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Water-Resources Investigations Report 98-4059

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Baltimore, Maryland
June, 1998

U.S. Department of the Interior
Bruce Babbitt, Secretary

U.S. Geological Survey
Thomas J. Casadevall, Acting Director

United States Government Printing Office: 1998

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	2.54	centimeter
inch per year (in/yr)	0.02540	meter per year
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.09290	meter squared per day
square mile (mi)	2.590	square kilometer
gallons	3.785	liters
gallons	0.00379	cubic meter
ton, short	907.2	kilogram

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Ground-Water Discharge and Base-Flow Nitrate Loads of Nontidal Streams, and Their Relation to a Hydrogeomorphic Classification of the Chesapeake Bay Watershed, Middle Atlantic Coast

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ABSTRACT

Existing data on base-flow and ground-water nitrate loads were compiled and analyzed to assess the significance of ground-water discharge as a source of the nitrate load to nontidal streams of the Chesapeake Bay watershed. These estimates were then related to hydrogeomorphic settings based on lithology and physiographic province to provide insight on the areal distribution of ground-water discharge. Base-flow nitrate load accounted for 26 to about 100 percent of total-flow nitrate load, with a median value of 56 percent, and it accounted for 17 to 80 percent of total-flow total-nitrogen load, with a median value of 48 percent.

Hydrograph separations were conducted on continuous streamflow records from 276 gaging stations within the watershed. The values for base flow thus calculated were considered an estimate of ground-water discharge. The ratio of base flow to total flow provided an estimate of the relative importance of ground-water discharge within a basin.

Base-flow nitrate loads, total-flow nitrate loads, and total-flow total-nitrogen loads were previously computed from water-quality and discharge measurements by use of a regression model. Base-flow nitrate loads were available from 78 stations, total-flow nitrate loads were available from 86 stations, and total-flow total-nitrogen loads were available for 48 stations. The percentage of base-flow nitrate load to total-flow nitrate load could be computed for 57 stations, whereas the percentage of base-flow nitrate load to total-flow total-nitrogen load could be computed for 36 stations. These loads were divided by the basin area to obtain yields, which were used to compare the nitrate discharge from basins of different sizes.

The results indicate that ground-water discharge is a significant source of water and nitrate to the total streamflow and nitrate load. Base flow accounted for 16 to 92 percent of total streamflow at the 276 sampling sites, with a median value of 54 percent. It is estimated that of the 50 billion gallons of water that reaches the Chesapeake Bay each day, nearly 27 billion gallons is base flow.

Generalized lithology (siliciclastic, carbonate, crystalline, and unconsolidated) was combined with physiographic province (the Appalachian Plateau, the Valley and Ridge, the Blue Ridge, the Piedmont, including the Mesozoic Lowland section, and the Coastal Plain) to delineate 11 hydrogeomorphic regions. Areal variation of base flow and base-flow nitrate yield were assessed by means of nonparametric, one-way analysis of variance on basins grouped by the dominant hydrogeomorphic region and by correlation analysis of base flow or base-flow nitrate yield with the percentage of land area of a given hydrogeomorphic region within a basin.

Base flow appeared to have a significant relation to the hydrogeomorphic regions. The highest percentages of base flow were found in areas underlain by carbonate rock,

crystalline rock with relatively low relief, and unconsolidated sediments. Lower percentages were found in areas underlain by siliclastic rocks and crystalline rocks with relatively high relief.

The relation between base-flow nitrate yield and hydrogeomorphic region is less clear. Although there is a relation between low nitrate yields and areas underlain by high-relief siliciclastic rocks, and a relation between high yields and carbonate rocks, much of this relation can be explained by the strong association between the hydrogeomorphic units and land use. In addition, most basins are mixtures of several hydrogeomorphic regions, so the nitrate yield from a basin depends on a large number of complex interacting factors. These unclear results indicate that the sample of available data used here may not be adequate to fully assess the relation between base-flow nitrate yield and the hydrogeomorphic setting of the basin. The results appear to show, however, that ground-water discharge is an important component of the total nontidal streamflow, and that ground-water discharge varies according to the hydrogeomorphic regions. Environmental management of the nontidal streams in the Chesapeake Bay watershed will thus have to consider the prevention of nutrient infiltration into aquifers as well as prevention of overland runoff of high-nitrogen waters.

INTRODUCTION

Chesapeake Bay (fig. 1) is the largest estuary in the United States. The Bay's thriving commercial and sport fisheries are highly vulnerable to changes in water quality. Excessive loading of nutrients into Chesapeake Bay has caused eutrophication and periods of hypoxia (Fisher and Butt, 1994; Harding and others, 1992), which in turn have killed and stressed living resources in many areas of the Bay. Algal blooms also decrease water clarity, which is largely responsible for the decline of submerged aquatic vegetation, one of the most critical components of the Chesapeake Bay ecosystem that provides habitat for shellfish and finfish, and provides food for waterfowl. Because of the value of the Bay's living resources, some of the States within the Bay's watershed and the Federal Government have placed a high priority on reducing nutrient loads to the Bay. The Federal Government, the District of Columbia, and the States of Maryland, Pennsylvania, and Virginia signed an agreement in 1987 to reduce controllable nutrient loads into the estuary by 40 percent by the year 2000. This goal was based on the results of computer simulations that indicate that the 40-percent reduction would eliminate hypoxia in the mainstem of the Bay (Thomann and others, 1994).

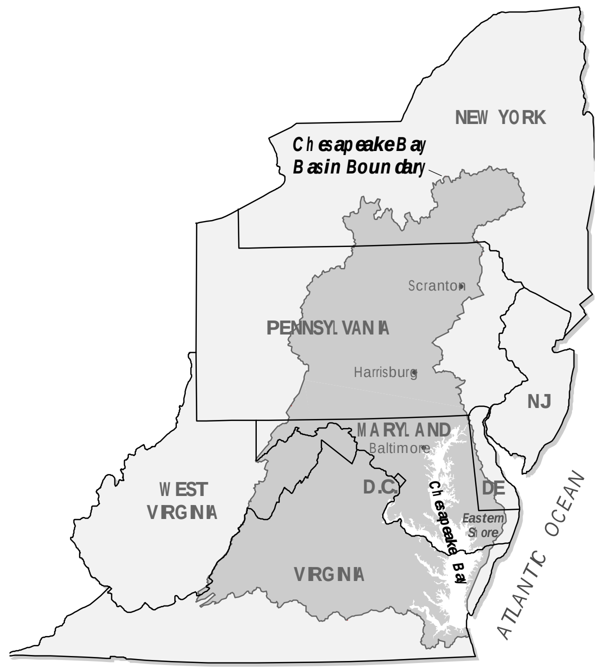


Figure 1. Chesapeake Bay watershed and surrounding area.

Strategies for the reduction of nutrient loads to the Bay have emphasized the importance of controlling nutrient runoff, and have been guided by a general-purpose watershed model that simulates the effects of various large-scale management strategies (Donigian and others, 1994). Recent research (Bachman and Phillips, 1996; McFarland, 1995), however, indicates that ground-water discharge may provide a significant percentage of the nitrogen load to the Bay. Further, ground water takes years to travel from recharge areas to discharge zones (Dunkle and others, 1993; Bohlke and Denver, 1995), so the effects of management practices may not be apparent as quickly as was anticipated. Those involved in the Chesapeake Bay restoration effort are thus interested in understanding the role of ground-water discharge in nutrient loads from nontidal streams. This report contains estimates, based on a hydrograph-separation analysis, of the relative amounts of ground-water discharge to total streamflow of nontidal streams in the Chesapeake Bay watershed. It also contains estimates, based on analysis of data compiled by Langland and others (1995), of the relative amounts of base-flow nitrate loads to total-flow loads of nontidal streams in the watershed. The report also describes relations between ground-water discharge, nitrate yields and land use, and geological and geomorphic features that provide insight into the areal distribution of nitrate discharge from ground water to nontidal streams in the watershed. The report does not contain any information about direct discharge of nitrate from coastal aquifers to tidal water, another possible large source of nitrate load (Simmons and others, 1990; McFarland, 1995).

Description of Study Area

The Chesapeake Bay watershed (fig. 1) covers an area of 64,000 mi^2 and is located within the States of Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia, and the District of Columbia. The climate of the watershed is generally “humid continental” with average annual temperatures ranging from 45 degrees Fahrenheit in the north and west to about 60 degrees Fahrenheit near the mouth of the Bay (National Oceanic and Atmospheric Administration [NOAA], written commun., 1997). Average annual precipitation ranges from about 35 in/yr in the northeastern parts of the watershed to more than 50 in/yr along the watershed’s western drainage divide in West Virginia (DeWeiest, 1965; NOAA, written commun, 1997).

The population of the watershed is about 15 million people (U.S. Environmental Protection Agency, written commun., 1995). Most of these people live in a large accretion of urban areas that extends from northeast of Baltimore, Md., through Washington, D.C., to Richmond Va. Another large metropolitan area is the “Tidewater” region (Norfolk, Hampton, Newport News, Va.) near the mouth of the Bay. Smaller urban areas include the Harrisburg-York-Lancaster region in Pennsylvania and the Binghamton area in New York, as well as many other smaller towns and cities scattered across the watershed. In all of these areas, population is spreading from the densely populated central cities to the exurban and rural fringes of the cities. Thus, a certain part of the nutrient load from sewage is being shifted from older sewage treatment plants to newer plants and to on-site sewage disposal systems.

The nonurban land in the watershed is divided between forests and wetlands and agricultural land. Forests are largely found in mountainous parts of the watershed, areas with steep slopes, and flatter areas with poorly drained soils. Agricultural land is generally found in valleys in the central part of the watershed, on the fringes of the large cities, and in the Coastal Plain. Most of the agricultural acreage is in corn-soybean small-grain rotation, and dairy cattle, beef cattle, and poultry are raised throughout the basin. Corn and small-grain crops are heavily fertilized, and cattle and poultry produce large quantities of manure; all of these are possible sources of nutrients found in ground water and surface water.

Ground- and surface-water flow is strongly affected by the distribution of rock types and resulting topographic expression of the watershed. The Chesapeake Bay watershed has a varied physiography that ranges from the flat-lying Coastal Plain to the relatively steep, high Appalachian Mountains. The rock types range from unconsolidated clastic sediments to igneous and metamorphic rocks to clastic and carbonate sedimentary rocks. Altitudes range from sea level to more than 4,000 ft above sea level. The watershed covers parts of five physiographic provinces as defined by Fenneman (1938)--the Coastal Plain, the Piedmont, the Blue Ridge, the Valley and Ridge, and the Appalachian Plateau.

Previous Investigations

Hydrologic budgets have been calculated for some small watersheds in the basin (for example, see Rasmussen and Andreason, 1959), and the contribution of ground water to streamflow is thus calculated. Such studies are valid only for the particular conditions within the watershed, however, and such studies are not found to cover the widest possible range of hydrologic conditions that exist in the Bay watershed. Hydrologic characteristics of shallow ground water were determined on a regional basis for the Appalachian Mountains and the Piedmont by Rutledge and Mesko (1996).

The computation of nitrogen loads is less readily available on an areally distributed regional basis. An estimate of base-flow nitrogen loads from shallow aquifers in the Coastal Plain based on extrapolation of data from a synoptic stream survey was presented by Bachman and Phillips (1996). A similar synoptic survey of base-flow nitrate was conducted in parts of the Potomac River Basin (Denis and Blomquist, 1995; Miller and others, 1997).

Regional estimates of the total loads transported by the large rivers to Chesapeake Bay, using the regression models of Gilroy and others (1990) and Cohn and others (1989), have been published by Cohn and others (1992) and Belval and others (1994, 1995). In these studies, total loads and not base-flow loads were computed. Langland and others (1995) presented nutrient loads, including computation of base-flow loads, for every possible stream site for which data were available for computation of the regression load model. The loads computed by Langland and others (1995) form the basis for the analysis presented here.

Acknowledgments

The authors wish to thank Michael Langland, Scott Hoffman, and Diana Dugas of the U.S. Geological Survey in Lemoyne, Pa., who made computerized map data and computed load data available. Thanks are due also to the field hydrologists and technicians who collected the data on which the load calculations are based. These include personnel of numerous State and local governmental agencies in Maryland, Pennsylvania, and Virginia, and the District of Columbia, as well as personnel of the U.S. Geological Survey. Cherie Miller and Kathryn Hunchak-Kariouk of the U.S. Geological Survey critically reviewed the manuscript and made helpful suggestions that have been included in the final report.

METHODS OF INVESTIGATION

Ground-water discharge was estimated by performing hydrograph-separation analysis on continuous-stream discharge data. The proportion of base-flow nitrate loads to total-flow loads was estimated by analysis of data compiled by Langland and others (1995). Estimates and analyses were made using station medians of annual discharge from the period 1972-96 and loads from the period 1972-92. The areal distribution of discharges and loads were assessed using "hydrogeomorphic regions," (HGMR's) based on the lithologic and physiographic subdivisions within the watershed.

