 1998). Increases in loads after 1993 are due in part to the large increases in flow from the Doswell combined outfall.

Mattaponi River Sub-Basin

Agriculture is the largest source of phosphorus in the Mattaponi River sub-basin as well, at nearly three-quarters of the budget (fig. 44b). From 1985 through 1998, there was a 15-percent decrease in the delivered load of phosphorus from agriculture, largely resulting from a 13-percent decrease in agricultural acreage, a 12-percent decrease in loads from fertilizer application, a 10-percent decrease in loads from manure application, and an estimated 20 percent reduction in loads from BMP implementation (table 23). Sales of phosphorus fertilizer increased during this period (fig. 46b). U.S. Census of Agriculture data showed generally increasing phosphorus manure generation between 1987 and 1997 (fig. 47b) (Puckett and others, 1998).

There was a 6-percent increase in acreage of urban areas, the second largest source of phosphorus in this sub-basin (fig. 44b). Contributions from forested areas, the third largest source, remained fairly constant from 1985 to 1998. Given that urban and forested areas made up only about 20 and 5 percent of the budget, respectively, these changes likely had little impact on the phosphorus trend in this sub-basin. Contributions from all other sources, including point sources, were negligible.

Ground Water

Between 1989 and 1998 at the Pamunkey River RIM station, an average of 19 percent of the total nitrogen load in the river came from ground-water inputs of nitrate (table 24). The load of nitrate from ground water increased 71 to 194 percent from 1985 to 1998. Similarly, at the Mattaponi River RIM station, an average of 17 percent of the total nitrogen load in the river came from ground water inputs of nitrate. However, at this station, there was no significant change in nitrate loads entering the river from ground water.

Table 24. Trends in dissolved nitrate load in base flow, percent base-flow nitrate load to surface-water total nitrogen load, and percent base flow to total streamflow in the York River Basin

[Trends expressed as percent change; percent change reported if significant at the 95-percent confidence level; NS, non-significant; --, not applicable or insufficient data]

Station number	Station name	Site number	Time period of trend	Trend in base-flow nitrate load	Percent base-flow nitrate load to surface-water total nitrogen load	Percent base flow to total streamflow
	Multi-Agency Nontidal Station					
01671020	North Anna River at Hart Corner near Doswell, Va.	24	1985-98	NS	--	43
	River Input Monitoring Program Stations					
01673000	Pamunkey River near Hanover, Va.	25	1989-98	+71 to +194	19	45
01674500	Mattaponi River near Beulahville, Va.	26	1989-98	NS	17	60

Summary

Pamunkey River Sub-Basin

There were no significant trends in either loads or flow-adjusted concentrations of nitrogen and phosphorus in the Pamunkey River sub-basin. For nitrogen, a 9-percent decrease in agricultural acreage combined with an estimated 17-percent decrease in nitrogen fertilizer loads and a 5-percent decrease in loads from BMP implementation somewhat offset the 4-percent increase in nitrogen loads from manure application. However, loads from urban areas, which contributed about 30 percent of the nitrogen budget, increased nearly 10 percent. Contributing to the increase in nitrogen was a large increase in nitrogen loads from point sources. The decreases in agriculture were not enough to overcome increases from urban areas and point sources. Therefore, there were no significant trends in either total nitrogen loads or flow-adjusted concentrations in this sub-basin.

Phosphorus loads from agricultural areas decreased only 4 percent. This was likely a result of increased loads from manure application offsetting agricultural acreage reductions and load reductions from BMP implementation and fertilizer nutrient management. Loads from urban areas, which were smaller than those from agriculture, increased 14 percent. The small net decrease in loads from agriculture combined with increases in loads from urban areas and point sources resulted in no significant trends in either total phosphorus loads or flow-adjusted concentrations in this sub-basin.

Mattaponi River Sub-Basin

There were no significant trends in the loads of total nitrogen and phosphorus in the Mattaponi River sub-basin; trends in flow-adjusted concentrations of total nitrogen and total phosphorus, however, were significantly downward. As in the Pamunkey River sub-basin, agriculture was the dominant nutrient source, contributing about 40 percent of the nitrogen budget and about 70 percent of the phosphorus budget. Downward flow-adjusted total nitrogen concentration trends in this basin resulted primarily from a 13-percent decrease in agricultural acreage combined with decreases in loads from fertilizer and manure application and an estimated 8-percent decrease in agricultural nitrogen loads from BMP implementation. These decreases offset the 6-percent increase in acreage of urban areas, the second largest contributor to the nitrogen budget.

The downward trend in flow-adjusted total phosphorus concentrations resulted primarily from the 13 percent reduction in agricultural acreage and the estimated 20 percent reduction in agricultural phosphorus loads from BMP implementation. Decreases in loads from fertilizer and manure application also contributed to the downward trend. Because agriculture makes up nearly three-quarters of the phosphorus budget, decreases in loads from agricultural areas outweighed increases in loads from urban areas, the second largest and only other major contributor to the phosphorus budget.

FACTORS AFFECTING TRENDS IN THE PATUXENT RIVER BASIN

Basin Description

The Patuxent River Basin, at 932 mi^2, is the second smallest of the seven RIM tributary basins. The Patuxent River originates north of Washington, D.C., and flows through the Piedmont and Coastal Plain Physiographic Provinces. The RIM station (01594440) is located near Bowie, Md., and receives drainage from 37 percent of the Patuxent River Basin (fig. 50). Of the nine rivers monitored, the Patuxent River contributes less than 1 percent of the total streamflow, the total nitrogen load, and the total phosphorus load to Chesapeake Bay (Belval and Sprague, 1999).

Land use above the monitoring station is 38 percent forest, 41 percent agriculture, and 13 percent urban (table 3). The basin is located between the Baltimore, Md., and Washington, D.C., metropolitan areas and has been subject to suburban development over the past decades, including in the towns of Columbia, Bowie, and Laurel, Md. The northern Patuxent River Basin is drained by three streams: the Little Patuxent, which drains much of the newly urbanized area of Columbia; the Middle Patuxent, which drains agricultural lands in the northern part of its drainage and the outer suburban areas of Columbia in the southern part of its basin; and the (upper) Patuxent River, which drains land that has remained primarily agricultural.

Trends

The stream discharge and observed total nitrogen and phosphorus concentrations at the RIM station from 1985 to 1998 are shown in figure 51. Total nitrogen concentrations ranged from 1.1 to 8.4 mg/L, with a median of 2.4 mg/L during the study period, and tended to be inversely correlated with discharge. Total phosphorus concentrations ranged from 0.02 to 1.2 mg/L, with a median of 0.15 mg/L. No relation is evident between total phosphorus concentrations and discharge.

Flow-adjusted total nitrogen concentrations decreased from 60 to 70 percent and flow-adjusted total phosphorus concentrations decreased 78 to 90 percent in the Patuxent River Basin between 1985 and 1998 (table 25). There was also a significant increasing trend in streamflow of 39 to 136 percent. Despite this increase in streamflow, loads of total phosphorus and total nitrogen decreased significantly, from 24 to 49 percent and 36 to 66 percent, respectively. The Patuxent River Basin has undergone the greatest nutrient reductions of the basins monitored by the RIM Program.

Nutrient Budgets and Yield Distributions

Nutrient Budgets

Nitrogen and phosphorus budgets were calculated for the Patuxent River Basin upstream from the Patuxent River RIM station (fig. 52). These budgets are Chesapeake Bay WSM estimates of the nutrient load delivered from six source categories, and are simulated for 1985 and 1998 using average hydrology in the basin. The WSM indicates that point sources, agriculture, and urban lands are the dominant nutrient sources in the Patuxent River Basin.

Nitrogen

Results of WSM simulations indicate that in 1985, point sources (47 percent) were the largest contributor to the total nitrogen budget in the Patuxent River Basin (fig. 52). Urban areas, agriculture, forested areas, and septic inputs contributed 29 percent, 17 percent, 4 percent, and 3 percent, respectively. In 1998, urban areas (47 percent) had replaced point sources (29 percent) as the largest contributor to the nitrogen budget. Agriculture and septic inputs contributed 14 percent and 5 percent of the nitrogen budget, respectively.

Phosphorus

Results of WSM simulations indicate that in 1985, point sources (58 percent) were the largest contributor to the total phosphorus budget in the Patuxent River Basin (fig. 52). Agriculture and urban areas contributed 26 percent and 15 percent, respectively. In 1998, urban areas were a much larger contributor of

EXPLANATION

PATUXENT RIVER BASIN DRAINAGE AREA

11 ▲ RIVER INPUT MONITORING STATION AND SITE NUMBER

10 ■ MULTI-AGENCY NONTIDAL MONITORING STATION AND SITE NUMBER

Figure 50. Location of the monitoring stations in the Patuxent River Basin.

phosphorus, at 40 percent of the budget. Agriculture (31 percent) was the second largest contributor, while point sources contributed 27 percent.

Nutrient Yield Distributions

The amount of nitrogen and phosphorus delivered to the Patuxent River RIM station from individual small reaches within the Patuxent River Basin was estimated using the SPARROW model for 1987 conditions. The yields shown in figure 53 are less than the yields generated within the basin because of on-land and in-stream losses that occur between the point of generation and the monitoring station.

Nitrogen

The SPARROW model results indicate that 30 percent of the nitrogen that is generated within the watershed reaches the Patuxent River RIM station (table 26). The predominantly agricultural areas of the northern Patuxent River Basin, where large amounts of nitrogen are applied to the surface, deliver relatively small yields of nitrogen to the RIM station. Conversely, the developing areas in the southern part of the basin deliver relatively large yields of nitrogen to the RIM station. Much of this delivered yield is from wastewater treatment facilities.

Phosphorus

The SPARROW model results indicate that 7.5 percent of the phosphorus that is generated within the watershed reaches the RIM station (table 26). The agricultural areas in the northern part of the basin deliver less phosphorus than the urban areas in the southern

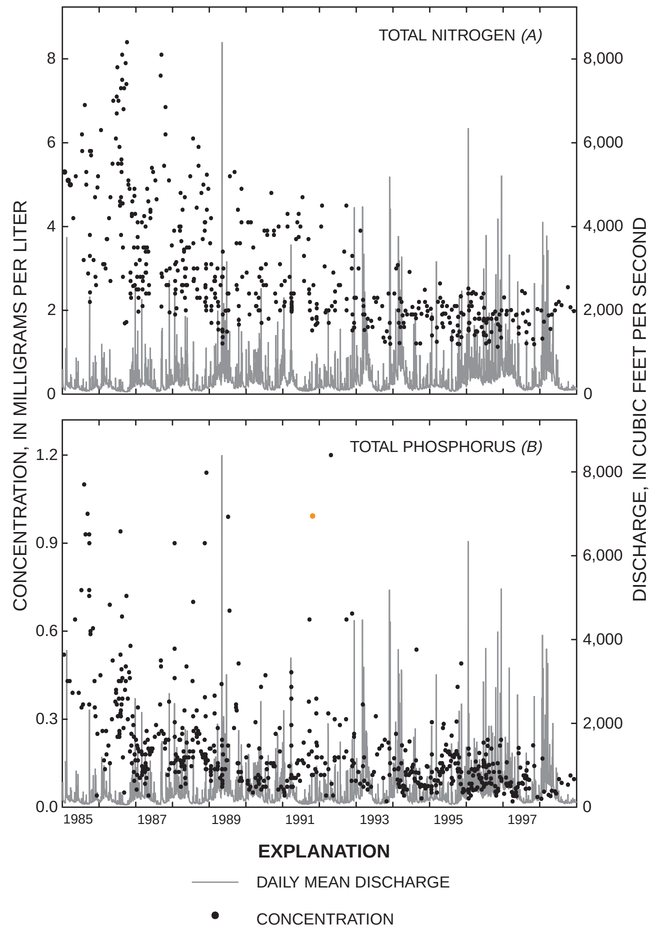


Figure 51. Observed total nitrogen *(A)* and total phosphorus *(B)* concentrations and daily mean discharge at the Patuxent River Basin RIM station, 1985 through 1998.

Table 25. Trends in monthly mean flow, monthly load of total nitrogen (TN) and total phosphorus (TP), and flow-adjusted concentrations of TN and TP for stations in the Patuxent River Basin

[TN, total nitrogen; TP, total phosphorus; NS, non-significant; trends expressed as percent change; percent change is reported if significant at the 95-percent confidence level]

Station number	Station name	Site number	Time period of trend	Monthly mean flow trend	Monthly load trend		Flow-adjusted concentration trend	
					TN	TP	TN	TP
Multi-Agency Nontidal Station								
01592500	Patuxent River at Laurel, Md.	10	1985-98	+26 to +222	+49 to +306	-6 to -7	+14 to +17	NS
River Input Monitoring Program Station								
01594440	Patuxent River near Bowie, Md.	11	1985-98	+39 to +136	-24 to -49	-36 to -66	-60 to -70	-78 to -90

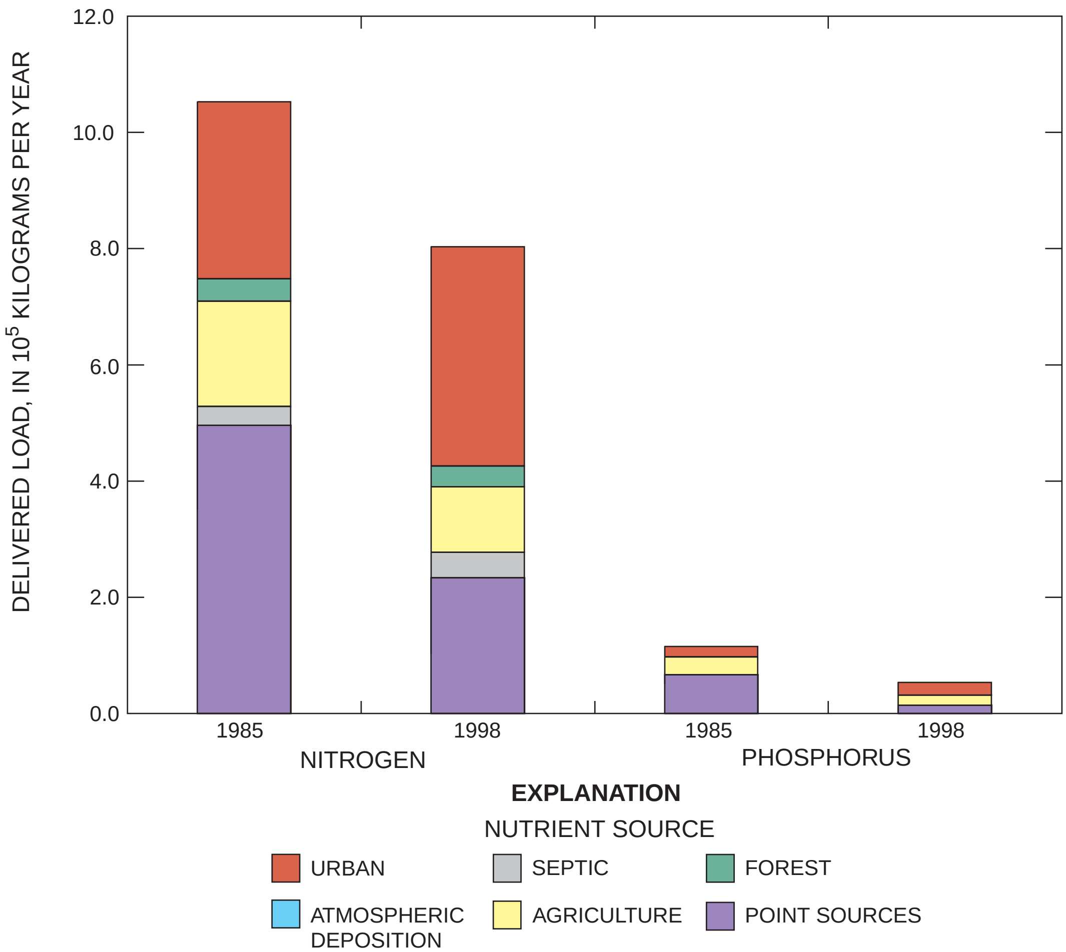


Figure 52. Contribution of major nutrient sources to the nitrogen and phosphorus budgets in the Patuxent River Basin during 1985 and 1998, generated by the Chesapeake Bay Watershed Model.

part of the basin. Greater travel times from the northern part of the basin and associated in-stream losses increase the disparity between the yields delivered from agricultural and urban areas. The largest contribution of phosphorus to the RIM station is from the urban areas of the basin.

Trends In Nutrient Sources

Estimates of changes in nutrient source loads, land use, and management practices during the study period were provided by WSM simulations. These WSM estimates are described in the following section. Data on manure generation, animal numbers, and fertilizer sales derived from the U.S. Census of Agriculture and data on point source discharges from the USEPA are presented for comparison with model data.

Nitrogen

In 1985, the dominant nitrogen source in the Patuxent River Basin was point sources; nitrogen loads from point sources decreased 53 percent from 1985 to 1998 (fig. 54), and by 1998, the dominant source was urban areas (table 27). There are 34 wastewater treatment facilities within the Patuxent River Basin; 8 of the 10 major facilities are located upstream of the RIM station. Annual mean discharge from the largest facilities in the basin remained relatively steady or increased during the monitoring period (fig. 55) (Wiedeman and Cosgrove, 1998); the largest increases occurred at the two largest treatment facilities, Little Patuxent and Western Branch. Annual mean discharge from Little Patuxent increased from about 9 Mgd in 1985 to more than 17.5 Mgd in 1998, an increase of 94 percent. Annual mean discharge from Western Branch increased from about 11 Mgd in 1985 to more than 17 Mgd in 1998, an increase of 59 percent.

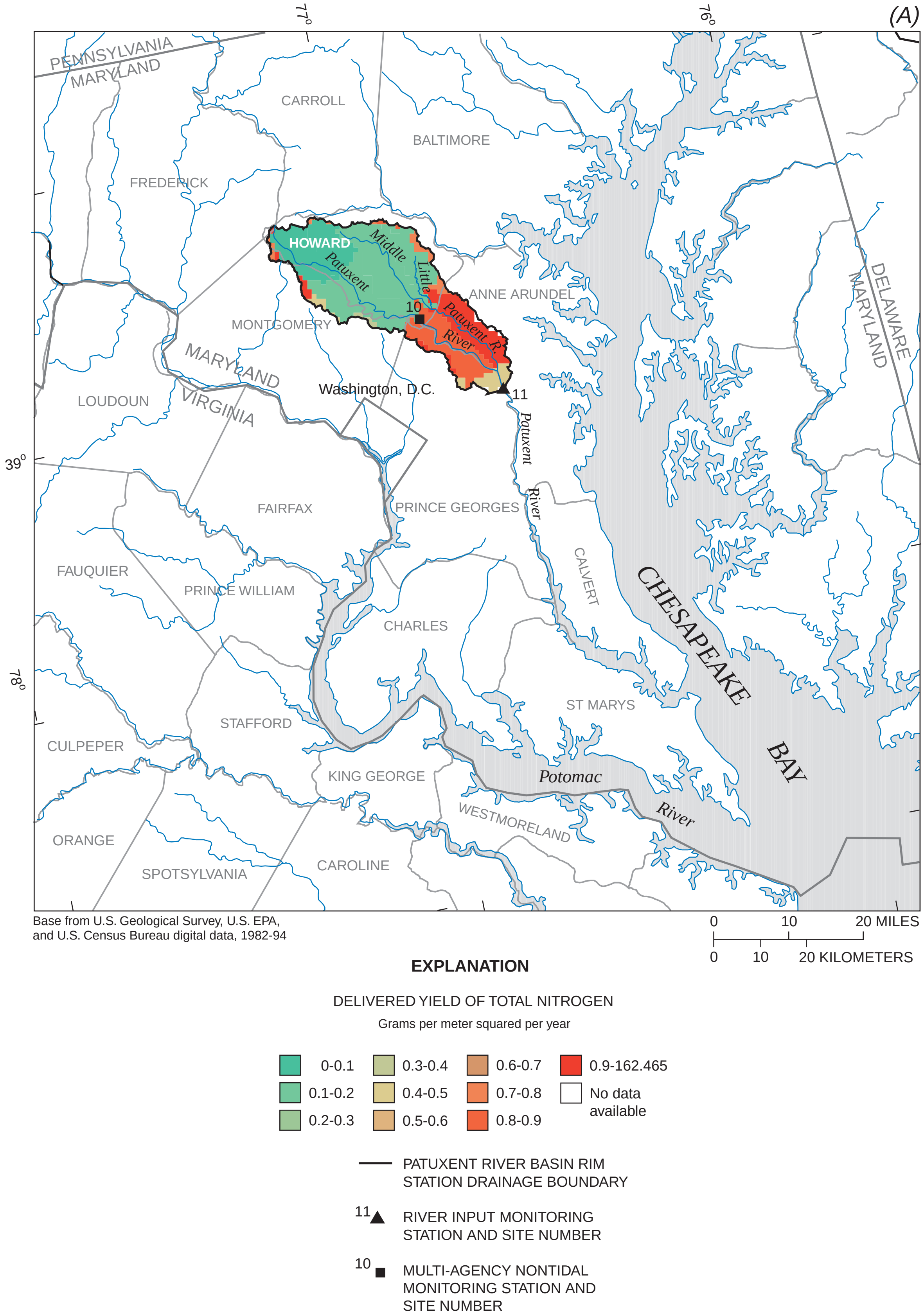


Figure 53. Delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the Patuxent River Basin in 1987, generated by the SPARROW model.