Compilation of Digital Geographic Data

The following digital coverages were obtained or compiled for this study: lithology, physiography, land cover, and drainage basin boundaries. The digital coverages were stored and processed using the Arc/Info Geographic Information System (GIS).

The lithology and physiographic province coverages were the same as those used in Langland and others (1995). They were created by hand-digitizing, scanning, and attributing geologic formation names from paper and mylar copies of intermediate-scale (1:250,000 to 1:500,000) published geologic maps that covered the Bay watershed. Physiographic province and rock type were generalized from the formation boundaries. Four lithologic types were generalized: Siliciclastic, carbonate, crystalline, and unconsolidated. The physiographic provinces were classified based on the work of

Fenneman (1938).

Drainage basin boundaries were created in Arc/Info from various sources and scales. The Chesapeake Bay watershed boundary was derived from the USGS 1:250,000 hydrologic unit coverages (Steeves and Nebert, 1994). Basin boundaries from subbasins, mostly at USGS gaging stations, were digitized from 1:24,000, 1:100,000, and 1:250,000 scale USGS topographic maps (Langland and others, 1995). Basin boundaries from Langland and others (1995) were checked, minor corrections were made, and additional basins not used in the previous report were digitized.

The land-cover data base used in the analysis was derived from the Multi-Resolution Land Characteristics (MRLC) project. The project provided multi-resolution 30-meter land cover characteristics from the early 1990's using Landsat Thematic Mapper data (Bara, 1994). The 15 land-cover classes found in the MRLC data were generalized into four classes--agricultural land (including row crops and pasture lands), forest (including deciduous forest, evergreen forest, mixed forest, and forested wetlands), urban land (including residential, commercial, and industrial), and "other" (including quarries, mines, emergent wetland, bare rock, and exposed sand).

Compilation of Streamflow Data

Hydrograph separation, the method used for estimating ground-water discharge, requires continuous streamflow records. The streamflow data are entered in a computer program that separates the total streamflow into components of runoff and base flow. For the purpose of this report, base flow was considered to be primarily from ground-water discharge. The source of streamflow data used in this report were the USGS National Water Information System (NWIS) data bases in Delaware, Pennsylvania, Maryland, New York, Virginia, and West Virginia. Data for any active and discontinued stream gaging stations in the Chesapeake Bay Basin were included in the compilation if basic criteria were met. These criteria were streams (1) with a minimum of 4 years of continuous streamflow record, (2) that were not regulated by withdrawals, discharges, or impoundments, and (3) with digital basin boundaries. Digital basin boundaries were generated if the other criteria were met, to expand the number of sites available for data analysis. Of over 500 stations in the study area, 276 met the basic criteria. Streamflow records from 1972 to 1996 were retrieved. These streamflow records were compiled to be used as the input data for the hydrograph-separation program. The locations of the stations with discharge measurements are shown in figure 2.

Compilation of Water-Quality Data

The analysis of base-flow nitrate loads and total-flow loads presented here was performed on a subset of the data previously compiled by Langland and others (1995). The data were reported as annual nitrate or total-nitrogen loads for a given station and were computed by a load estimator model (Cohn and others, 1989; Gilroy and others, 1990) that performs a regression of concentration to discharge and time. Annual loads for each station were aggregated, and a median was calculated to provide a single load estimate for the station. The locations of the stations for which load measurements were available are shown in figure 2.

A major limitation of this data set was the small number of stations for which load measurements of suitable parameters were available. The best analysis would be to compare base-flow total-nitrogen load to total-flow total-nitrogen load. Total nitrogen was not sampled at every station, however, and at many of those stations, too few samples were collected at base flow to compute a base-flow load. Thus, base-flow loads of dissolved nitrate were used as a surrogate for base-flow loads of total nitrogen. This can be justified in a general sense by noting that, especially at higher concentrations and loads, nitrate behaves in a manner similar to total nitrogen, and in oxidized ground water, nitrate comprises virtually all of the total dissolved nitrogen. Correlation of dissolved nitrate loads with total-flow nitrate loads shows a strong positive, monotonic relation (fig. 3), so it might be expected that base-flow nitrate loads and

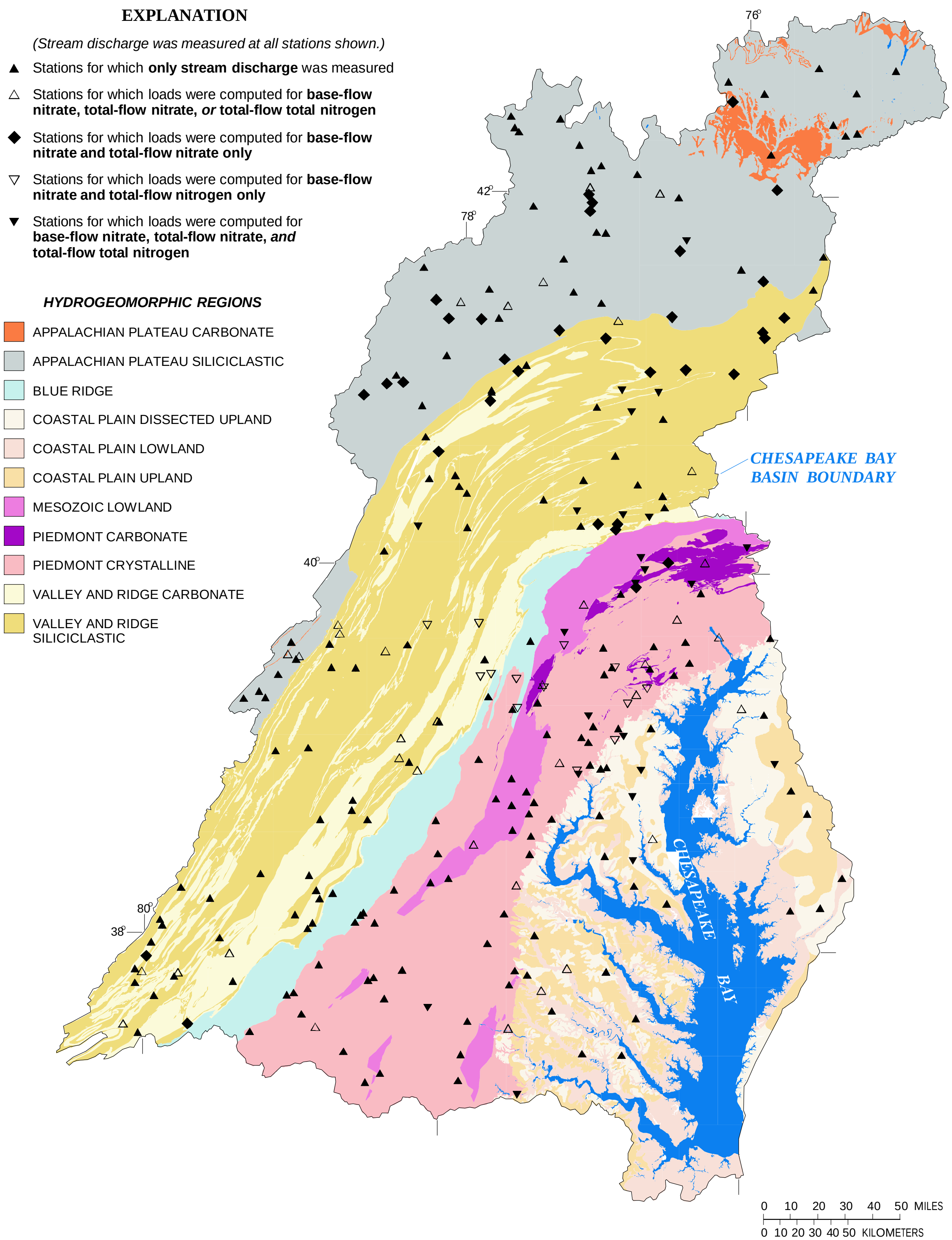


Figure 2. Locations of stations with discharge measurements and stations with load estimates.

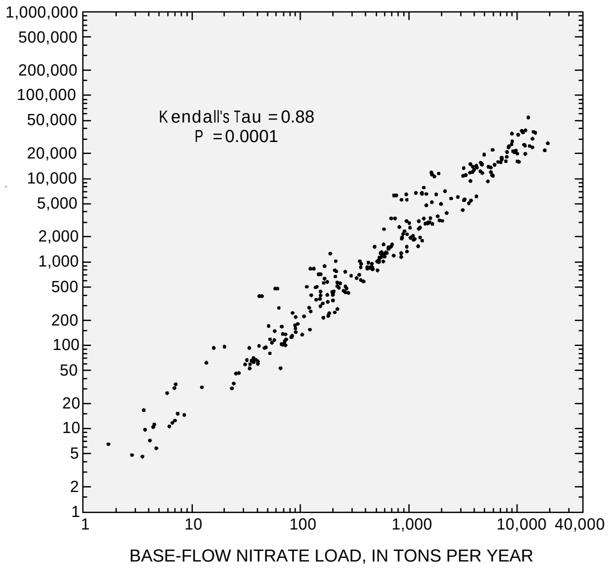


Figure 3. Relation between base-flow dissolved nitrate loads and total-flow total-nitrogen loads *(data from all annual load measurements from all stations, 1972–92).*

base-flow total-nitrogen loads should also have this close relation. At the very least, base-flow nitrate loads provide a conservative estimate of the base-flow total-nitrogen load.

Data Analysis

Estimation of Base Flow Using Hydrograph Separation

Streamflow was conceptualized as having three basic components to assess the proportion of streamflow that is due to ground-water discharge (DeWiest, 1965): *Overland flow,* which runs directly from the land surface to the streams during storm events; *interflow*, subsurface stormflow that enters the stream from the unsaturated zone; and *ground-water discharge,* water that enters the stream from the saturated zone of an aquifer. Because these components cannot be measured directly, hydrographs (plots of total streamflow and time) are often analyzed to estimate these components. In a hydrograph, peaks showing the rapid response to precipitation events are called "direct runoff" and mainly represent overland flow and interflow. Subsequent periods of streamflow recession show the sustained flow of water are referred to as "base flow," and are mainly from ground-water discharge. Mathematical techniques called *hydrograph separation* can be used to distinguish between base flow and direct runoff and estimate the amount of base flow during the period of record.

This conceptualization does not apply to every stream hydrograph. For example, for basins in which base flow is sustained by discharges from wastewater treatment plants, industrial outfalls, and irrigation return flows, estimation of base flow will result in a value higher than actual ground-water discharge. In basins regulated by dams or large water withdrawals, it will be difficult, if not impossible, to relate base-flow separation analysis with amounts of ground-water discharge. Finally, base flow in larger basins may be sustained as much by flow from upstream parts of the watershed as by ground-water discharge, so again, interpretation of the hydrograph separation is difficult. For these reasons, basins in which the streams were known to be regulated by withdrawals, discharges, or impoundments were excluded from the data analysis.

A final consideration is that actual ground-water discharge may not be the source of the base flow of a large river draining a large basin. In large basins, direct runoff peaks become attenuated the further downstream one goes, and much of the water that the hydrograph-separation analysis identifies as base flow may actually be part of the attenuated storm. Thus, for the larger basins, base-flow measurements may not adequately represent true ground-water discharge. Assessment of the effects of lithology, physiography and land use are also more difficult in large basins, because the larger basins are more likely to be a mixture of lithologies, physiography and land use than are smaller basins. For these reasons, the larger basins (those greater than 1,000 mi^2) were excluded from the assessment of the effects of the HGMR's on base flows and loads. This area of 1,000 mi^2 was selected on the basis of analysis of a probability plot (Sinclair, 1974) of basin areas

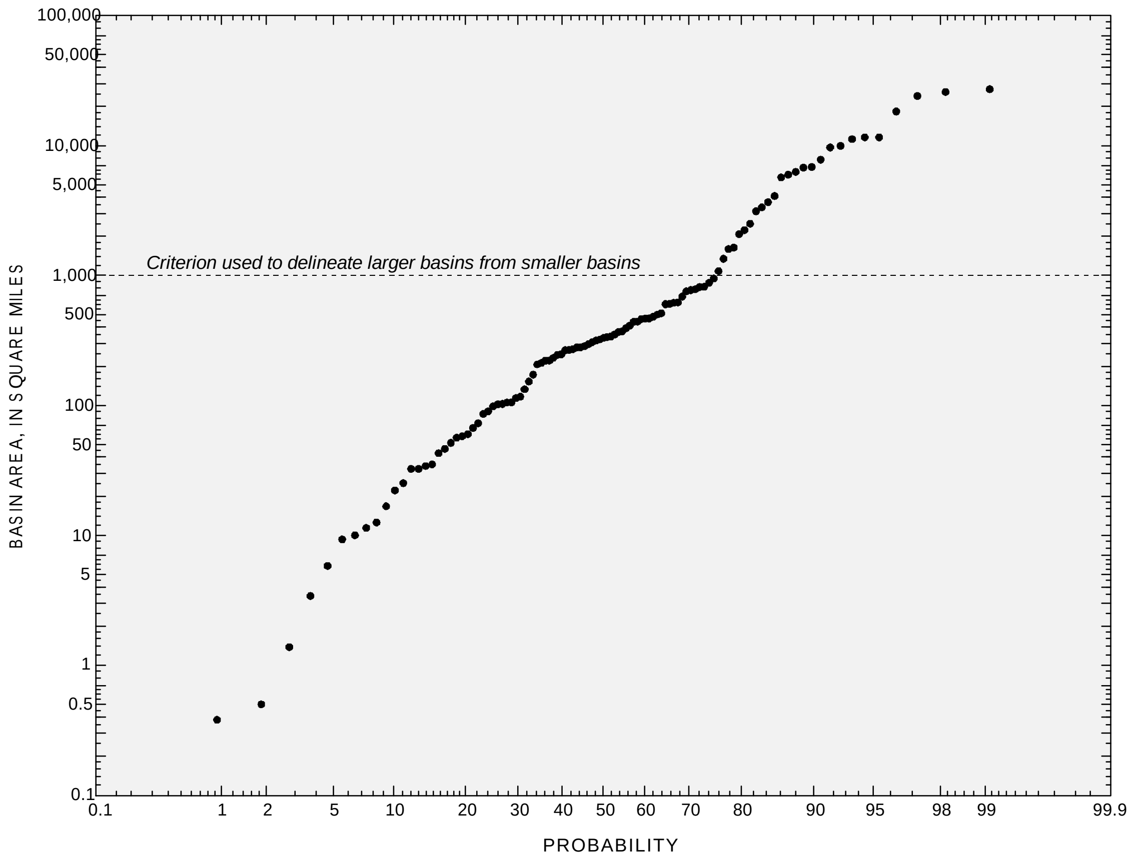


Figure 4. Distribution of areas of basins for which load data were available.

for which load data were available (fig. 4).

Many graphical and computer techniques of hydrograph separation have been developed (Pettyjohn and Henning, 1979; Sloto and Crouse, 1996; Rutledge, 1993). These methods use the general assumptions that the time of appearance of hydrograph peaks after precipitation can be used to classify the source of the water. The methods differ largely in the techniques used to estimate the contribution of base flow during hydrograph peaks formed in response to precipitation events, and, therefore, estimates of base flow will vary on the basis of the separation method chosen. Some of the uncertainty in estimating base flow under a hydrograph peak is caused by the difficulty of determining how much of the increase in stream-flow is from interflow (direct runoff) and how much comes from a short-term rise in discharge from the aquifer (base flow). Temporary storage and release of water from stream banks provides additional uncertainty in interpreting results of hydrograph separations. The proportions of direct runoff and base flow during a storm are also related to the level of soil saturation prior to the storm, the intensity of the storm, and the duration of the storm.

Hydrograph separations presented in this report were performed using the local minima method (Pettyjohn and Henning, 1979; Sloto and Crouse, 1996) on streamflow data compiled from USGS gaging stations. The local minima method represents a conservative or low estimate of the contribution of base flow to total streamflow when compared with other methods. It is important to note, however, that the calculations of base flow used to estimate ground-water discharge for this report are based on calculations using one of several available methods, and are not a result of direct measurement.

Statistical Analysis

Estimates of ground-water discharge and base-flow nitrate and nitrogen loads were statistically analyzed using the SAS system (SAS Institute, 1990). Minima, maxima, medians and inter-quartile ranges were computed for values of base flow, base-flow nitrate load, total-flow nitrate load, total-flow total-nitrogen load, the percent of base-flow nitrate load to total-flow nitrate load and the percent of base-flow nitrate load to total-flow total-nitrogen load. In addition, the effects of hydrogeomorphic settings were estimated by statistical analysis in which median values of the measured variables for basins dominated by selected hydrogeomorphic settings were compared using the Kruskal-Wallis test (Helsel and Hirsch, 1992). The nonparametric Tukey multiple comparison test (Helsel and Hirsch, 1992) was used to assess the nature of any differences among group medians revealed by the Kruskal-Wallis test. Relations between ground-water discharge, base-flow loads and hydrogeomorphic setting were also assessed by correlation, using the Kendall's tau correlation coefficient (Helsel and Hirsch, 1992), between the percentage of the basin in a given hydrogeomorphic setting and ground-water discharge of base-flow nitrate load. Nonparametric statistical methods were used because the frequency distributions of many of the variables studied were nonnormal (Helsel and Hirsch, 1992).

DELINEATION OF HYDROGEOMORPHIC REGIONS

The Chesapeake Bay watershed was divided into "hydrogeomorphic regions" that were postulated to have similar amounts of ground-water discharge and similar responses to the application of nutrients. Previous investigators have shown that ground-water-flow patterns and water quality in a variety of hydrogeologic settings are strongly affected by landscape features (Hamilton and others, 1993; Bachman, 1980, 1994; Phillips and Bachman, 1996; Miller and others, 1997). These landscape features may be strongly related to bedrock or surficial lithology, geologic structure, mineral composition of the aquifer material or a combination of some or all of the above. Ground-water discharge and base-flow nitrate loads are analyzed in this report on the basis of a simplified hydrogeomorphic classification system based on rock type and physiographic province. The rock type provides a surrogate for permeability and mineral composition of the aquifers, and the physiographic province serves as a surrogate for slope and relief, and thus, hydraulic gradients.

The rock type and physiographic province coverages described earlier were generalized into four rock types (siliciclastic, carbonate, crystalline, and unconsolidated) and six physiographic provinces (Coastal Plain, Piedmont, Mesozoic Lowland, Blue Ridge, Valley and Ridge, and Appalachian Plateau) and subdivisions of those provinces. The hydrogeomorphic units were then defined on the basis of combinations of rock type and physiographic provinces (table 1).

In delineating the hydrogeomorphic regions, not one of the 28 possible combinations of rock type and physiographic province was included. Some combinations simply do not occur. For example, there are no areas in the Blue Ridge Physiographic Province underlain by carbonates. Other combinations may occur, for example unconsolidated alluvial deposits and glacial deposits are found in the Valley and Ridge and Appalachian Plateau Provinces, but their occurrences either were not mapped on the source maps, or they were not mapped in a consistent manner.

The rock types were expected to have the following characteristics that would affect ground-water discharge and base-flow nitrate loads:

***Carbonate**:* Ground-water flow in carbonate rocks is dominated by flow in solution-enlarged fractures (Trap and Horn, 1997). Because the fractures are enlarged by dissolution, permeability and flow rates in carbonate rocks are expected to be higher than in other kinds of fracture dominated by consolidated-rock aquifers. Carbonates are more soluble than other consolidated rock types that tend to erode in humid climates, and thus are found in valleys and under lower hydraulic gradients. Also, being in valleys or relatively flat

Table 1. *Delineation of hydrogeomorphic regions by combination of rock type and physiographic province*

[--, not used in delineation of hydrogeomorphic region]

Hydrogeomorphic region	Rock type	Physiographic province
Appalachian Plateau Siliciclastic (APS)	Siliciclastic	Appalachian Plateau
Appalachian Plateau Carbonate (APC)	Carbonate	Appalachian Plateau
Valley and Ridge Siliciclastic (VRS)	Siliciclastic	Valley and Ridge
Valley and Ridge Carbonate (VRC)	Carbonate	Valley and Ridge
Blue Ridge (BR)	--	Blue Ridge
Mesozoic Lowland (ML)	--	Mesozoic Lowland
Piedmont Carbonate (PCA)	Carbonate	Piedmont
Piedmont Crystalline (PCR)	Crystalline and unconsolidated	Piedmont
Coastal Plain Upland (CPU) [1]	Unconsolidated	Coastal Plain
Coastal Plain Dissected Upland (CPD) [1]	Unconsolidated	Coastal Plain
Coastal Plain Lowlands and Valleys (CPL) [1]	Unconsolidated	Coastal Plain

[1] Manually delineated on the basis of topography, surficial lithology, and stratigraphic unit.

areas, carbonate rocks are more likely to underlie areas developed for urban and agricultural land uses. The combination of a readily available source of nitrogen from anthropogenic sources and the high permeability of carbonate aquifers makes them more likely to have high concentrations of dissolved nitrate than other consolidated rock types.

Siliciclastic: Ground-water flow in the sandstone, siltstone, and shales of the Appalachian Plateau and Valley and Ridge Provinces is dominated by fracture flow, and is highly variable (Trap and Horn, 1997). Zones with extensive fracturing may have high permeabilities, whereas other areas have low permeabilities. Sandstones tend to underlie ridges, where relief may exceed 500 ft and hydraulic gradients may be very steep. The sandstone ridges tend to be forested, whereas the shale valleys may be either forested or farmed. Dissolved nitrogen concentrations may be as high as in carbonate areas, but in general, nitrogen concentrations in siliciclastic areas are expected to be lower than in carbonates because of the greater amount of forested area underlain by siliciclastic rocks.

Crystalline*:* Ground-water flow in these rocks is similar to that of siliciclastic rocks and is dominated by flow in fractures. These rocks, including igneous and metamorphic rocks of the Blue Ridge and Piedmont, however, are not layered in the same way as siliciclastic rocks, and so the orientation and scale of fracturing may be different. These rocks also are overlain by a thick weathered zone, or saprolite (Trap and Horn, 1997), in which significant quantities of ground water may flow and discharge to streams. Areas underlain by crystalline rocks are forested and also highly urbanized and intensively farmed.

Unconsolidated*:* Ground-water flow in these rocks is dominated by flow through the primary pore spaces between the individual particles of the rocks. Sand and gravel are highly permeable, silt and clay are less permeable. Some of the surficial sand aquifers of the Coastal Plain are among the most productive in the Chesapeake Bay watershed. A well in a surficial sand deposit near Salisbury, Md., was tested and found to have a transmissivity of 53,000 ft^2/d, one of the highest values ever recorded in the State of Maryland (Mack and Thomas, 1972). High nitrate values in these surficial sands have been extensively documented (Bachman, 1984; Hamilton and others, 1993). Areas underlain by unconsolidated deposits are forested, highly urbanized, and intensively farmed.

In some cases (such as the Blue Ridge and Mesozoic Lowland), the hydrogeomorphic subregion was based solely on the physiographic province. In the Coastal Plain, additional hydrogeomorphic subregions were manually delineated on the basis of topographic position and degree of dissection of land surface.

The GIS analysis resulted in some minor areas where there were anomalous rock types for a given physiographic province. In the vicinity of the Fall Line, the boundary between the Piedmont and Coastal Plain Provinces, it is common for unconsolidated deposits to form a thin cover over the Piedmont crystalline rocks. These areas were considered to be in the Piedmont Crystalline HGMR, as the unconsolidated deposits have minimal saturated thickness. Spurious occurrences of "crystalline" rocks were mapped in the Valley and Ridge, where such rocks are not found, and these areas were incorporated into the Valley and Ridge Siliciclastic HGMR. Quartzite, a siliciclastic rock found in the Piedmont, was included in the Piedmont Crystalline HGMR because its hydrogeologic characteristics are similar to crystalline rocks. Finally, some unconsolidated alluvial deposits were mapped in the Valley and Ridge of West Virginia, but nowhere else. These deposits were underlain by siliciclastic rocks, so they were included in the Valley and Ridge Siliciclastic HGMR.

The generalized MRLC land cover coverage was overlain on the HGMR coverage to assess whether certain land uses are more commonly found in some HGMR's than others. In general, the vast majority of land in the entire watershed is either forest (65 percent) or agricultural (30 percent), with urban land accounting for only about 4 percent of the total watershed area (fig. 5). The Valley and Ridge Carbonate, the Piedmont Carbonate, and the Mesozoic Lowland have higher percentages of agricultural land than the entire watershed, whereas the Appalachian Plateau Siliciclastic, the Valley and Ridge Siliciclastic, and Blue Ridge have higher percentages of forested land than the entire watershed (fig. 5). The Piedmont Carbonate, Piedmont Crystalline and the three Coastal Plain HGMR's have higher percentages of urban land than the entire watershed, but in no case is the urbanized area greater than 13 percent of the total area of an HGMR (fig. 5).