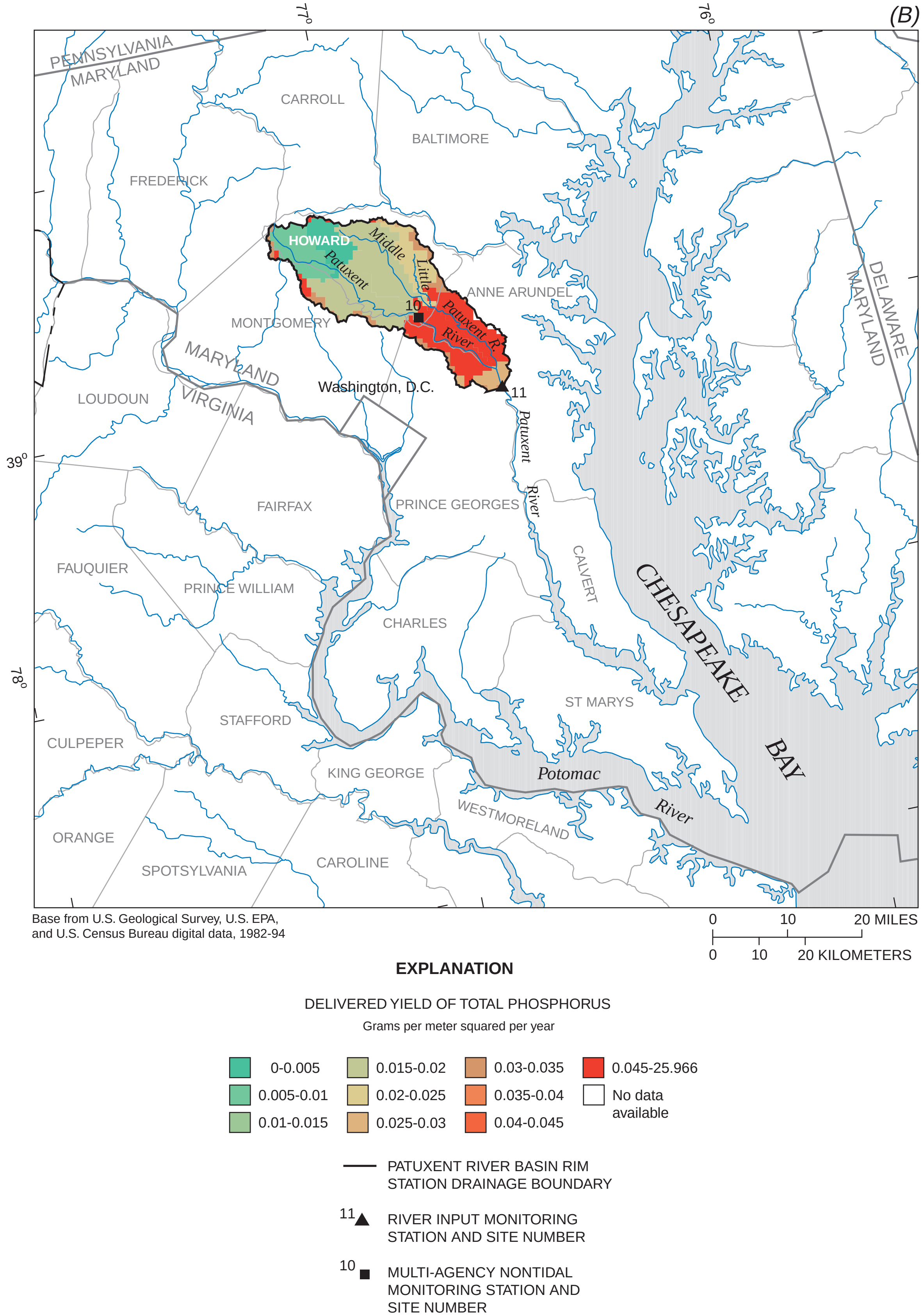


Figure 53. Delivered yield of total nitrogen *(A)* and total phosphorus *(B)* in the Patuxent River Basin in 1987, generated by the SPARROW model.

Table 26. SPARROW model estimates of the percentage of total nitrogen and total phosphorus load generated in the watershed that is delivered to monitoring stations in the Patuxent River Basin

Station number	Station name and number	Site number	Percent delivered to station	
			Total nitrogen	Total phosphorus
	Multi-Agency Nontidal Station			
01592500	Patuxent River at Laurel, Md.	10	21	3.4
	River Input Monitoring Program Station			
01594440	Patuxent River near Bowie, Md.	11	30	7.5

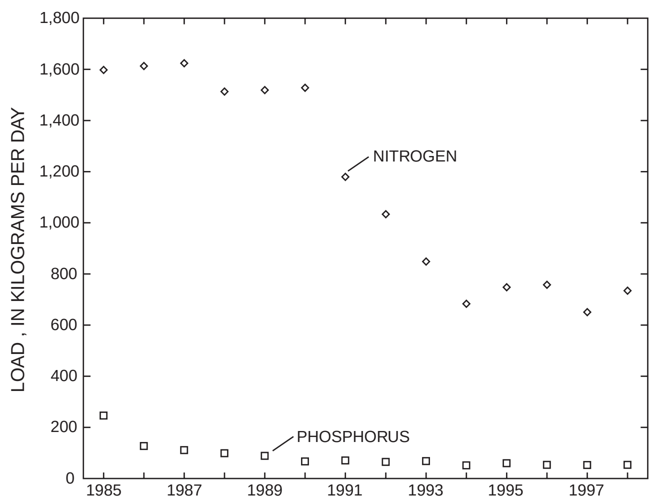


Figure 54. Annual mean point source load of total nitrogen and total phosphorus discharged in the Patuxent River Basin, 1985 to 1998.

Total nitrogen effluent concentrations decreased for most of the wastewater treatment facilities (fig. 56), due primarily to BNR implementation during the early 1990’s at nine facilities within the Patuxent River Basin (table 28). Seven of these nine facilities are located in the nontidal area upstream of the RIM station. Due to these decreasing concentrations, and despite the increasing discharges from some of the facilities, loads of nitrogen from point sources decreased (fig. 54). During the late 1980’s before BNR implementation, nitrogen loads for some of the facilities, including the Little Patuxent and Western Branch Facilities, increased as effluent discharge increased. Loads then decreased during the early 1990’s (fig. 57). Nitrogen loads at the two largest facilities increased during the mid to late 1990’s—after the BNR upgrades were in place—as effluent discharge continued to increase (Wiedeman and Cosgrove, 1998). This suggests that continuing urbanization in these areas may lead to increasing nitrogen loads from point sources unless treatment facilities are upgraded further.

Nitrogen loads from urban areas, which had become the largest contributor to the nitrogen budget in the Patuxent River Basin by 1998, increased 24 percent from 1985 through 1998 (table 27). During this time, the population of the Patuxent River Basin increased 34 percent. The impact of this increasing population is seen in the conversion of agricultural and forest lands to urban lands during the monitoring period. Urban acreage increased 21 percent from 1985 to 1998, while agricultural and forest acreages decreased by 27 percent and 2 percent, respectively. In addition, nitrogen loads from septic inputs increased 38 percent.

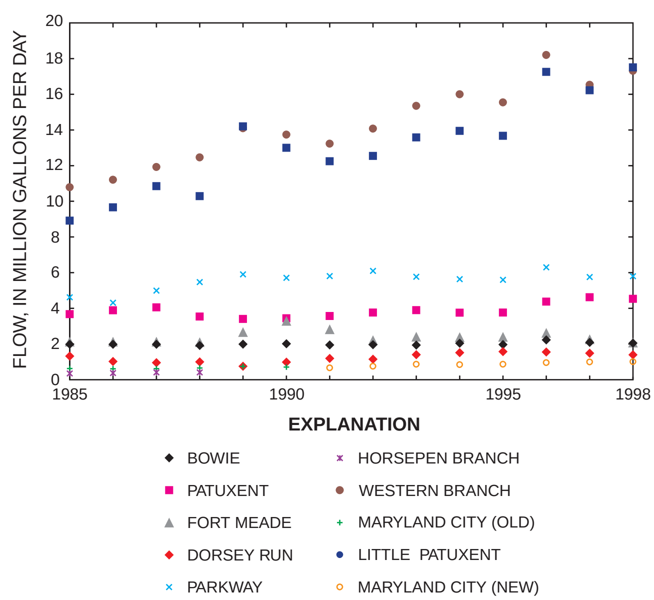


Figure 55. Annual mean flow from major contributing facilities in the Patuxent River Basin, 1985 to 1998.

Table 27. Watershed Model estimates of percent change in land use acreage, percent change in loads due to best management practice implementation, source loads, delivered loads, and percent change in loads between 1985 and 1998 for nitrogen and phosphorus in the Patuxent River Basin

[BMP, best management practice; kg/yr, kilograms per year; <, less than; reported load values are either source (input) loads or delivered (output) loads from the Watershed Model]

	% Acreage change	% Load change from BMP implementation	Load (kg/yr)		
			1985	1998	% Change
Nitrogen					
Agriculture (Delivered)	-27	-10	1.74×10^5	1.08×10^5	-38
Fertilizer (Source)			1.54×10^6	1.12×10^6	-27
Manure (Source)			5.05×10^5	2.99×10^5	-41
Urban areas (Delivered)	+21	-2	2.93×10^5	3.62×10^5	+24
Fertilizer (Source)			8.69×10^5	1.09×10^6	+26
Forested areas (Delivered)	-2	<-1	3.70×10^4	3.45×10^4	-7
Point sources (Delivered)			4.76×10^5	2.24×10^5	-53
Septic (Delivered)			2.92×10^4	4.02×10^4	+38
Atmospheric deposition (Delivered)			2.15×10^3	2.20×10^3	+2
Phosphorus					
Agriculture (Delivered)	-27	-16	2.85×10^4	1.60×10^4	-44
Fertilizer (Source)			2.27×10^5	1.69×10^5	-25
Manure (Source)			1.36×10^5	8.13×10^4	-40
Urban areas (Delivered)	+21	-2	1.70×10^4	2.05×10^4	+21
Fertilizer (Source)			0	0	0
Forested areas (Delivered)	-2	<-1	7.52×10^2	7.26×10^2	-3
Point sources (Delivered)			6.41×10^4	1.37×10^4	-79
Septic (Delivered)			0	0	0
Atmospheric deposition (Delivered)			3.19×10^2	3.15×10^2	-1

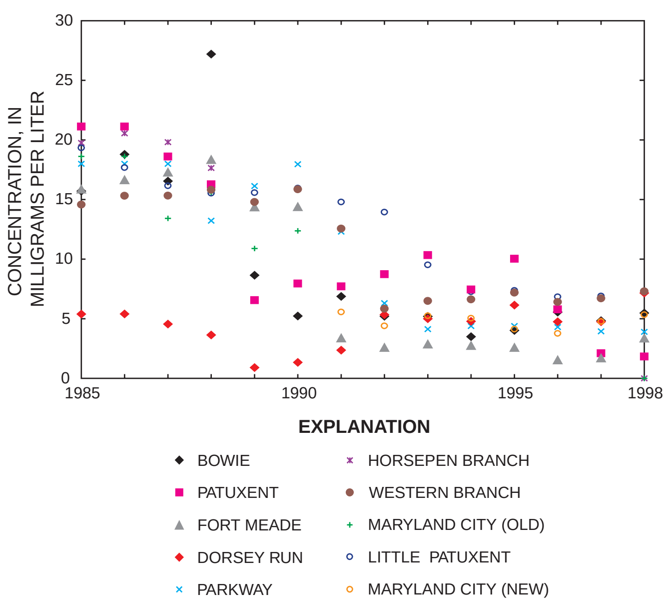


Figure 56. Annual mean total nitrogen concentrations discharged from major contributing facilities in the Patuxent River Basin, 1985 to 1998.