A short description of the hydrogeologic and land use characteristics of each of the subregions follows:

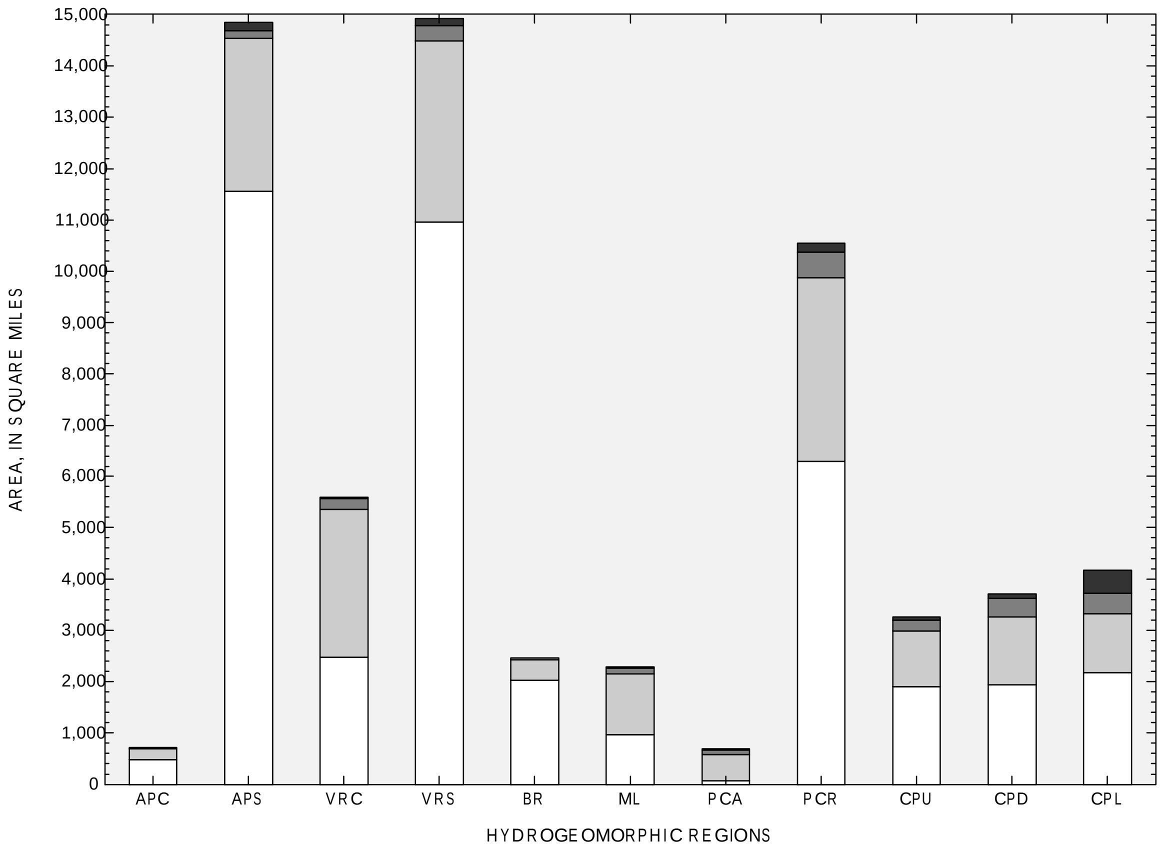
Appalachian Plateau Carbonate: An area of flat-lying carbonate rocks, mostly found in the northern part of the watershed. The relief is lower than the Appalachian Plateau siliciclastic region, and land use is more heavily agricultural (29 percent) than the siliciclastic region (20 percent).

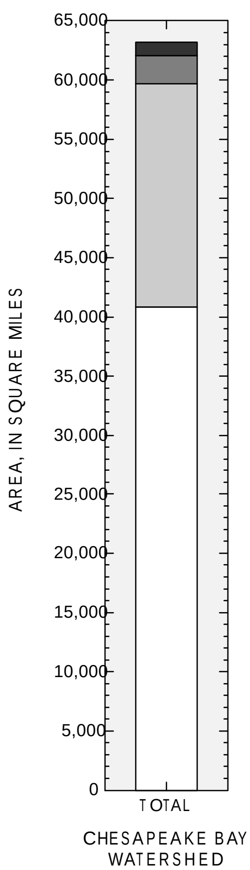
Appalachian Plateau Siliciclastic: An area of flat-lying to gently folded (dips rarely exceeding 10 degrees) siliciclastic rocks. The area has high relief, commonly exceeding 500 ft, with resulting steep hydraulic gradients. It is mostly forested (78 percent), with some agriculture (20 percent), small towns, and areas that have been disturbed as a result of strip mining for bituminous coal.

Valley and Ridge Carbonate: An area of intensely folded limestone and dolomite. Relief is usually less than 500 ft. Land use is heavily agricultural (52 percent); only 44 percent of the area is forested. Karst topography is widespread.

Valley and Ridge Siliciclastic: An area of intensely folded siliciclastic rocks. Relief is commonly greater than 500 ft. Land use is mostly forested (74 percent), with some agriculture (24 percent) in shale valleys.

Blue Ridge: An area underlain mostly by crystalline rocks, with some minor siliciclastics. Relief is commonly greater than 500 ft. Land use is mostly forested (83 percent).





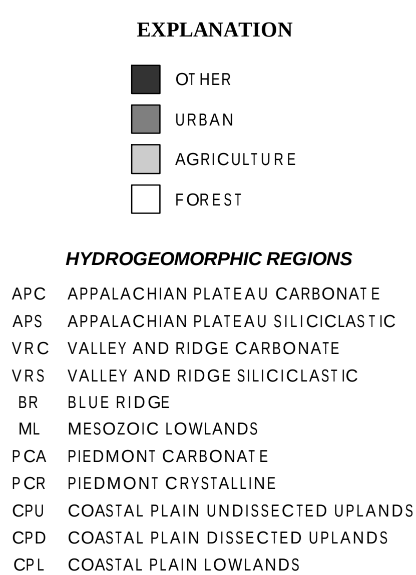


Figure 5. Distribution of land uses within the Chesapeake Bay watershed and within each hydrogeomorphic region (HGMR).

Mesozoic Lowland: An area underlain mostly by red sandstones and shales, but includes some igneous intrusions. Relief is commonly less than 500 ft. Land use is heavily agricultural (52 percent) and urban (5 percent).

Piedmont Carbonate*:* An area underlain by metamorphosed carbonated rocks surrounded by the low hills of the Piedmont Crystalline sub-region. The relief is commonly less than 100 ft. Land use is heavily agricultural (74 percent) and urban (13 percent). Forested land accounts for only 11 percent of the total area.

Piedmont Crystalline*:* An area underlain by metamorphic and igneous rocks with some minor areas underlain by quartzite. It forms a gently rolling upland with relief generally less than 500 ft. The crystalline rocks are overlain by a thick layer of weathered material. Land use is mostly forested (60 percent) and agricultural (34 percent), and there is a relatively high (5 percent) proportion of urbanized land.

Coastal Plain Upland*:* An area underlain by unconsolidated deposits. It is found along the major drainage divides between the large tidal rivers. This upland area may be underlain by sandy deposits or by finer grained deposits. In general, it is poorly dissected, poorly drained, and ground water flows through short, shallow flow-paths and has low gradients (Hamilton and others, 1993; Bachman, 1994). The area can be forested (58 percent), farmed (33 percent), or urban (6 percent).

Coastal Plain Dissected Upland: An area underlain by unconsolidated rocks, it is found between the undissected upland along the drainage divides and the lowlands along the major tidal rivers and Chesapeake Bay. This upland area is more likely to be underlain by sandy deposits, and is well dissected. Shallow ground-water flow-paths are up to a mile long, and hydraulic gradients may be larger. Land use is a mix of forested (52 percent) and agricultural (35 percent). The proportion of urban area (6 percent) is higher than the entire watershed (4 percent). Agricultural tracts are larger and more continuous than in the undissected upland.

Coastal Plain Lowlands and Valleys*:* An area of unconsolidated estuarine deposits located immediately adjacent to Chesapeake Bay and the tidal rivers. It is a lowland of low relief, and nontidal streams do not originate or flow through the region. Ground water discharges directly from the coastal aquifers into the bodies of tidal water. Land use is forested (52 percent), agricultural (28 percent), and the urban area (10 percent) includes the shorelines of the large established coastal cities. Much of the area is also rapidly urbanizing, as waterfront property is considered highly desirable real estate.

The areal distribution of the HGMR’s is shown in figure 2. One noteworthy fact of this distribution is that Chesapeake Bay and its tidal tributaries are completely bordered by the three Coastal Plain HGMR’s, in particular the Coastal Plain Lowlands. Thus, discharge from Coastal Plain streams has the greatest chance to enter the estuaries directly, whereas discharge from streams in other HGMR’s may pass through one or more HGMR’s before reaching tidewater.

GROUND-WATER DISCHARGE

Hydrograph separations were conducted using records from the period 1972-96 for 276 USGS streamflow measurement stations (fig. 2) within the Chesapeake Bay watershed. Sites where flow was subject to artificial regulation, such as the outflow of a dam, were excluded, as were sites with less than 4 years of continuous record. Base flow ranged from 16 to 92 percent of total streamflow with a median of 54 percent (table 2). The location of discharge stations was generally evenly distributed across the Chesapeake Bay watershed and among the HGMR’s. The data analysis focused on determining if the “dominant HGMR” of a basin (the HGMR comprising more than 50 percent of the basin area) was related to base flow. Comparisons showed that the ratio of base flow to total flow varied significantly among HGMR’s on an annual and spatial basis.

Table 2. *Summary of statistics of mean annual streamflow, annual base flow, and the base-flow index for the stations with discharge measurements*

[All measurements are using median of annual values from 1972-96; Mean annual streamflow and annual base flow are measured in inches of runoff per square mile per year; Base-flow index is measured in percentages]

	Number of stations	Minimum	25th percentile	Median	75th percentile	Maximum	Interquartile range
Mean annual streamflow	276	6.3	14.7	17.4	21.1	33.7	6.4
Annual base flow	276	2.9	7.6	9.5	11.9	23.5	4.3
Base-flow index	276	15.5	49.3	54.2	61.2	91.5	11.9

The base flow (as measured in inches of runoff per square mile per year) of all of the stations ranged from 2.9 to 23.5 in. (table 2). (One inch of runoff per square mile is approximately 17 million gallons per square mile) per year, with a median of 9.5 in. (table 2). It is estimated from this data set that of the 50 billion gallons of water that reaches the Chesapeake Bay each day, nearly 27 billion gallons is from base flow. Base flow is sustained by the water that infiltrates into the aquifer and, therefore, is related to the variation in meteorological conditions such as precipitation and evapotranspiration. Precipitation is generally highest along the western and northern boundary of the watershed, and potential evapotranspiration generally increases from north to south in the Chesapeake Bay Basin within Pennsylvania (Flippo, 1982). These factors explain why the mean annual streamflow in the Appalachian Plateau, the Blue Ridge, and the Valley and Ridge Physiographic Provinces is generally greater than the mean annual streamflow in the Piedmont or the Coastal Plain Physiographic Provinces (table 3). Comparing the quantities of base flow from region to region shows a similar pattern, but does not provide insight into the relative contributions of base flow and direct runoff in those areas. The base-flow index (the ratio of base flow to total streamflow) is used as an indicator of the relative importance of ground water in each region, and to make comparisons among regions.

Although measurement stations were distributed relatively uniformly across the study area, some HGMR's are not well represented. No basins had Coastal Plain Lowland as the dominant HGMR, only one basin had Piedmont Carbonate as the dominant HGMR, and only one basin had Appalachian Plateau Carbonate as the dominant HGMR. Kruskal-Wallis and nonparametric Tukey tests were performed in the 222 basins which were less than 1,000 mi^2 in area and for which dominant HGMR's were available for more than 4 basins.

The base-flow index varied among the HGMR's (fig. 6; table 3). The Kruskal-Wallis one-way ANOVA showed significant differences in the base-flow index among the hydrogeo-morphic regions (p = 0.0001). The results of the Tukey test shows four distinct groups and the relative ranking of the base-flow index among HGMR's for basins less than 1,000 mi^2 (fig. 6; table 3). The analysis appears to be insensitive to the defining criterion for "dominant" HGMR. When the analysis was repeated using 75 percent

Table 3. *Median value of mean annual discharge and median of annual base flow from selected streams in hydrogeomorphic regions in the Chesapeake Bay watershed, 1972-96*

[One inch of streamflow equals approximately 17 million gallons per square mile; 23 basins with no dominant HGMR (Hydrogeomorphic region); 1 basin in APC, and 1 basin in PCA not included]

Hydrogeomorphic region	Median of mean annual streamflow discharge (inches)	Median of annual base-flow discharge (inches)	Number of basins
Appalachian Plateau Siliciclastic	22.5	11.7	74
Valley and Ridge Siliciclastic	18.7	9.6	59
Valley and Ridge Carbonate	16.1	9.5	16
Blue Ridge	17.3	9.0	14
Mesozoic Lowland	16.3	5.9	9
Piedmont Crystalline	14.9	8.5	60
Coastal Plain Upland	15.2	9.0	12
Dissected Coastal Plain	15.3	8.7	8

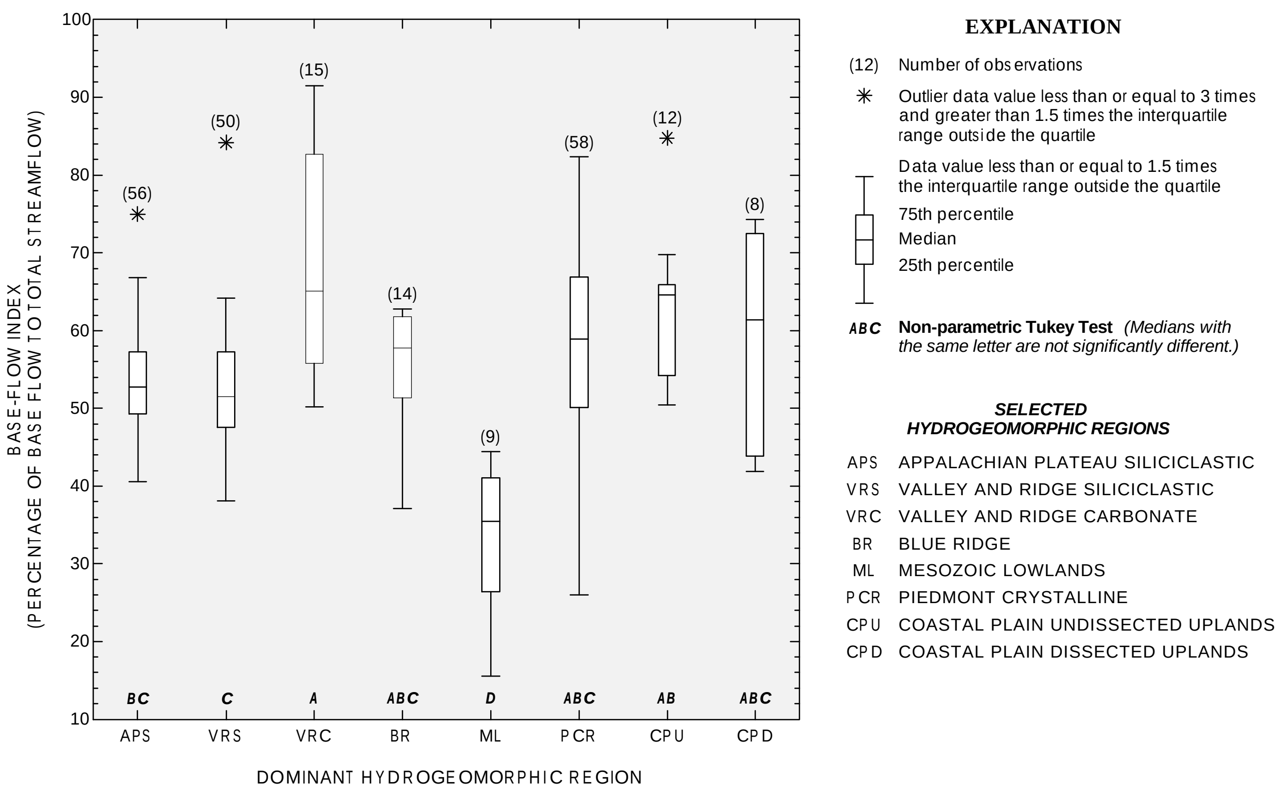


Figure 6. Distribution of base-flow index among hydrogeomorphic regions (HGMR's).

of a basin within a single HGMR as the criterion for determining the dominant HGMR, the results were similar to analysis in which 50 percent of basin area was the criterion.

Correlation analyses were conducted to determine relations between the percentage of a given HGMR in a basin and the base-flow index (table 4). High percentages of Valley and Ridge Carbonate, Coastal Plain Undissected Upland, Piedmont Crystalline, Piedmont Carbonate, and Coastal Plain Lowland were all associated with a higher base-flow index. Although these were all statistically significant correlations ($p < 0.05$), only the Coastal Plain and Piedmont Carbonate HGMR's had correlation coefficients that were high enough so that the relation would be useful in predicting the base-flow index from the percentage of the HGMR. Increasing percentages of Appalachian Plateau Siliciclastic, Valley and Ridge Siliciclastic, and Mesozoic Lowland HGMR's were all associated with a lower base-flow index; however, these correlations were not strong either.

GROUND-WATER NITRATE LOADS

Base-flow total nitrogen or nitrate load and yield data are available for far fewer stations than the number of stations for which for streamflow and ground-water-discharge data are available (fig. 2). On the basis of an analysis of data from Langland and others (1995), base-flow nitrate loads were available during the period 1972-92 for 78 stations, total-flow nitrate loads were available for 86 stations, and total-flow total-nitrogen

Table 4. *Correlation between percentage of basin area within a given hydrogeomorphic region and base-flow index*

[Kendall's tau correlation coefficient shown in table. **Bold** values represent significant correlation at *alpha* = 0.05 with a null hypothesis of tau being equal to zero. Numbers in parentheses are the numbers of data pairs upon which correlation coefficient was calculated. Basins which had no area within a given hydrogeomorphic region were excluded from the calculations]

Hydrogeomorphic region:	Correlation
Applachian Plateau Siliciclastic	**-0.198** (96)
Appalachian Plateau Carbonate	0.182 (31)
Valley and Ridge Siliciclastic	**-0.262** (109)
Valley and Ridge Carbonate	**0.239** (91)
Blue Ridge	0.140 (48)
Mesozoic Lowland	**-0.212** (41)
Piedmont Carbonate	**0.317** (28)
Piedmont Crystalline	**0.160** (97)
Coastal Plain Undissected Upland	**0.347** (28)
Coastal Plain Dissected Upland	0.120 (38)
Coastal Plain Lowland	**0.511** (16)

loads were available for 48 stations (table 5). These stations do not overlap exactly; only 57 stations have both total-flow and base-flow nitrate loads, and only 36 stations have both base-flow nitrate load and total-flow total-nitrogen load (table 5). The stations that have both base-flow and total-flow measurements do not have an even geographic distribution (fig. 2), but, they do include all of the hydrogeomorphic settings found in the watershed. All of these sites had at least 3 years of continuous discharge and water-quality records, so it is unlikely that the yield estimate for a station is biased by data only being collected at a station during short periods of unusually high or low streamflow.

The data in table 5 are presented as yields (the load divided by the basin area) in order to allow for comparison of basins of different sizes. Base-flow nitrate makes up a significant part of the total nitrogen yield from these nontidal stream basins. The percentage of base-flow nitrate yield to total-flow nitrate yield (called here the "base-flow nitrate index," or BFNI) ranged from 26 percent to 104 percent [1], with a median value of 56 percent. The percentage of base-flow nitrate yield to total-flow total-nitrogen yield (called here the "base-flow total nitrogen index," or BFTI) ranged from

[1] Some percentages exceeded 100 percent because of error in the regression model used to calculate loads from chemical analyses and stream-discharge measurements.

Table 5. *Summary statistics of station median, base-flow nitrate yield, total-flow nitrate yield, total nitrogen yields and percentage of base-flow nitrate to total-flow nitrate and nitrogen yields*

[Base-flow and total-nitrate yield are measured in tons per square mile per year. Base-flow nitrate index is the percent of base-flow nitrogen yield to total-flow nitrogen yield. Base-flow total nitrogen index is the percent of base-flow nitrate yield to total-flow total nitrogen yield. Percentages of base-flow to total-flow yield may exceed 100 percent due to error in the regression model used to calculate loads from chemical analyses and continuous discharge measurements]

Nitrate yield	Number of stations	Minimum	25th percentile	Median	75th percentile	Maximum	Interquartile range
Base-flow nitrate yield	78	0.10	0.54	0.82	1.4	6.9	0.86
Total-flow nitrate yield	86	.07	.65	1.2	2.2	9.1	1.6
Base-flow nitrate index	57	26	49	56	70	104	21
Total-flow total-nitrogen yield	48	.30	1.56	2.23	3.94	12	2.38
Base-flow total-nitrogen index	36	17	37	48	54	80	17

17 to 80 percent, with a median value of 48 percent (table 5).

The distributions of dominant HGMR's for the load basins is such that many HGMR's are not represented. Of the 11 HGMR's, only 3--the Appalachian Plateau Siliciclastic, the Valley and Ridge Siliciclastic, and the Piedmont Crystalline--were dominant HGMR's for enough basins to perform the Kruskal-Wallis test and nonparametric Tukey test. This precluded analysis of any carbonate HGMR's, which, on the basis of the ground-water-discharge analysis, appear to con-tribute a disproportionate share of ground-water discharge, and thus might be expected to con-tribute an equally disproportionate share of ground-water nitrate load.

A further examination of the frequency distributions of the percentage of HGMR area to total basin area using probability plots (Helsel and Hirsch, 1992; Sinclair, 1974) revealed that in some cases, two populations of HGMR areas were present--one the populations of basins with the HGMR dominant, the other with the HGMR not dominant. In most cases, the analysis showed that the 50-percent criterion used to define dominant HGMR's was reasonable, but data for the Valley and Ridge Carbonate (VRC) HGMR indicated that basins with VRC as the dominant HGMR might be found when VRC areas were as low as 43 percent (fig. 7). By use of the revised criterion to define dominant HGMR's, it was possible to add four dominant VRC basins to include that HGMR in the Kruskal-Wallis and nonparametric Tukey test.

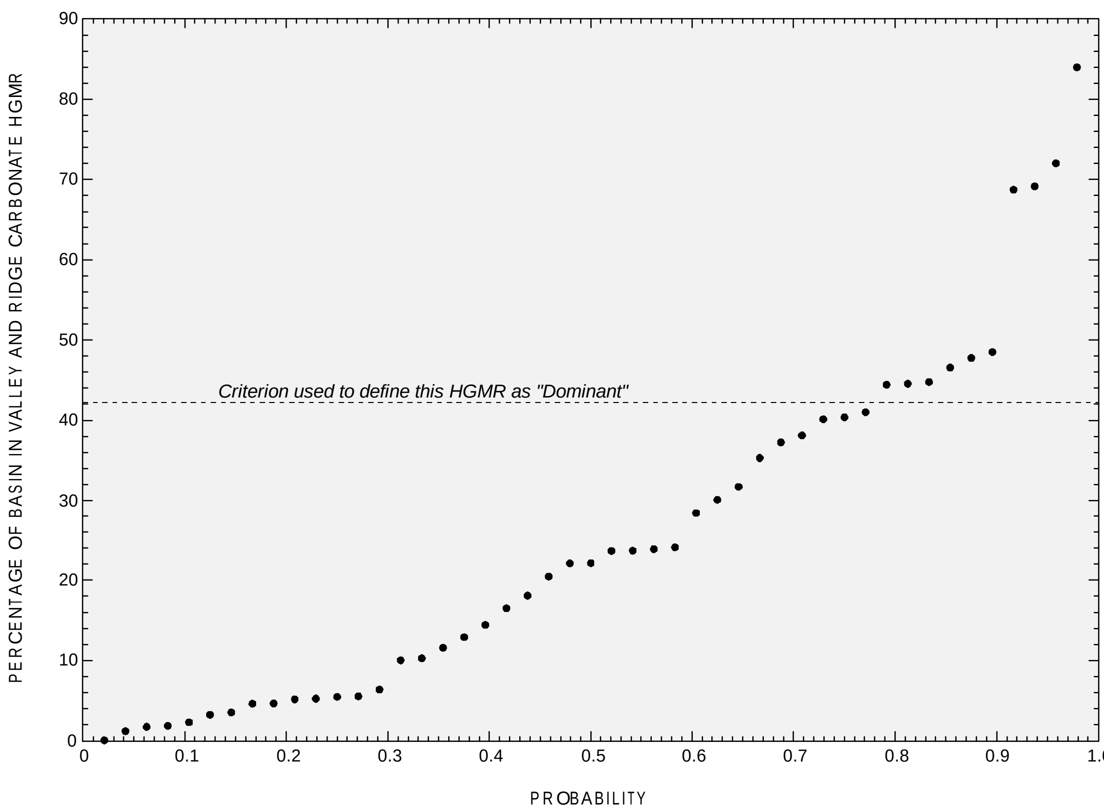


Figure 7. Frequency distribution of the percent area of the Valley and Ridge Carbonate hydrogeomorphic region (HGMR) for which load data were available.

The results of the Kruskal-Wallis and nonparametric Tukey tests are shown in figure 8. Although the Kruskal-Wallis test indicates that it is likely that at least one of the HGMR medians is different (p = 0.0001) for base-flow nitrate yield, there is considerable overlap among the HGMR's. The median for the Appalachian Plateau Siliciclastic, however, is clearly lower than the others. The null hypothesis that yields in the Valley and Ridge Carbonate, the Valley and Ridge Siliciclastic, and the Piedmont Crystalline are the same cannot be rejected on the basis of this test (fig. 8). A similar pattern exists for the BFNI, although it is difficult to interpret the meaning of the results for the Valley and Ridge Carbonate due to the small sample size.