Table 28. Major point source dischargers in the Patuxent River Basin that have implemented biological nutrient removal (BNR), and the date of implementation

[NPDES; National Pollutant Discharge Elimination System]

Facility	NPDES ID	BNR Implementation Date
Bowie	MD0021628	5/1/1991
Dorsey Run	MD0063207	1/1/1992
Fort Meade	MD0021717	1/1/1990
Little Patuxent	MD0055174	5/1/1993
Maryland City	MD0062596	1/1/1990
Parkway	MD0021725	1/1/1992
Patuxent	MD0021652	1/1/1990
Pine Hill Run	MD0021679	6/1/1998
Western Branch	MD0021741	1/1/1995

Nitrogen loads from agriculture, the third largest source of nitrogen in the Patuxent River Basin, decreased 38 percent from 1985 to 1998 (table 27). This was largely a result of the conversion of agricultural land to urban land during the monitoring period; agricultural acreage decreased 27 percent. Nitrogen loads from fertilizer application decreased 27 percent, though fertilizer sales remained fairly constant (fig. 58) (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999). The fertilizer sales data presented here should be interpreted with caution. Nitrogen loads from manure application decreased 41 percent. U.S. Census of Agriculture data show a substantial decrease in nitrogen manure generation between 1987 and 1997 (fig. 59) (Puckett and others, 1998). Numbers of beef and dairy cows and poultry also decreased during the monitoring period (fig. 60) (USDA National Agricul-

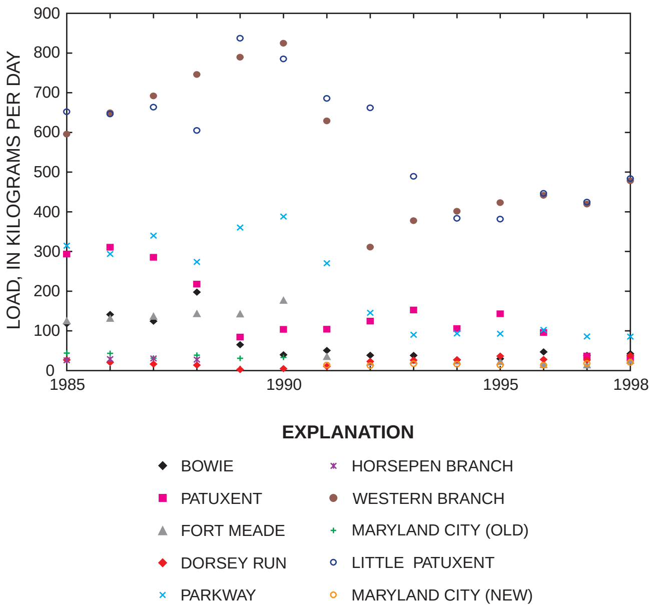


Figure 57. Annual mean total nitrogen loads discharged from major contributing facilities in the Patuxent River Basin, 1985 to 1998.

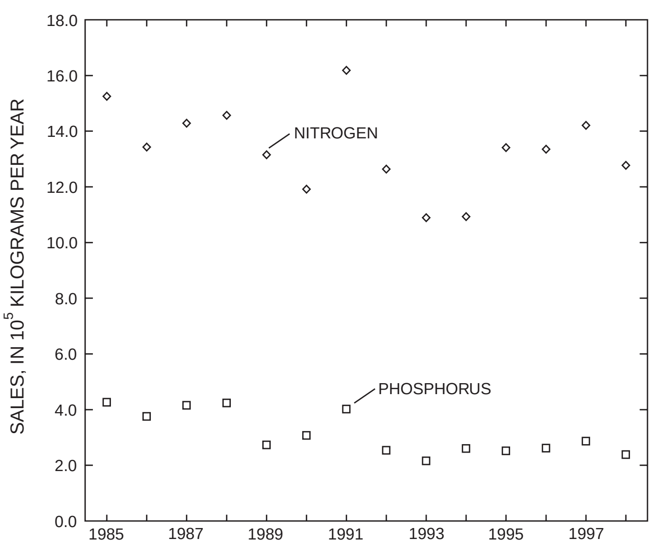


Figure 58. Annual sales of nitrogen and phosphorus fertilizer in the Patuxent River Basin, 1985 to 1998.

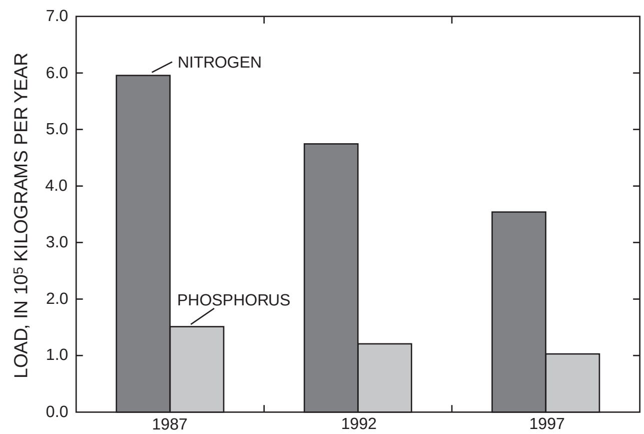


Figure 59. Annual load of nitrogen and phosphorus from manure generated in the Patuxent River Basin in 1987, 1992, and 1997

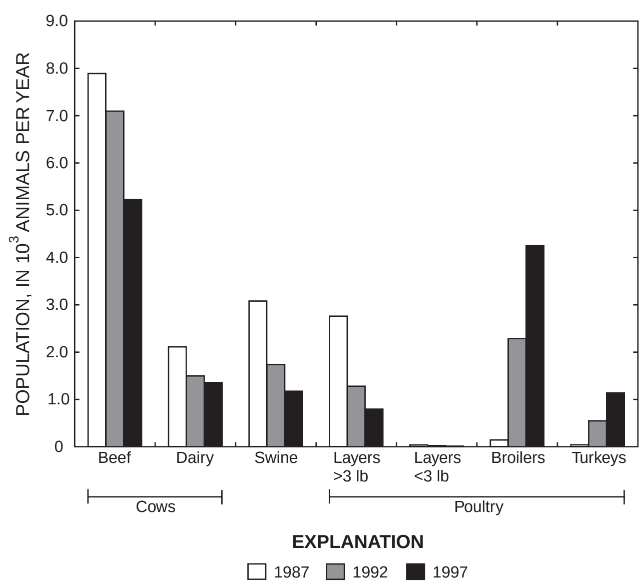


Figure 60. Population distribution of agricultural animals in the Patuxent River Basin in 1987, 1992, and 1997.

tural Statistics Service, 1997). In addition, BMP implementation in the basin led to an estimated 10-percent decrease in nitrogen loads (table 27).

Phosphorus

As with nitrogen, in 1985 the dominant phosphorus source in the Patuxent River Basin was point sources. However, phosphorus loads from point sources decreased 79 percent from 1985 to 1998 (table 27); by 1998, the dominant phosphorus source was urban areas. Point source discharges from the largest facilities in the basin remained relatively steady or increased, but total phosphorus effluent concentrations decreased for most of the facilities (figs. 55 and 61) (Wiedeman and Cosgrove, 1998). As a result, loads of phosphorus from these facilities, and in the basin overall, decreased (figs. 54 and 62).

Phosphorus loads from urban areas had become the largest contributor to the phosphorus budget in the Patuxent River Basin by 1998, increasing 21 percent from 1985 through 1998 and surpassing loads from both point sources and agricultural areas (table 27). This increase was due in large part to the 21-percent increase in urban acreage from 1985 to 1998, driven by the population increase during this period.

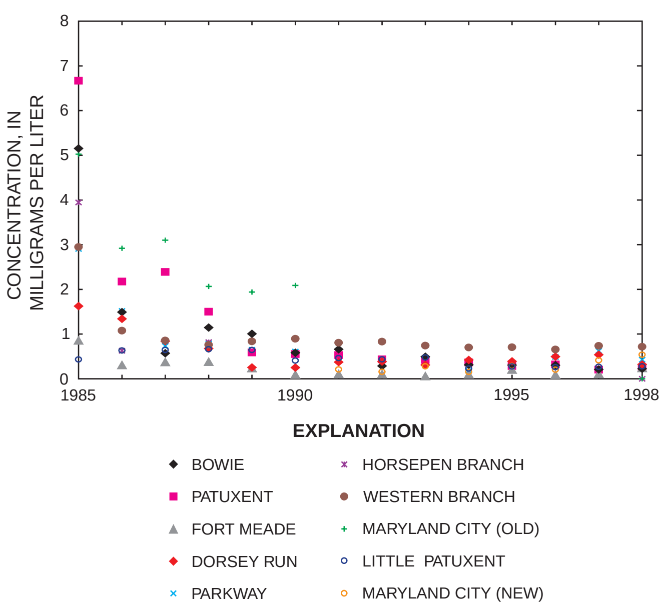


Figure 61. Annual mean total phosphorus concentrations discharged from major contributing facilities in the Patuxent River Basin, 1985 to 1998.

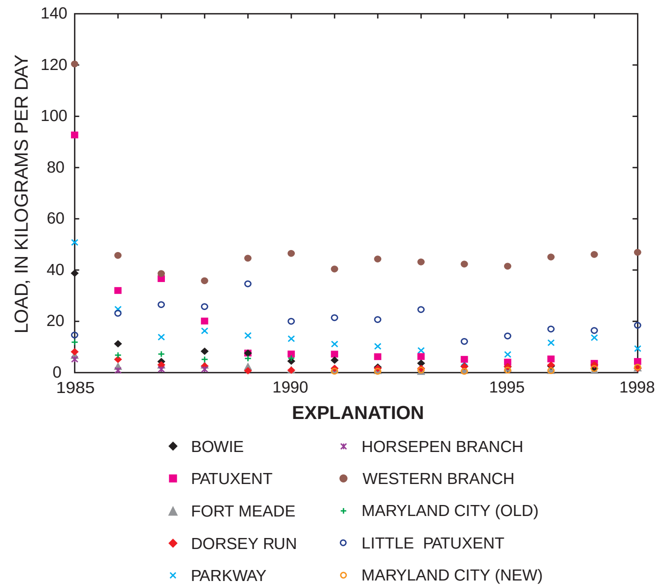


Figure 62. Annual mean total phosphorus loads discharged from major contributing facilities in the Patuxent River Basin, 1985 to 1998.

Phosphorus loads from agriculture, the second largest phosphorus source in both 1985 and 1998, decreased 44 percent from 1985 through 1998. Agricultural acreage decreased 27 percent during this period. Phosphorus loads from fertilizer application decreased 25 percent (table 27); phosphorus fertilizer sales fluctuated during this period (fig. 58) (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999). Phosphorus loads from manure application decreased 40 percent. U.S. Census of Agriculture data showed a decrease in phosphorus manure generation between 1987 and 1997 (fig. 59) (Puckett and others, 1998).

Ground Water

The base-flow load at the Patuxent River RIM station is a mixture of ground water and wastewater treatment facility discharges. For example, on October 2, 1986, the total nitrogen concentration was 8.4 mg/L, the highest nitrogen concentration observed within the monitoring period. Instantaneous discharge at the time of sampling was 95 cfs. In 1986, prior to BNR upgrades, the eight large treatment facilities upstream of the RIM station were discharging relatively high concentrations of nitrogen, with an annual mean concentration of 16.5 mg/L. As an estimate, daily discharge fluctuation and flow lag times are ignored and mean annual discharge from the eight large facilities located within five stream miles of the monitoring station are added to obtain 24 Mgd, or 37 cfs. This sewage treatment component of base flow would be 39 percent of the 95 cfs instantaneous discharge at the time of sampling. Additionally, wastewater flow varies during any given day; the daily peak typically occurs between 10 am and noon and commonly is assumed to be 225 percent of the daily mean flow (Lindeburg, 1997, p. 8-9). The sample was taken at 11:10 am, in the middle of this typical peak flow period. With this adjustment taken into account, the wastewater treatment effluent component of the total base flow may have been as high as 84 cfs, or 88 percent of the instantaneous discharge.

From 1985 through 1998, the base-flow nitrate contribution to the total nitrogen load in surface water decreased from about 55 percent to 33 percent. On average throughout the study period, base-flow inputs of nitrate made up 47 percent of the total nitrogen load in surface water (table 29). Overall, base-flow nitrate loads decreased 70 to 78 percent from 1985 to 1998. The decreasing contribution of base-flow nitrate indicates that sewage was not as large of a source of nitrogen in the Patuxent River in 1998 as it was in 1985.

Summary

Flow-adjusted concentrations of both total nitrogen and total phosphorus decreased significantly at the Patuxent River RIM station from 1985 through 1998. In spite of significantly increasing streamflow, loads of total nitrogen and total phosphorus also decreased significantly during this period.

The major sources of nitrogen and phosphorus in the Patuxent River Basin were point sources, urban areas, and agriculture. The decreasing trends in nutrients were due primarily to the installation of BNR treatment processes at eight sewage treatment facilities above the RIM station. Additional decreases resulted from decreasing loads from fertilizer and manure application, decreasing numbers of animals, and the implementation of BMPs during the monitoring period. However, the rapid urbanization and increasing population of this basin mitigated the effects of these reductions through increased runoff from developed areas and increased wastewater treatment discharges. Despite the large reductions that have been made in nitrogen and phosphorus effluent concentrations, as wastewater discharges increase, loads likely will increase also unless additional wastewater treatment process upgrades are implemented.

Table 29. Trends in dissolved nitrate load in base flow, percent base-flow nitrate load to surface-water total nitrogen load, and percent base flow to total streamflow in the Patuxent River Basin

[Trends expressed as percent change; percent change reported if significant at the 95-percent confidence level; NS, non-significant]

Station number	Station name	Site number	Trend in base-flow nitrate load	Percent base-flow nitrate load to surface-water total nitrogen load	Percent base flow to total streamflow
			Multi-Agency Nontidal Station		
01592500	Patuxent River at Laurel, Md.	10	NS	42	58
			River Input Monitoring Program Station		
01594440	Patuxent River near Bowie, Md.	11	-70 to -78	47	60

Basin Description

The Choptank River Basin, at 795 mi^2, is the smallest of the seven Chesapeake Bay tributary basins monitored by the RIM program. The river originates in Kent County, Del., and flows southwest, becoming tidally controlled near Greensboro, Md. The entire basin lies within the Coastal Plain Physiographic Province. The RIM station near Greensboro (01491000) receives drainage from 14 percent of the watershed (fig. 63). Of the nine rivers monitored by the RIM program, the Choptank River contributes less than 1 percent of the streamflow, total nitrogen load, and total phosphorus load to Chesapeake Bay (Belval and Sprague, 1999).

Land use above the RIM station is 29 percent forested, 50 percent agricultural, and 1 percent urban (table 3). The Choptank River Basin, like all of the Eastern Shore, is largely agricultural, but also has a sizeable amount of forested areas. Its preponderance of poorly draining soils and forest makes this basin atypical compared to much of the Eastern Shore. Much of the Choptank River Basin is drained through ditches that have been installed over many decades to drain the flatlands for agriculture use. The drains are typically kept clear of vegetation, expediting flow; consequently there is less opportunity for nutrient uptake and denitrification.

Trends

The stream discharge and observed nitrogen and phosphorus concentrations at the RIM station from 1985 through 1998 are shown in figure 64. Total nitrogen concentrations ranged from 0.83 to 3.6 mg/L, with a median of 1.7 mg/L. Total nitrogen concentrations tended to be poorly correlated with discharge. Total phosphorus concentrations ranged from less than 0.01 to 0.26 mg/L, with a median of 0.06 mg/L. Total phosphorus concentrations generally were positively correlated with discharge.

From 1985 to 1998 at the Choptank River RIM station, there was a significantly increasing trend in total nitrogen loads of 25 to 179 percent, but no significant trend in total phosphorus loads (table 30). In addition, streamflow increased 40 to 108 percent. When streamflow was removed as a factor affecting in-stream concentrations, there was a significant decrease in flow-adjusted total phosphorus concentrations of 13 to 39 percent. There was no trend in flow-adjusted total nitrogen concentrations.

Nutrient Budgets and Yield Distributions

Nutrient Budgets

Nitrogen and phosphorus budgets were calculated for the Choptank River Basin upstream from the Choptank River RIM station (fig. 65). These budgets are Chesapeake Bay WSM estimates of the nutrient load delivered from six source categories, and are simulated for 1985 and 1998 using average hydrology in the basin. The WSM indicates that agriculture is the dominant source of both nitrogen and phosphorus within the basin.

Nitrogen

Results of WSM simulations indicate that in 1985, agriculture was the largest contributor to the nitrogen budget in the Choptank River Basin, at 79 percent (fig. 65). Urban areas, forested areas, and septic inputs contributed 9 percent, 7 percent, and 4 percent, respectively. The one small point source in the upper basin contributed less than 1 percent of the nitrogen budget. In 1998, agriculture was still the largest contributor to the total nitrogen budget, at 76 percent. The contributions of urban areas, forested areas, and septic inputs all increased slightly to 11 percent, 8 percent, and 5 percent, respectively. The one point source still contributed less than 1 percent of the total nitrogen budget in the basin.

Phosphorus

Results of WSM simulations indicate that in 1985, agriculture was the largest contributor to the total phosphorus budget, at 83 percent (fig. 65). Urban and forested areas contributed 14 percent and 2 percent, respectively. In 1998, the contribution of agriculture

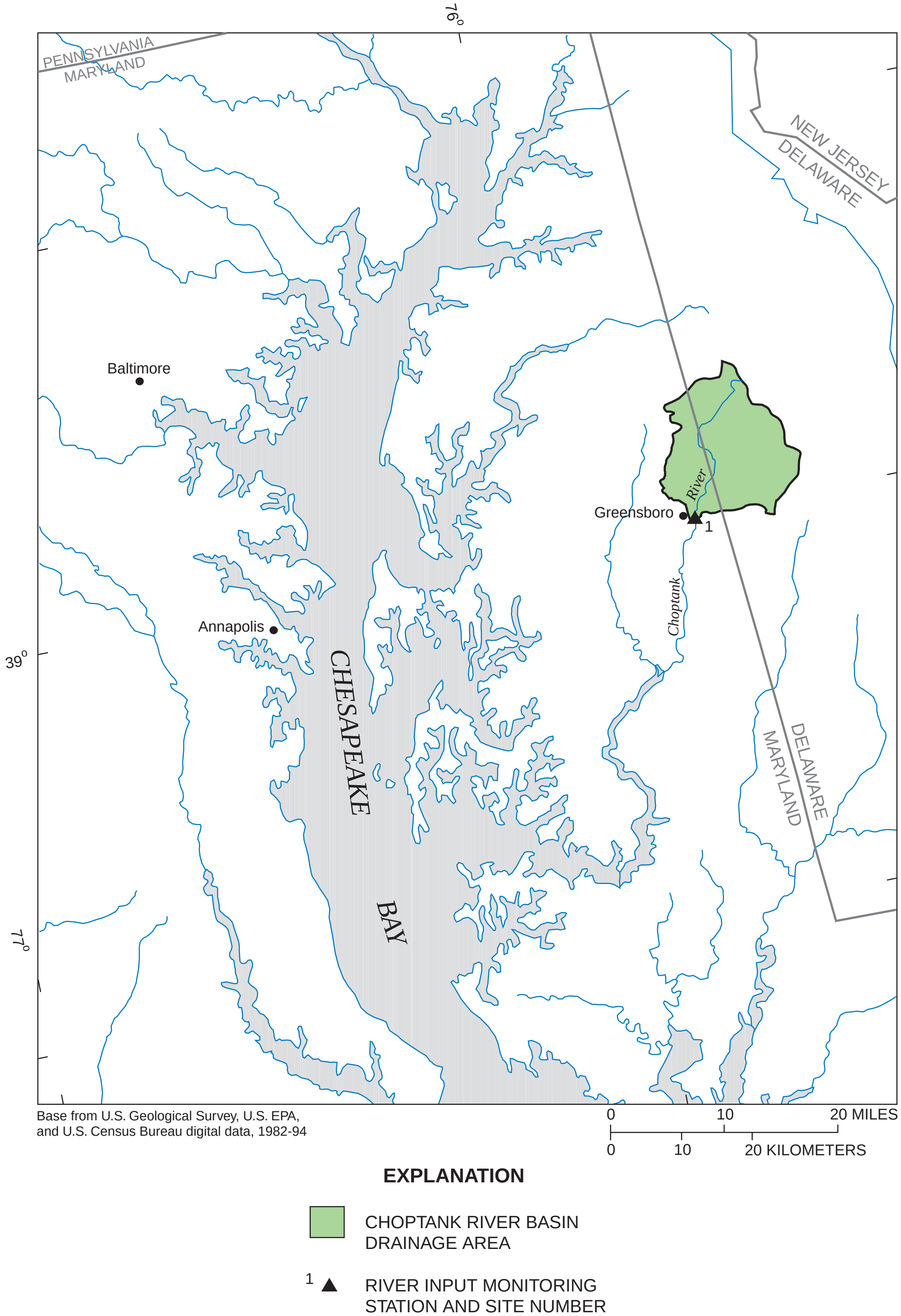


Figure 63. Location of the monitoring stations in the Choptank River Basin.

decreased to 80 percent, while the contribution of urban and forested areas increased to 17 percent and slightly less than 3 percent, respectively. The one point source in the basin contributed less than 1 percent of the total phosphorus budget throughout the study period.

Nutrient Yield Distributions

The amount of nitrogen and phosphorus delivered to the Choptank River RIM station from individual small reaches within the Choptank River Basin was estimated using the SPARROW model for 1987 conditions. The yields shown in figure 66 are less than the yields generated within the basin because of on-land and in-stream losses that occur between the point of generation and the monitoring station.

Based upon the 1987 SPARROW model results, 14 percent of the nitrogen and 1.9 percent of the phosphorus generated within the watershed reach the RIM station (table 31). Most of the upper Choptank River Basin delivers relatively high yields of nitrogen and phosphorus to the RIM station. This is due to the large amount of agricultural activity in this area and the relatively short travel times to the monitoring station.

Trends In Nutrient Sources

Estimates of changes in nutrient source loads, land use, and management practices during the study period were provided by WSM simulations. These WSM estimates are described in the following section. Data on manure generation, animal numbers, and fertilizer sales derived from the U.S. Census of Agriculture and data on point source discharges from the USEPA are presented for comparison with model data.