Correlation coefficients were computed to test the association between nitrate yields, BFNI, and the percentage of basin area within an HGMR (table 6). Sufficient data were found to compute correlation coefficients for all of the HGMR's except the Coastal Plain Lowland. A significant negative correlation was found between the percentage of basin area having the Appalachian Plateau Siliciclastic HGMR and base-flow nitrate yield and BFNI, which is consistent with the results of the Kruskal-Wallis and nonparametric Tukey tests. A significant positive correlation was found between base-flow nitrate yields, BFNI, and percent of basin area within the Piedmont Carbonate. No other correlations were significant. This will be discussed further in the next section.

Table 6. *Correlation between percentage of basin area within a given hydrogeomorphic region and nitrate yields*

[Kendall's tau correlation coefficient shown in table. **Bold** values represent significant correlation at *alpha* = 0.05 with a null hypothesis of tau being equal to zero. Numbers in parentheses are the numbers of data pairs upon which correlation coefficient was calculated. Total-flow nitrate yield, base-flow nitrate yield and percentage of base-flow to total-flow nitrate yields are station medians. Basins which had no area within a given hydrogeomorphic region were excluded from the calculations; BFNI, Base-Flow Nitrate Index; --, no data available]

Hydrogeomorphic region	Nitrate yield		
	Base-flow yield	Total-flow yield	Percentage of base-flow to total-flow yield (BFNI)
Applachian Plateau Carbonate	-0.17 (18)	**-0.56** (10)	0.56 (9)
Appalachian Plateau Siliciclastic	**-0.54** (40)	**-0.64** (37)	**-0.50** (30)
Valley and Ridge Carbonate	0.19(30)	-0.16 (34)	-0.08 (21)
Valley and Ridge Siliciclastic	0.09 (37)	0.01(42)	-0.07(27)
Blue Ridge	0.26 (17)	-0.10 (18)	0.11 (10)
Mesozoic Lowland	0.03 (15)	**0.31** (21)	0.03 (12)
Piedmont Crystalline	-0.02 (26)	-0.07 (25)	0.16 (14)
Piedmont Carbonate	**0.64** (20)	**0.67** (14)	**0.42** (11)
Coastal Plain Undissected Upland	0 (5)	0 (9)	0 (5)
Coastal Plain Dissected Upland	0.14 (7)	0.13 (11)	0.07(6)
No basins have any area of Coastal Plain Lowland	--	--	--

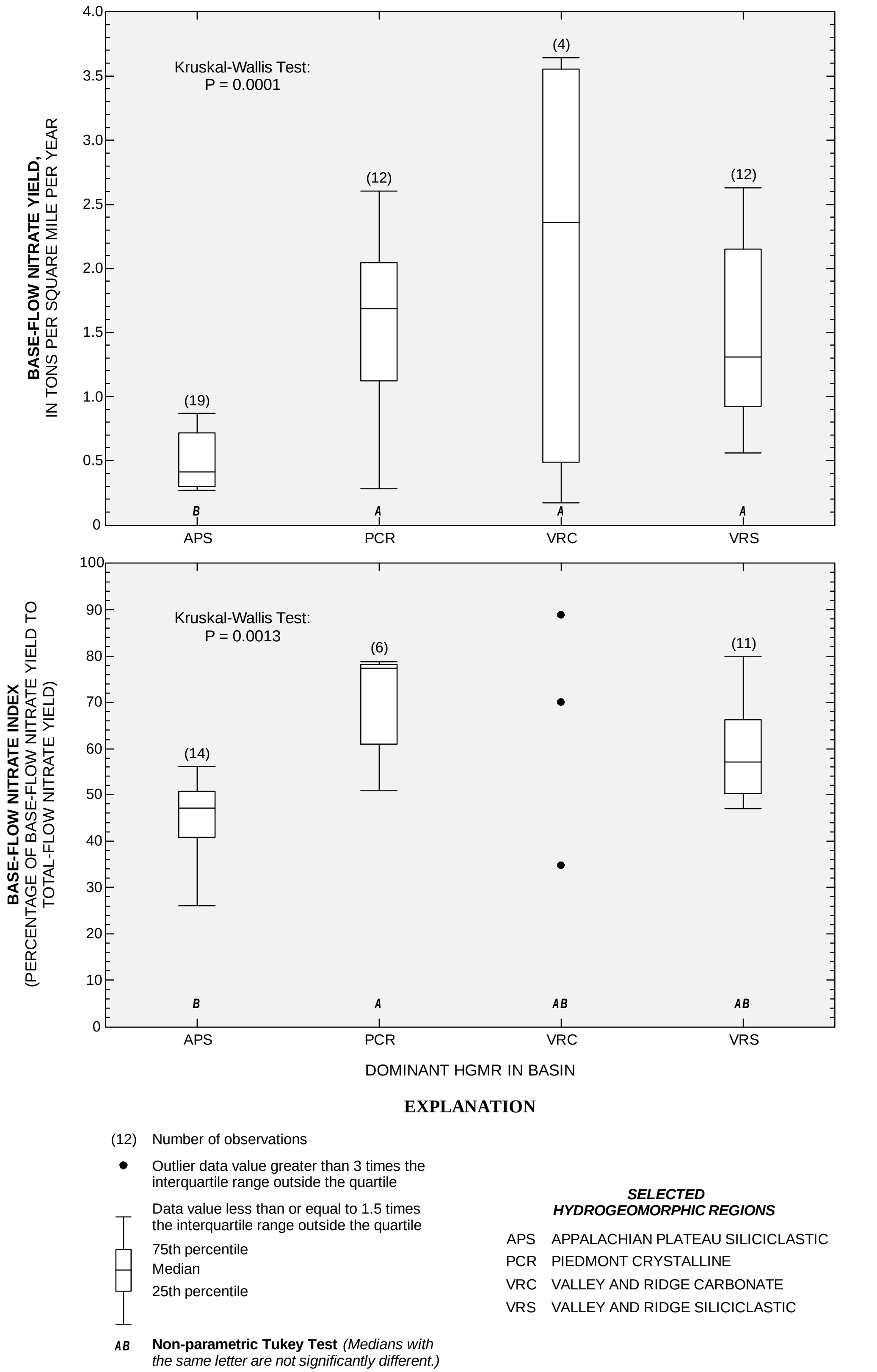


Figure 8. Frequency distributions of nitrate yield and base-flow nitrate index among basins with dominant hydrogeomorphic regions (HGMR's). *(Only those HGMR's with 3 or more basins dominant are shown. Basins with areas greater than 1,000 square miles were excluded from the analysis.)*

RELATION BETWEEN GROUND-WATER DISCHARGE, BASE-FLOW NITRATE YIELDS AND HYDROGEOMORPHIC REGIONS

Base-flow indices were highest in the regions underlain by carbonate bedrock, followed by the regions of unconsolidated sediments, crystalline bedrock, and siliciclastic bedrock. The Valley and Ridge Carbonate region has permeable soils, highly fractured bedrock, and flat topography that favors infiltration over direct runoff. Sinkholes commonly direct surface water directly into the ground-water system, and many ground-water-flow systems are dominated by conduit flow. Many of the streams in the carbonate region are fed by large perennial springs. These factors explain why a high percentage of flow to streams in the carbonate region would be from base flow. Areas underlain by unconsolidated sediments in the Coastal Plain have permeable soils and flat topography, so direct runoff is minimized. The sand aquifers are highly permeable, and thus are capable of yielding large quantities of water. Coastal Plain aquifers do not have the conduit flow characteristic of the carbonate aquifers, however, and so water yields in the Coastal Plain are slightly less than in the carbonate HGMR's. Crystalline areas have steeper topography and moderately drained soils, but commonly a mantle of saprolite or regolith covers slopes of hills and ridges and acts a reservoir for ground water. Areas underlain by siliciclastic bedrock are characterized by poorly drained soils, bedrock with low transmissivity, and steep topography that would favor direct runoff over infiltration.

The base-flow index varies temporally due to variations in precipitation and total flow. To determine the variability in total flow, the total annual flow was divided by the median of total annual flow for the 25-year period (1972-96) to calculate a ratio for each site for each year, and the median of these ratios among all sites was plotted for each year (fig. 9). The median base-flow index was also calculated for each year, to show the relation between base flow and total flow in wet and dry years. A strong negative correlation exists between base-flow index and total flow ($p = 0.0001$). Dry years generally have a higher contribution of the total flow from base flow and wet years generally have a greater amount of direct runoff in relation to base flow (fig. 9). Variation in total annual flow causes fluctuation of 10 to 20 percent in the base-flow index. Annual variation in base flow is similar in all of the hydrogeomorphic regions. Studies that include a smaller number of years may not observe the entire range of possible values for the base-flow index for a given site.

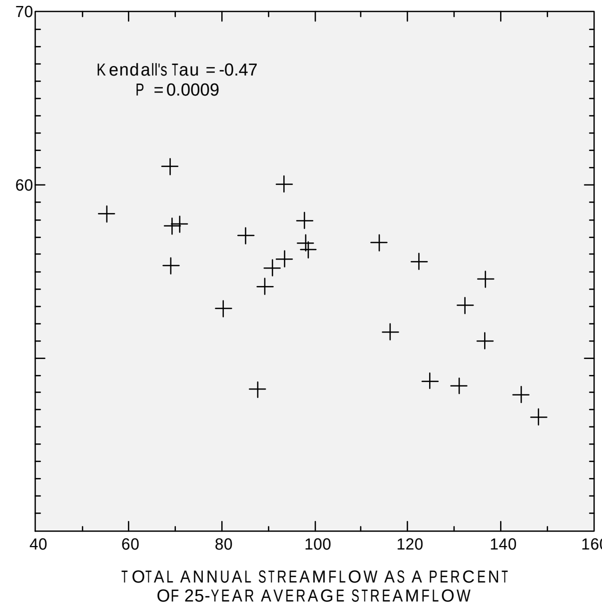


Figure 9. Relation between annual streamflow and base-flow index.

In addition to the meteorological factors affecting the annual variation in base flow, and the lithologic factors affecting base flow, other variables also influence the relations between base flow and total flow. Basin relief, drainage density, soil type, and infiltration capacity are some of these factors. The hydrogeomorphic regions were delineated to represent many of these factors. Further analysis of individual basin characteristics may enhance the understanding of the factors that affect the relations between base flow and direct runoff.

Base-flow calculations have been conducted for many hydrologic studies, and results of these studies often are cited as typical for a given province or bedrock type. Rutledge and Mesko (1996) calculated base-flow index for the Appalachian-Piedmont Regional Aquifer System Analysis (APRASA) program's study of 157 sites in the Valley and Ridge, the Blue Ridge, and the Piedmont Physiographic Provinces. The study included much of the Chesapeake Bay Basin, but extended south as far as Georgia and Alabama. The base-flow index in the APRASA study ranged from 32 to 94 percent, with a median of 67 percent, all of which are higher than indexes computed in this study of streams in the Chesapeake Bay. Reasons for the higher percentages of base flow include: (1) the APRASA study did not include the Appalachian Plateau Siliciclastic HGMR, an area with a low base-flow index, (2) the highest base-flow index in the APRASA study was in the southern part of the Blue Ridge Physiographic Province, an area not in the Chesapeake Bay study, and (3) the PART method (Rutledge, 1993) used in the APRASA study produces estimates of base flow 5 to 10 percent higher than the HYSEP local minima method (Sloto and Crouse, 1996) when comparing the same streams and the same years.

Ground-water nitrate yields do not seem to be as strongly related to the HGMR's as ground-water discharge. This may be due to complications induced by variations of land use within each HGMR, or it may be due to changes in nitrate concentrations due to instream processes between the point of ground-water discharge and the sampling station. Such processes may include decreases in nitrate concentration due to uptake by algae and submerged and streamside plants, decreases in nitrate concentrations due to denitrification in anoxic bottom sediments (Bradley and others, 1995), and possibly increases in nitrate concentration due to nitrification of ammonia-rich pore water that moves from anoxic bottom sediments to more oxygenated parts of the water column. However, none of the effects of these postulated processes were assessed in this study.

The nitrate yield or load is the product of both the nitrate concentration and the discharge rate. The concentration is related to the amount of anthropogenic nitrogen applied to the land surface, which in turn is related to the land use. Urban and agricultural areas will likely have higher rates of anthropogenic nitrogen application than forested areas. Thus, it is likely that nitrate loads will also be affected by the land use as well as the HGMR.

The percentage of each land-use/HGMR combination was computed for the basins in which load estimates were available. A correlation analysis was performed on the percentage of each land-use/HGMR combination to assess the effect of land use on nitrate yields. If land use were the sole factor controlling nitrate yields, the following relations between land use and nitrate yield for each HGMR would be expected: (1) the percentage of agricultural and urban land would be positively correlated with the nitrate yield, and the percentage of forested lands would be negatively correlated with nitrate yield; (2) correlations of BFNI and percentage of land-use/HGMR combinations would be similar, but the intensity of the correlation would be different in different HGMR's, as the HGMR's apparently are related to ground-water discharge. These differences in intensity of the correlation should be similar to those in table 3, because the BFNI should be more likely to reflect the discharge component of the load, whereas the land use would reflect the concentration component.