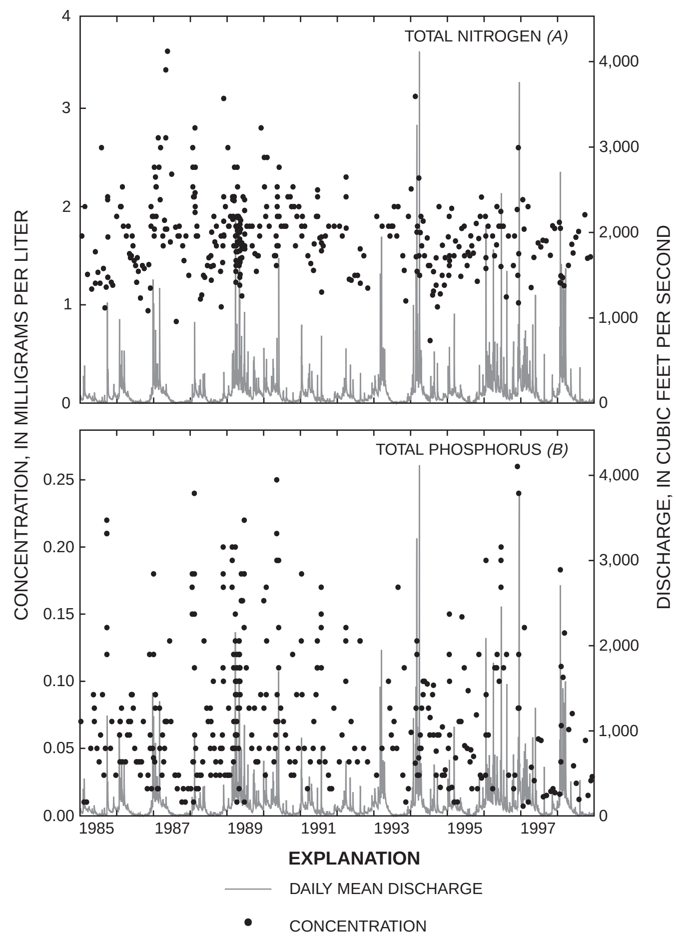


Figure 64. Observed total nitrogen *(A)* and total phosphorus *(B)* concentrations and daily mean discharge at the Choptank River Basin RIM station, 1985 through 1998.

Nitrogen

Agriculture made up approximately three-quarters of the nitrogen budget in the Choptank River Basin (fig. 65). Between 1985 and 1998, agricultural loads of nitrogen decreased 9 percent (table 32). Agricultural

Table 30. Trends in monthly mean flow, monthly load of total nitrogen (TN) and total phosphorus (TP), and flow-adjusted concentrations of TN and TP for stations in the Choptank River Basin

[TN, total nitrogen; TP, total phosphorus; NS, non-significant; trends expressed as percent change; percent change is reported if significant at the 95-percent confidence level]

Station number	Station name	Site number	Time period of trend	Monthly mean flow trend	Monthly load trend		Flow-adjusted concentration trend	
					TN	TP	TN	TP
				River Input Monitoring Program Station				
01491000	Choptank River near Greensboro, Md.	1	1985-98	+40 to +108	+25 to +179	NS	NS	-13 to -39

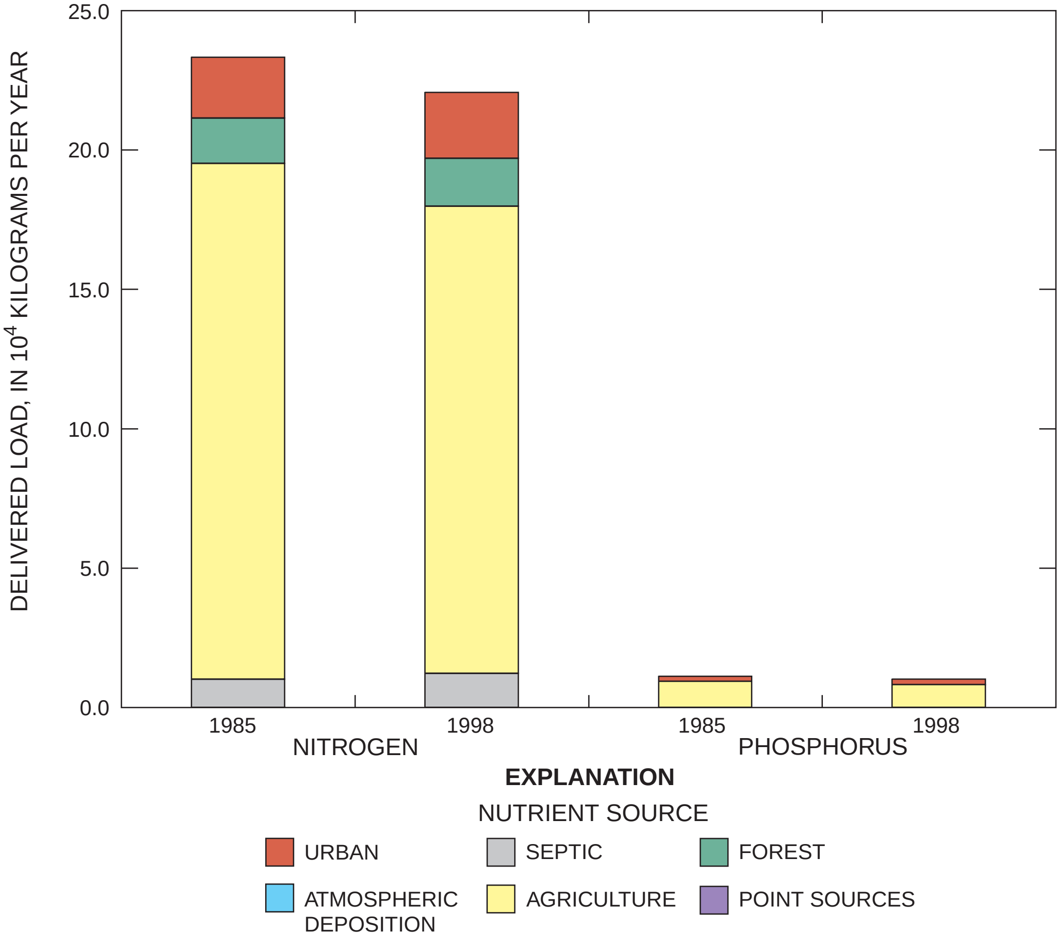


Figure 65. Contribution of major nutrient sources to the nitrogen and phosphorus budgets in the Choptank River Basin during 1985 and 1998, generated by the Chesapeake Bay Watershed Model.

acreage within the basin decreased 7 percent and BMP implementation led to an estimated 7-percent decrease in agricultural nitrogen loads during this period. Nitrogen loads from fertilizer application decreased 7 percent between 1985 and 1998. Fertilizer sales of nitrogen fluctuated during this period (fig. 67) (Bataglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999). The fertilizer sales data presented here should be interpreted with caution. Loads from application of manure, a smaller source of nitrogen than fertilizer, increased 5 percent during the study period. U.S. Census of Agriculture data showed a relatively large decrease in nitrogen manure generation between 1987 and 1992, followed by a large increase through 1997 to near 1987 levels (fig. 68) (Puckett and others, 1998). This pattern mirrors the pattern in numbers of poultry broilers during that period (fig. 69).

The second largest source of nitrogen in the Choptank River Basin was urban areas, but the loads from urban areas made up only about 10 percent of the total nitrogen budget (fig. 65). The population of the Choptank River Basin above the RIM station increased 18 percent between 1985 and 1998. This population increase led to a 7-percent increase in urban acreage, and nitrogen loads from urban areas increased 9 percent (table 32). The only other measurable contributor to the nitrogen budget in the basin was forested areas; nitrogen loads from forested areas increased 5 percent during the study period, largely a result of a 5-percent increase in forested acreage. Nitrogen loads from the single point source facility above the RIM station increased over 1,000 percent during the monitoring period (fig. 70) (Wiedeman and Cosgrove, 1998). However, because point source loads made up less than

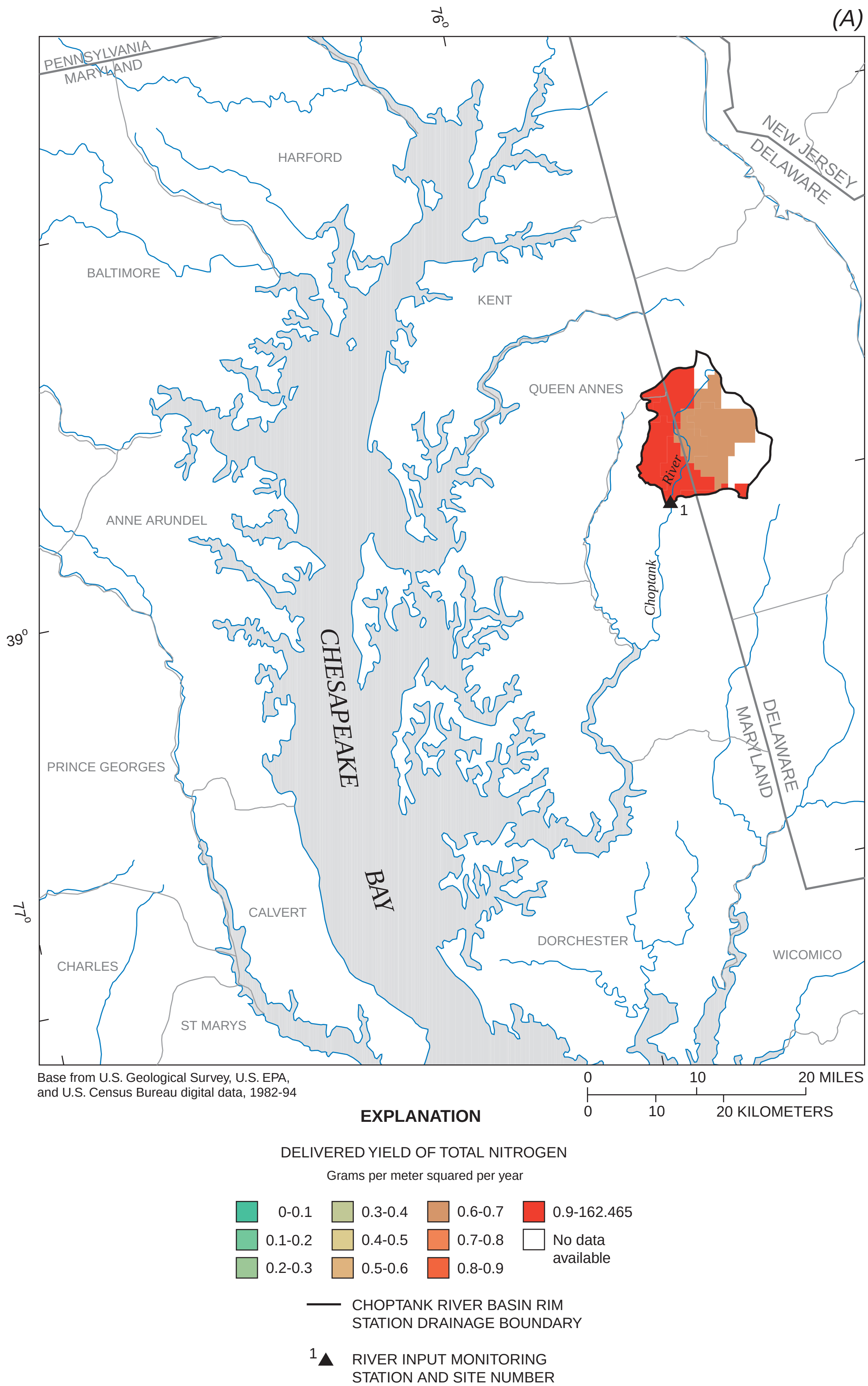
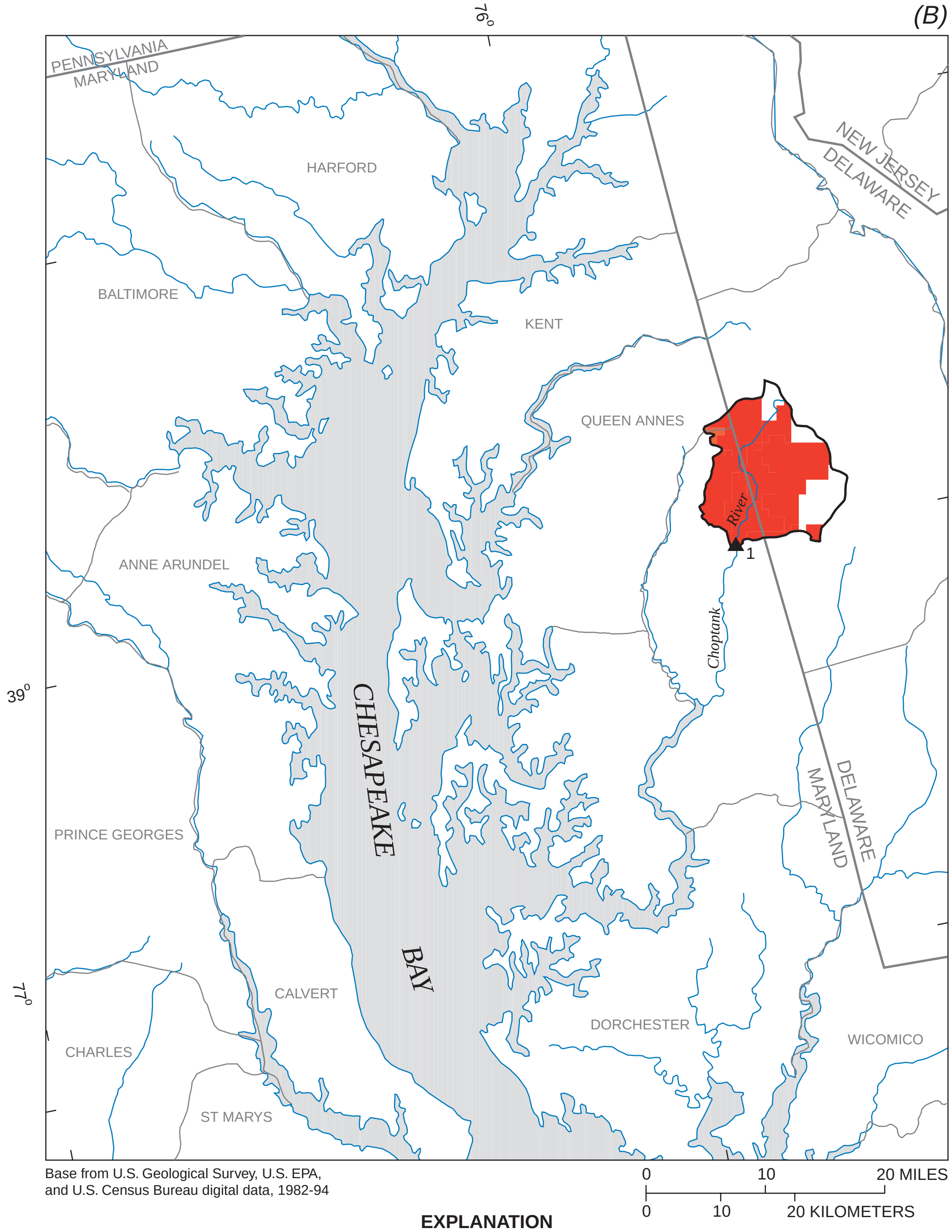