The results of the correlation analysis are shown in table 7. The analysis was only partly successful in testing the expected relations. In many cases (especially for analysis of the BFNI), the correlation coefficients were not significant, which does not necessarily disprove the hypothesized relations, but rather may indicate that additional factors may be confounding the analysis. In other cases, the number of available data pairs were too small to make a meaningful interpretation of the analysis. In a few cases, however, the analysis showed that land use, and thus nitrogen input, was a significant factor in explaining the variability of base-flow nitrate yields.

Table 7. *Correlation between percentage of basin area in a given land-use/hydrogeomorphic region combination and nitrate yield*

[Kendall's tau correlation coefficient shown in table. **Bold** values represent significant correlation at *alpha* = 0.05 with a null hypothesis of tau being equal to zero. Numbers in parentheses are the number of pairs for which the correlation coefficient was calculated. "ID" ("insufficient data") represents groups in which there were less than four data pairs and in which the correlation coefficient is not reported. "--" indicates that there were no basins that contained the particular land-use/hydrogeomorphic region combination. Base-flow nitrate index is the percent of base-flow to total-flow nitrate yield]

Hydrogeomorphic region	Nitrate yield	Percentage of basin area within land-use/hydrogeomorphic region combination		
		Agricultural	Urban	Wooded
Appalachian Plateau Carbonate	Base-flow nitrate yield	0.2 (5)	--	--
	Total-flow nitrate yield	0.4 (5)	--	--
	Base-flow nitrate index	0.2 (5)	--	--
Appalachian Plateau Siliciclastic	Base-flow nitrate yield	0.09 (32)	ID	**-0.48** (40)
	Total-flow nitrate yield	-0.02 (30)	ID	**-0.57** (37)
	Base-flow nitrate index	-0.04 (25)	ID	**-0.39** (30)
Valley and Ridge Carbonate	Base-flow nitrate yield	**0.58** (25)	0.05 (7)	0.0 (25)
	Total-flow nitrate yield	**-0.38** (30)	0.14 (8)	**-0.32** (28)
	Base-flow nitrate index	0.32 (18)	0.2 (5)	-.07 (16)
Valley and Ridge Siliciclastic	Base-flow nitrate yield	**0.32** (31)	**-0.87** (6)	0.06 (33)
	Total-flow nitrate yield	**0.57** (34)	**-0.81** (7)	-0.09 (38)
	Base-flow nitrate index	-0.03 (22)	-0.07 (6)	-0.03 (25)
Blue Ridge	Base-flow nitrate yield	-0.2 (6)	--	0.06 (12)
	Total-flow nitrate yield	-0.07 (6)	--	-0.36 (1.3)
	Base-flow nitrate index	ID	--	-0.07 (6)
Mesozoic Lowland	Base-flow nitrate yield	-0.02 (10)	ID	0.30 (12)
	Total-flow nitrate yield	0.2 (11)	ID	0.36 (13)
	Base-flow nitrate index	-0.14 (7)	ID	0.39 (9)
Piedmont Carbonate	Base-flow nitrate yield	**0.56** (11)	ID	0.33
	Total-flow nitrate yield	**0.56** (9)	ID	ID
	Base-flow nitrate index	**0.71** (7)	ID	ID

Table 7. *Correlation between percentage of basin area in a given land-use/hydrogeomorphic region combination and nitrate yield--Continued*

Hydrogeomorphic region	**Nitrate yield**	**Percentage of basin area within land-use/hydrogeomorphic region combination**		
		Agricultural	**Urban**	**Wooded**
Piedmont Crystalline	Base-flow nitrate yield	0.13 (23)	-0.24 (10)	**-0.34** (23)
	Total-flow nitrate yield	0.14 (24)	**-0.87** (6)	**-0.49** (23)
	Base-flow nitrate index	0.0 (13)	**-0.8** (5)	-0.15 (13)
Coastal Plain Undissected Upland	Base-flow nitrate yield	-0.67 (4)	ID	-0.67 (4)
	Total-flow nitrate yield	-0.67 (6)	ID	-0.24 (7)
	Base-flow nitrate index	-0.33 (4)	ID	-0.33 (4)
Coastal Plain Dissected Upland	Base-flow nitrate yield	ID	ID	-0.67 (4)
	Total-flow nitrate yield	0.33 (6)	0 (4)	-0.23 (7)
	Base-flow nitrate index	ID	ID	-0.33 (4)

As expected, yields in agricultural basins had positive correlations. This was found in the Valley and Ridge Carbonate, the Valley and Ridge Siliciclastic, and the Piedmont Carbonate HGMR's. This may explain why the yields for the Valley and Ridge Carbonate and Valley and Ridge Siliciclastic appear to be the same (fig. 8). The agricultural areas in Valley and Ridge Siliciclastic-dominated basins and the mixture of some Valley and Ridge Carbonate agricultural area in the Valley and Ridge Siliciclastic-dominated basins could have affected the median yield values for these basins. Yields in wooded basins had significant negative correlations in the Appalachian Plateau Siliciclastic and the Piedmont Crystalline HGMR's.

Comparisons of scatterplots of a few selected HGMR's separated by land use (fig. 10) suggests that water flow, and thus HGMR, may be a relatively significant factor controlling nitrate yield. For example, the magnitudes of nitrate yields in the Valley and Ridge Carbonate appear to be similar in both agricultural and wooded areas, even if the correlation between nitrate yield and percentage of wooded area is not significant. Further, yields in both carbonate land uses tend to be higher than the yields in the Appalachian Plateau Siliciclastic HGMR, whether wooded or agricultural. Even carbonate areas may behave differently from each other, as the slope of the monotonic trend between the percentage of agricultural area and base-flow nitrate yield appears steeper in the Piedmont Carbonate than in the Valley and Ridge Carbonate. This trend may be due to greater rates of nitrogen application in Piedmont farms than in Valley and Ridge farms, the effect of other nitrogen sources in the Piedmont [the Piedmont Carbonate has 13 percent urban land, as opposed to 4 percent for the Valley and Ridge Carbonate (fig. 5)], or possibly higher ground-water yields from Piedmont carbonate

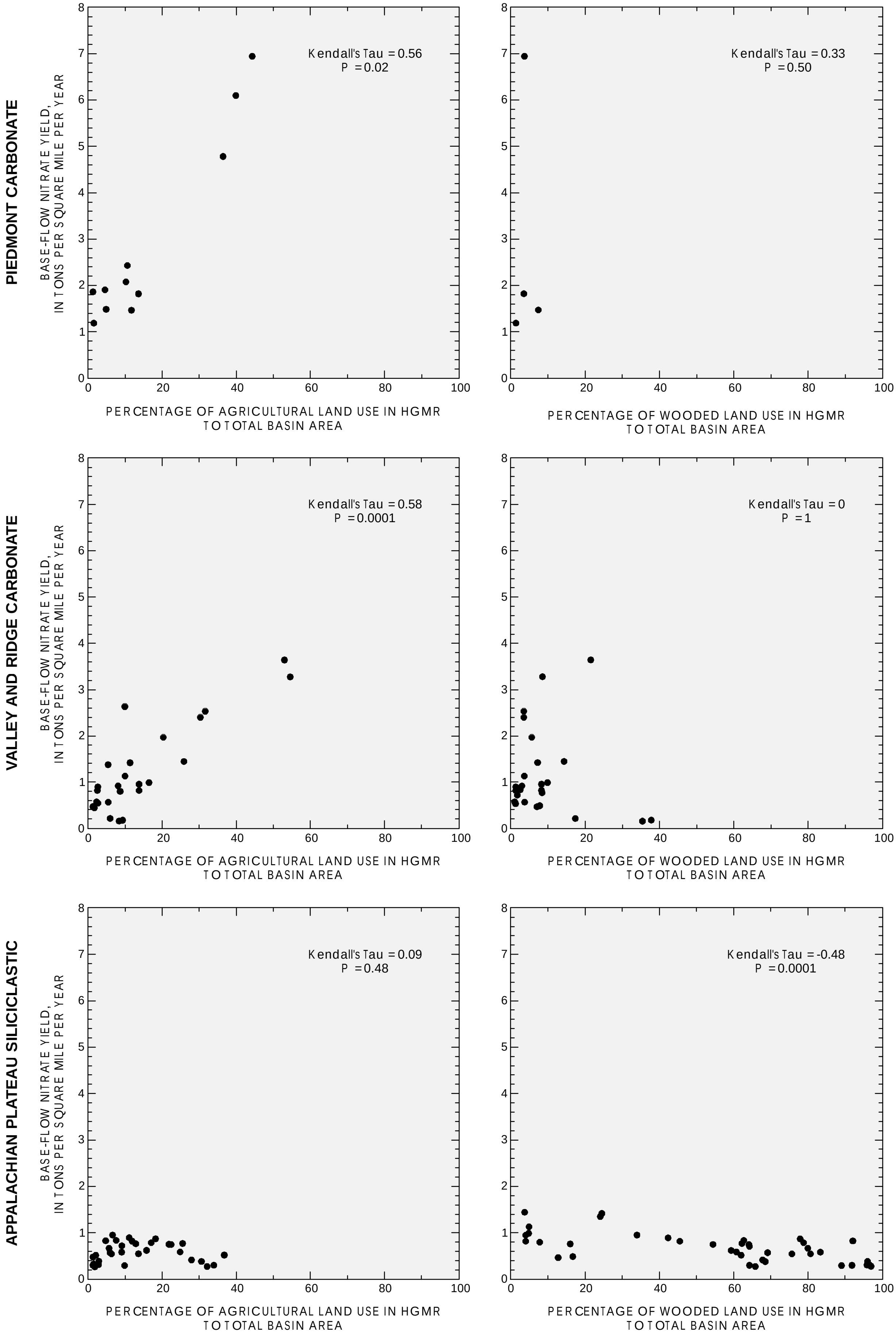


Figure 10. Relation between base-flow nitrate yield and selected land-use/hydrogeomorphic region (HGMR) combinations.

rocks than come from Valley and Ridge carbonate rocks.

Much of the difference in relations displayed in figure 10 could be explained by the mixed nature of most watersheds. Watersheds that contain wooded areas also have agricultural areas, and these two land uses may be interspersed within the basin. Furthermore, the various combinations of HGMR's that are found in a watershed are not consistent across the watershed. For example, basins that are found in the Valley and Ridge Carbonate might include areas in the Valley and Ridge Siliciclastic and Blue Ridge, but not in any other HGMR. It is also unlikely that a single small (less than 100 mi^2) basin would contain areas in the Blue Ridge, the Valley and Ridge Siliciclastic, and the Valley and Ridge Carbonate. On the other hand, basins found in the Coastal Plain will not contain any of the Valley and Ridge or Appalachian Plateau HGMR's. Thus, between variations in land use and variations between the exact combinations of HGMR's in a basin, it is not surprising that the relation between nitrate yield and HGMR's is as poorly defined as it is.

SUMMARY AND CONCLUSIONS

Streamflow data compiled from U.S. Geological Survey (USGS) streamgaging stations and nitrate load data compiled from USGS and other agency water-quality sampling were used to assess the relative importance of ground-water discharge to total water flow and to nitrate load to Chesapeake Bay from nontidal streams and rivers. On the basis of analysis of data from more than 276 streamgaging stations, base flow, or ground-water discharge, accounted for 16 to 92 percent of the streamflow, with a median value of 54 percent. On the basis of data from 57 sampling stations, the percentage of base-flow nitrate load to total-flow nitrate load ranges from 26 percent to close to 100 percent, with a median value of 56 percent. The percentage of base-flow nitrate load to total-flow total-nitrogen load ranged from 17 percent to 80 percent, with a median of 48 percent at 36 stations.

The base-flow index, or percentage of base flow to total flow, was related to hydrogeomorphic regions (HGMR's) that were delineated on the basis of lithology and physiographic province. The base-flow index was highest in the Valley and Ridge Carbonate, next highest in the Coastal Plain and the Piedmont Crystalline, and lowest in the siliciclastic rocks of the Appalachian Plateau and the Mesozoic Lowland. The results overlap considerably, probably because most of the basins, even those dominated by a given HGMR, contain a mixture of two or more HGMR's. The differences in base-flow index among the HGMR's is most likely a result of differences in lithology. Carbonate aquifers provide the highest ground-water yields because solution-enlarged fractures result in extremely high permeability. Sandy sediments of the Coastal Plain provide relatively high permeability, but areas underlain by lower-permeability silty or clayey sediments could result in lower base-flow yields. Ground water in crystalline and siliciclastic rocks is derived from fractures, and aquifer yields are lower than those from other lithologies. The higher values reported for the Piedmont Crystalline may be due to the presence of a thick mantle or weathered saprolite that overlies the crystalline rock and acts as an unconsolidated-rock aquifer.