Figure 66. Delivered yield of total nitrogen (A) and total phosphorus (B) in the Choptank River Basin in 1987, generated by the SPARROW model.



EXPLANATION

DELIVERED YIELD OF TOTAL PHOSPHORUS

Grams per meter squared per year

- 0-0.005
- 0.005-0.01
- 0.01-0.015
- 0.015-0.02
- 0.02-0.025
- 0.025-0.03
- 0.03-0.035
- 0.035-0.04
- 0.04-0.045
- 0.045-25.966
- No data available

CHOPTANK RIVER BASIN RIM STATION DRAINAGE BOUNDARY

1 ▲ RIVER INPUT MONITORING STATION AND SITE NUMBER

Figure 66. Delivered yield of total nitrogen (A) and total phosphorus (B) in the Choptank River Basin in 1987, generated by the SPARROW model.

Table 31. SPARROW model estimates of the percentage of total nitrogen and total phosphorus load generated in the watershed that is delivered to monitoring stations in the Choptank River Basin

Station number	Station name and number	Site number	Percent delivered to station	
			Total nitrogen	Total phosphorus
	River Input Monitoring Program Station			
01491000	Choptank River near Greensboro, Md.	1	14	1.9

Table 32. Watershed Model estimates of percent change in land use acreage, percent change in loads due to best management practice implementation, source loads, delivered loads, and percent change in loads between 1985 and 1998 for nitrogen and phosphorus in the Choptank River Basin

[BMP, best management practice; kg/yr, kilograms per year; <, less than; reported load values are either source (input) loads or delivered (output) loads from the Watershed Model]

	% Acreage change	% Load change from BMP implementation	Load (kg/yr)		
			1985	1998	% Change
Nitrogen					
Agriculture (Delivered)	-7	-7	1.78×10^5	1.61×10^5	-9
Fertilizer (Source)			9.14×10^5	8.48×10^5	-7
Manure (Source)			3.33×10^5	3.50×10^5	+5
Urban areas (Delivered)	+7	<-1	2.09×10^4	2.28×10^4	+9
Fertilizer (Source)			7.86×10^4	8.74×10^4	+11
Forested areas (Delivered)	+5	<-1	1.56×10^4	1.65×10^4	+5
Point sources (Delivered)			1.61×10^1	1.90×10^2	+1078
Septic (Delivered)			9.55×10^3	1.14×10^4	+19
Atmospheric deposition (Delivered)			1.69×10^2	1.69×10^2	<+1
Phosphorus					
Agriculture (Delivered)	-7	-14	8.98×10^3	7.87×10^3	-12
Fertilizer (Source)			3.09×10^5	2.34×10^5	-24
Manure (Source)			1.13×10^5	8.69×10^4	-23
Urban areas (Delivered)	+7	<-1	1.55×10^3	1.70×10^3	+10
Fertilizer (Source)			0	0	0
Forested areas (Delivered)	+5	<-1	2.49×10^2	2.66×10^2	+7
Point sources (Delivered)			6.10	2.57×10^1	+321
Septic (Delivered)			0	0	0
Atmospheric deposition (Delivered)			9.15	9.15	0

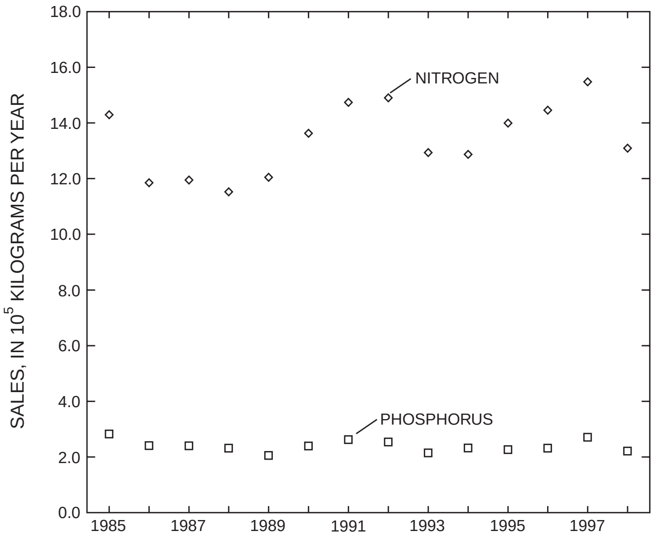


Figure 67. Annual sales of nitrogen and phosphorus fertilizer in the Choptank River Basin, 1985 to 1998.

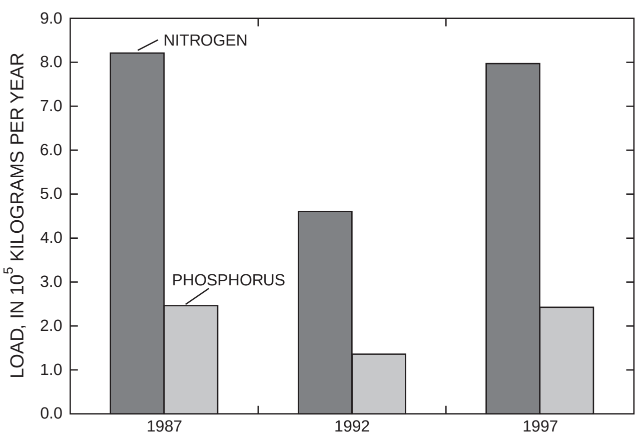


Figure 68. Annual load of nitrogen and phosphorus from manure generated in the Choptank River Basin in 1987, 1992, and 1997.

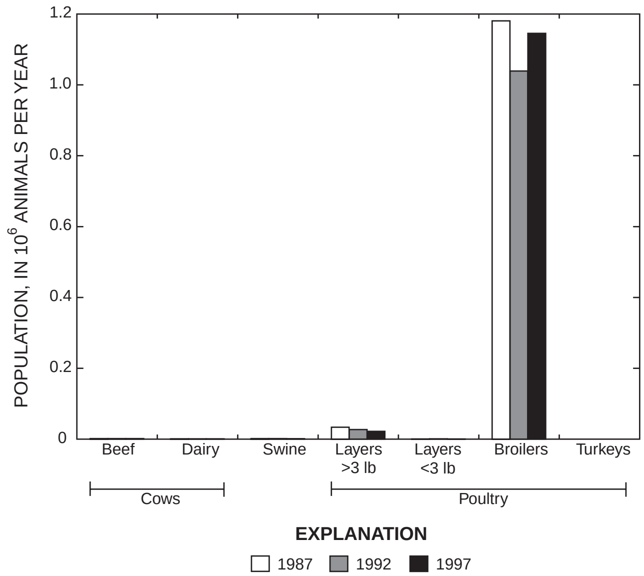


Figure 69. Population distribution of agricultural animals in the Choptank River Basin in 1987, 1992, and 1997.

1 percent of the total nitrogen loads in the Choptank River Basin, the increase likely had little impact on the overall nitrogen trends.

Phosphorus

As with nitrogen, agriculture made up approximately three-quarters of the phosphorus budget in the Choptank River Basin (fig. 65). Between 1985 and 1998, agricultural loads of phosphorus decreased 12 percent (table 32). Agricultural acreage within the basin decreased 7 percent and BMP implementation led to a 14-percent decrease in agricultural phosphorus loads. Nutrient management had a greater impact on fertilizer application of phosphorus than nitrogen in the basin, as phosphorus loads from fertilizer application decreased 24 percent. Fertilizer sales of phosphorus remained fairly steady during this period (fig. 67) (Battaglin and Goolsby, 1994; D.L. Lorenz, written commun., 1999). Loads from application of manure, a slightly smaller source of phosphorus than fertilizer, decreased 23 percent during the study period. U.S. Census of Agriculture data showed a relatively large decrease in phosphorus manure generation between 1987 and 1992, followed by a large increase through 1997 to near 1987 levels (fig. 68) (Puckett and others, 1998). The shift in poultry production in the basin (fig. 69) affected phosphorus manure loadings, as poultry waste has a significantly greater amount of phosphorus than other animal manure.

The second largest source of phosphorus in the Choptank River Basin was urban areas, but the loads from urban areas made up only about 15 percent of the total phosphorus budget from 1985 through 1998 (fig. 65). The population increase in the basin led to a 7-percent increase in urban acreage, and phosphorus loads from urban areas increased 10 percent (table 32). The only other measurable contributor to the phosphorus budget in the basin was forested areas; phosphorus loads from forested areas increased 7 percent during the study period as forested acreage increased 5 percent.

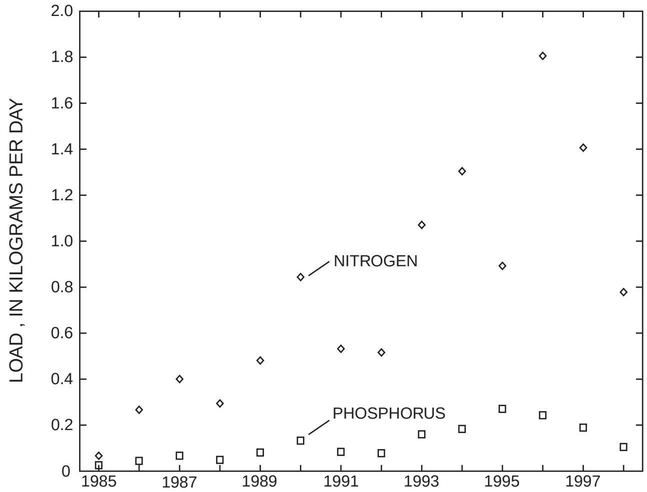


Figure 70. Annual mean point source load of total nitrogen and total phosphorus discharged in the Choptank River Basin, 1985 to 1998

Ground Water

The annual base flow nitrate contribution to the total nitrogen load in surface water varied from 57 percent to 73 percent during the monitoring period—on average, 64 percent of the total nitrogen load at the RIM station was from ground-water inputs of nitrate (table 33). There was no trend in the contribution of nitrate from ground water during the monitoring period.

Summary

At the RIM station on the Choptank River, there was a significant upward trend in discharge and an upward trend in total nitrogen load from 1985 through 1998. Flow-adjusted total nitrogen concentrations did not change significantly. There was no trend in total phosphorus loads, but flow-adjusted total phosphorus concentrations decreased significantly.

The largest source of nitrogen and phosphorus within the Choptank River Basin was agriculture. Loads from agriculture comprised approximately three-quarters of the total nitrogen and phosphorus budgets in the basin, and changes in agriculture offset changes in all other sources. For nitrogen, an increase in loads from manure application somewhat offset load reductions from BMP implementation and fertilizer nutrient management. As a result, flow-adjusted total nitrogen concentrations did not change significantly from 1985 through 1998. With the strongly increasing streamflow in the Choptank River Basin during the monitoring period, total nitrogen loads increased.

For phosphorus, cumulative decreases in loads from fertilizer and manure application and BMP implementation led to the significant downward trend in flow-adjusted total phosphorus concentrations. However, the increase in flow during this period offset these reductions, preventing a similar downward trend in total phosphorus loads in the Choptank River Basin.

Table 33. Trends in dissolved nitrate load in base flow, percent base-flow nitrate load to surface-water total nitrogen load, and percent base flow to total streamflow in the Choptank River Basin

[Trends expressed as percent change; percent change reported if significant at the 95-percent confidence level; NS, non-significant]

Station number	Station name	Site number	Time period of trend	Trend in base-flow nitrate load	Percent base-flow nitrate load to surface-water total nitrogen load	Percent base flow to total streamflow
	River Input Monitoring Program Station					
01491000	Choptank River near Greensboro, Md.	1	1985-98	NS	64	65

SUMMARY AND CONCLUSIONS

Comparison of the Trends and Major Influencing Factors Throughout the Chesapeake Bay Watershed

Trends

Nutrient trends were computed using water-quality data collected between 1985 and 1998 at the 9 River Input Monitoring (RIM) stations in the 7 major tributary basins in the Chesapeake Bay Watershed—the Susquehanna, Potomac, James, Rappahannock, York, Patuxent, and Choptank River Basins. No statistically significant trends in either total nitrogen or total phosphorus loads were identified at 6 of the 9 RIM stations. Loads of total nitrogen were up at the Choptank River RIM station, and down at the Patuxent River RIM station. Loads of total phosphorus were down at both the Susquehanna River RIM station and the Patuxent River RIM station.

Higher streamflows normally lead to higher nutrient loads, even if nutrient concentrations have held steady or have decreased over time. The significant increases in streamflow at the Choptank River and Potomac River RIM stations contributed to the increase or the lack of a significant decrease in loads at these stations. Streamflow also increased significantly at the Patuxent River RIM station; however, total nitrogen and total phosphorus loads at this station decreased, largely as a result of the substantial decrease in loads from point sources, a major nutrient source in this basin.

When streamflow was removed as an influencing factor, the trends in nitrogen and phosphorus concentrations were more encouraging. These flow-adjusted concentration trends reflect changes due to factors other than streamflow—primarily changes in nutrient sources. Downward trends in flow-adjusted total nitrogen concentrations were identified at six of the nine RIM stations: the Susquehanna, Patuxent, Rappahannock, Mattaponi, James, and Appomattox River stations. Trends in flow-adjusted concentrations of total phosphorus also were downward at seven of the nine RIM stations: the Susquehanna, Choptank, Patuxent, Potomac, Rappahannock, Mattaponi, and James River stations.

Nutrient Sources

Agriculture was the dominant source of both nitrogen and phosphorus from 1985 to 1998 in six of the seven Chesapeake Bay tributary basins that were monitored by the RIM program. The exception was the Patuxent River Basin, a heavily urbanized basin where point sources and urban inputs dominated the nutrient budgets. Because of the predominance of agricultural inputs in six of the seven basins, changes in agricultural sources such as manure and fertilizer, combined with decreases in agricultural acreage, had the greatest impact on the trends in flow-adjusted nutrient concentrations. Fertilizer nutrient management and implementation of structural best management practices (BMPs) appear to be having a positive effect throughout the nontidal Chesapeake Bay Watershed.

Urban acreage, however, is increasing in all of the tributary basins, and as a result, inputs from urban areas are becoming a larger portion of the nutrient budgets. The Chesapeake Bay Watershed Model (WSM) simulations indicate that delivered loads of nitrogen and phosphorus from urban areas increased between 1985 and 1998 in all tributary basins. These increases have offset many of the reductions achieved from agricultural sources. Additionally, though some reductions have been achieved through the phosphate detergent ban and biological nutrient removal (BNR) upgrades to wastewater treatment facilities, increasing population is leading to increased nutrient loading from point sources in many of the tributary basins.

Future Information Needs and Implications for Management

Data on Best Management Practices

The increase in nutrient loads from urban areas between 1985 and 1998 suggests that as the population in the Chesapeake Bay Watershed continues to increase, and as agricultural acreage is further reduced, greater emphasis on minimizing loads delivered from urban areas will be required. Nutrient runoff from areas such as residential lawns and golf courses will likely increase. More information is needed on urban BMPs and their effectiveness in order to direct efforts towards reducing loads from urban areas.

While the impact of nutrient management is evident in the downward trends in flow-adjusted nutrient concentrations in many areas, trends in load are important when considering the health of aquatic organisms in the Bay. There have been relatively few significant reductions in the load of nutrients entering the Bay from these nontidal tributary basins, which is due in large part to increases in streamflow during the study period. Therefore, when nutrient reduction goals in the Chesapeake Bay Watershed are set, the effect of natural variations in streamflow needs to be addressed.

Another factor that may have contributed to the lack of significant decreases in loads is the ineffectiveness of some structural BMPs during high-flow conditions. This suggests the need for development of BMPs that are effective at high flows. The effectiveness of BMPs that are now being implemented in the Chesapeake Bay Watershed is largely unknown, under either high or low-flow conditions. The WSM estimates of nutrient reductions achieved through the implementation of BMPs are based on values from studies that are not specific to the hydrogeology in all areas of the Chesapeake Bay Watershed, and the accuracy of these estimates has not been thoroughly tested or quantified. Further study and documentation of BMP implementation within the Bay watershed is needed to determine the effectiveness of BMPs under a full range of hydrologic conditions and in different areas of the watershed, which would aid in improving the predictions of the WSM and in refining tributary strategies.

Data on Sources and Transport of Nutrients

Development of urban BMPs will necessitate more detailed information on fertilizer sales and applications. Currently, only rough estimates on urban fertilizer use and application rates are available, and the data on agricultural fertilizer sales and applications have limitations. The basic source data on fertilizer sales in this report were compiled during two time periods—1985 through 1991, and 1992 through 1998—using different methods, making it difficult to determine if the trend in the data was due to data compilation differences or to changes in the sales of fertilizer. The fertilizer data used in the WSM were based on state agency estimates that may be spatially or temporally inconsistent. An internally consistent data set would be beneficial in modeling nutrient transport and distribution, as well as in explaining nutrient trends.

Environmental conditions in the Chesapeake Bay Watershed are an important factor affecting nutrient transport. Results from the SPARROW model suggest that only a small fraction of the nitrogen and phosphorus applied on the land is transported to the Bay. Naturally occurring watershed processes that minimize nutrient transport include retention in the soil, transport and transformation in ground water, and in-stream processing. The influence of these processes varies throughout the watershed depending on environmental conditions such as soil type, geology, and geomorphology. Therefore, the distribution of these environmental conditions and their relation to watershed processes and nutrient sources should be considered both in revising tributary strategies and in understanding changes in nutrient trends in the future.

Model Simulations

While a goal of both the USGS method using the ESTIMATOR model and the Chesapeake Bay Program's Watershed Model (WSM) is to detect changes in nitrogen and phosphorus delivered to the Bay caused by factors other than natural changes in flow, the USGS "flow-adjusted concentration" trend results and the WSM "constant-hydrology load" trend results cannot be compared directly. In the USGS method, the variation in concentration over the entire monitoring period due to factors other than flow and season is statistically determined. In contrast, hydrology is held constant in the WSM by the use of the same 1985 to 1994 hydrology for the simulation of the beginning year of the study period and the ending year, and the trend estimates are the difference in predicted loading between those two years. Additional insight into the effects of watershed processes on observed nutrient loads and trends would be gained by running the WSM simulations using the actual hydrology for the period of study.

For this study, the only available SPARROW model output was from 1987. Therefore, it was not possible to track any changes in the distribution of nutrient yields over the monitoring period. More recent SPARROW models for the Chesapeake Bay Watershed are currently under development, but different source data sets are being used, which will make temporal comparisons difficult. More timely SPARROW simulations incorporating consistent data sets would be beneficial to managers.

Monitoring and Trends Information

At present, only a limited monitoring network provides data for load and trend analysis in the tributary basins to Chesapeake Bay. This report uses data from selected upstream stations in each basin to help explain trends at the RIM stations. There are few stations with adequate data to compute loads and trends upstream of the RIM stations, however, which limits the understanding of the watershed response to nutrient changes. Expanding the current non-tidal monitoring network would provide additional insight into the influence of watershed characteristics on nutrient transport and would help target management practices to specific critical areas in the watershed that contribute high loads. Long-term and increased monitoring of more stations distributed throughout these tributary basins would help in improving WSM predictions and in refining tributary strategies.

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