Base-flow discharges and nitrate yields were also related to HGMR's. The highest nitrate yields were observed in the Valley and Ridge Carbonate, the Valley and Ridge Siliciclastic, and the Piedmont Crystalline. The highest percentages of base-flow nitrate yield to total-flow nitrate yield were found in the Piedmont crystalline. The lowest base-flow nitrate yields and percentage of base-flow nitrate yield to total-flow nitrate yield were found in the Appalachian Plateau Siliciclastic.

Base-flow nitrate yield is a product of both the amount of ground-water discharge and the nitrate concentration of the water in the aquifer. The high yields in the Valley and Ridge Carbonate and Piedmont Crystalline and low yields in the

Appalachian Plateau Siliciclastic may be due to the effects of lithologic differences on the volume of discharge from the aquifers. Differences in the concentration of nitrate in an aquifer due to differential nitrate applications as a result of various agricultural and urban land uses may explain some of the results, however. For example, similarities in base-flow nitrate yields in the Valley and Ridge Siliciclastic and the Valley and Ridge Carbonate may be due to the fact that both HGMR's have a substantial percentage of agricultural land. Nitrate yields and the percent of agricultural land in a basin are strongly correlated within the Valley and Ridge Carbonate and the Valley and Ridge Siliciclastic. Separation of the effect of land use from the effect of the amount of ground-water discharge is difficult with the data available, however. Many of the relations between HGMR and ground-water nitrate discharge are inconclusive, which may be due to an insufficient sample size or the fact that the individual basins contain a wide range of hydrogeomorphic settings and that the combinations of settings are not consistent within a land use or a rock type.

The results of the study presented here have some implications for the Chesapeake Bay restoration effort. A considerable portion of the nontidal stream flow to the Bay is comprised of ground-water discharge. This means that management practices designed to reduce nutrient loads from the nontidal streams will have to consider ways to reduce infiltration and recharge to aquifers as well as reducing overland runoff. It also means that high-nitrate ground water in the aquifer will be a long-term reservoir of delayed discharge of nitrogen. This delayed discharge of ground-water nitrogen will need to be accounted for when assessing the effectiveness of any nutrient management strategy. The relative amounts of ground-water discharge and base-flow nitrate load are not evenly distributed across the basin, but rather are distributed on the basis of lithology, physiographic province, and land use. The maximum ground-water discharge will be found in carbonate aquifers in the Valley and Ridge and the Piedmont, the Piedmont Crystalline, the Coastal Plain, and in agricultural areas in the Valley and Ridge Siliciclastic HGMR's. Managing ground-water nitrogen loads in these settings would probably have the greatest impact on reducing the effects of ground-water nitrogen discharge to the nontidal tributaries of Chesapeake Bay.

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APPENDIX

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*

[°, degree; ′, minute; ", second; BFNI, Base-Flow Nitrate Index; BFTI, Base-Flow Total Nitrogen Index; --, no data available; Yields are in tons of nitrogen per year per square mile. "Nitrate percentage years" is the number of years of record in which both base-flow nitrate yield and total-flow nitrate yield estimates are available. "Total nitrogen percentage years" is the number of years of record in which both base-flow nitrate yield and total-flow nitrogen yield estimates are available. Hydrogeomorphic regions (HGMR's) are abbreviated as follows:

APC, Appalachian Plateau Carbonate
APS, Appalachian Plateau Siliciclastic
VRC, Valley and Ridge Carbonate
VRS, Valley and Ridge Siliciclastic
BR, Blue Ridge
ML, Mesozoic Lowland
PCA, Piedmont Carbonate
PCR, Piedmont Crystalline
CPU, Coastal Plain, Undissected
CPD, Coastal Plain, Dissected
CPL, Coastal Plain Lowland]

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01485000	Pocomoke River near Willards, Md.	38 23 20	75 19 30	CPU	25	14.7	9.5	59.9
01485500	Nassawango Creek near Snow Hill, Md.	38 13 44	75 28 19	CPU	25	15.8	8.7	51.7
01486000	Manokin Branch near Princess Anne, Md.	38 12 50	75 40 18	CPD	2	12.5	7.2	63.5
01487000	Nanticoke River near Bridgeville, Del.	38 43 42	75 33 44	CPU	25	16.4	12.	84.8
01488500	Marshyhope Creek near Adamsville, Del.	38 50 59	75 40 24	CPU	25	16.4	9.2	69.8
01491000	Choptank River near Greensboro, Md.	38 59 50	75 47 10	CPU	25	14.8	8.8	65.1
01493000	Unicorn Branch near Millington, Md.	39 14 59	75 51 40	CPD	25	15.9	11.	74.3
01493500	Morgan Creek near Kennedyville, Md.	39 16 48	76 00 54	CPD	25	10.3	6.3	59.2
01495000	Big Elk Creek at Elk Mills, Md.	39 39 26	75 49 20	PCR	25	17.9	10.	64.3
01496500	Oaks Creek at Index, N.Y.	42 39 56	74 57 36	APS	23	22.9	17.	75.0
01500000	Ouleout Creek at East Syndey, N.Y.	42 20 00	75 14 07	APS	25	22.1	11.	45.7

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
CPU	--	--	--	--	--	--	--	--	--	--	01485000
CPU	--	--	--	--	--	--	--	--	--	--	01485500
CPD	--	--	--	--	--	--	--	--	--	--	01486000
CPU	--	--	--	--	--	--	--	--	--	--	01487000
CPU	--	--	--	--	--	--	--	--	--	--	01488500
CPU	8	0.71297	19	1.04287	18	1.7712	8	72.203	8	42.9609	01491000
CPD	--	--	--	--	--	--	--	--	--	--	01493000
CPD	0	--	18	1.38315	0	--	0	--	0	--	01493500
PCR	--	--	--	--	--	--	--	--	--	--	01495000
APS	--	--	--	--	--	--	--	--	--	--	01496500
APS	--	--	--	--	--	--	---	--	--	--	01500000

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01500500	Susquehanna River at Unadilla, N.Y.	42 19 17	75 19 01	APS	23	21.2	13.	63.1
01502000	Butternut Creek at Morris, N.Y.	42 32 43	75 14 22	APS	23	21.6	13.	62.2
01502500	Unadilla River at Rockdale, N.Y.	42 22 40	75 24 23	APS	23	21.3	13.	58.1
01503000	Susquehanna River at Conklin, N.Y.	42 02 07	75 48 12	APS	25	21.7	12.	55.5
01505000	Chenango River at Sherburne, N.Y.	42 40 43	75 30 39	APS	23	20.3	12.	60.5
01509000	Tioughnioga River at Cortland, N.Y.	42 36 10	76 09 35	APS	25	22.5	13.	61.7
01509150	Gridley Creek above East Virgil, N.Y.	42 30 04	76 07 38	APC	7	31.7	15.	58.1
01510000	Otselic River at Cincinnatus, N.Y.	42 32 28	75 54 00	APS	25	25.1	14.	57.3
01512500	Chenango River near Chenango Forks, N.Y.	42 13 05	75 50 55	APS	25	21.8	11.	55.3
01515000	Susquehanna River near Waverly, N.Y.	41 59 05	76 30 05	APS	23	21.3	10.	52.7
01516350	Tioga River near Mansfield, Pa.	41 47 34	77 04 44	APS	19	16.0	9.4	55.7
01516500	Corey Creek near Mainesburg, Pa.	41 47 27	77 00 54	APS	24	12.7	7.1	56.2
01518000	Tioga River at Tioga, Pa.	41 54 30	77 07 47	APS	24	16.9	7.7	46.6
01518700	Tioga River at Tioga Junction, Pa.	41 57 09	77 06 56	APS	19	14.1	6.8	47.4
01518862	Cowanesque River at Westfield, Pa.	41 55 23	77 31 56	APS	12	12.9	6.9	53.7

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
APS	--	--	--	--	--	--	--	--	--	--	01500500
APS	--	--	--	--	--	--	--	--	--	--	01502000
APS	--	--	--	--	--	--	--	--	--	--	01502500
APS	13	0.74589	16	1.13400	0	--	13	70.058	0	--	01503000
APS	--	--	--	--	--	--	--	--	--	--	01505000
APS	--	--	--	--	--	--	--	--	--	--	01509000
APC	5	0.76000	6	1.35000	0	--	5	58.462	0	--	01509150
APS	--	--	--	--	--	--	--	--	--	--	01510000
APS	--	--	--	--	--	--	--	--	--	--	01512500
APS	--	--	--	--	--	--	--	--	--	--	01515000
APS	--	--	--	--	--	--	--	--	--	--	01516350
APS	--	--	--	--	--	--	--	--	--	--	01516500
APS	11	0.26962	11	0.93100	0	--	10	26.065	0	--	01518000
APS	14	0.29764	16	0.65678	0	--	14	45.583	0	--	01518700
APS	--	--	--	--	--	--	--	--	--	--	01518862

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ″)	Longitude (° ′ ″)	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01520000	Cowanesque River near Lawrenceville, Pa.	41 59 48	77 08 25	APS	24	12.5	5.1	40.5
01520500	Tioga River at Lindley, N.Y.	42 01 43	77 07 57	APS	23	13.9	6.2	45.0
01521500	Canisteo River at Arkport, N.Y.	42 23 45	77 42 42	APS	25	15.4	6.9	47.1
01523500	Canacadea Creek near Hornell, N.Y.	42 20 05	77 41 00	APS	25	14.7	6.5	43.2
01524500	Canisteo River below Canacadea Creek at Hornell, N.Y.	42 18 50	77 39 05	APS	25	13.4	6.6	52.9
01526500	Tioga River near Erwins, N.Y.	42 07 16	77 07 46	APS	25	13.1	5.3	41.9
01528000	Fivemile Creek near Kanona, N.Y.	42 23 18	77 21 29	APS	23	14.6	6.9	48.8
01529500	Cohocton River near Campbell, N.Y.	42 15 09	77 13 01	APS	25	12.6	6.5	54.6
01529950	Chemung River at Corning, N.Y.	42 08 47	77 03 28	APS	21	13.0	6.1	46.7
01530500	Newtown Creek at Elmira, N.Y.	42 06 16	76 47 54	APS	25	14.8	7.5	51.9
01531000	Chemung River at Chemung, N.Y.	42 00 08	76 38 06	APS	25	13.5	6.1	46.2
01531500	Susquehanna River at Towanda, Pa.	41 45 55	76 26 28	APS	24	18.4	8.7	49.2
01532000	Towanda Creek near Monroeton, Pa.	41 42 25	76 29 06	APS	24	17.4	8.5	49.4
01533400	Susquehanna River at Meshoppen, Pa.	41 36 26	76 03 02	APS	20	18.3	9.3	52.3
01534000	Tunhannock Creek near Tunkhannock, Pa.	41 33 03	75 53 42	APS	24	18.0	9.0	50.1

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
APS	8	0.51768	21	0.77334	0	--	8	40.918	0	--	01520000
APS	0	--	4	0.64965	4	0.5817	0	--	0	--	01520500
APS	--	--	--	--	--	--	--	--	--	--	01521500
APS	--	--	--	--	--	--	--	--	--	--	01523500
APS	--	--	--	--	--	--	--	--	--	--	01524500
APS	--	--	--	--	--	--	--	--	--	--	01526500
APS	--	--	--	--	--	--	--	--	--	--	01528000
APS	--	--	--	--	--	--	--	--	--	--	01529500
APS	--	--	--	--	--	--	--	--	--	--	01529950
APS	--	--	--	--	--	--	--	--	--	--	01530500
APS	0	--	10	0.70425	0	--	0	--	0	--	01531000
APS	20	0.76724	22	1.24184	10	1.8933	20	63.432	10	39.9488	01531500
APS	21	0.37785	7	0.68840	0	--	7	47.414	0	--	01532000
APS	--	--	--	--	--	--	--	--	--	--	01533400
APS	17	0.41222	16	0.81488	0	--	16	50.048	0	--	01534000

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ″)	Longitude (° ′ ″)	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01534300	Lackawanna River near Forest City, Pa.	41 40 47	75 28 20	APS	25	24.4	13.	55.8
01534500	Lackawanna River at Archbald, Pa.	41 30 16	75 32 33	APS	24	24.3	15.	66.8
01536000	Lackawanna River at Old Forge, Pa.	41 21 33	75 44 41	VRS	24	20.0	11.	54.9
01536500	Susquehanna River at Wilkes-Barre, Pa.	41 15 03	75 52 52	APS	25	17.8	8.9	53.4
01537000	Toby Creek at Luzerne, Pa.	41 16 51	75 53 46	VRS	22	17.8	9.7	59.4
01538000	Wapwallopen Creek near Wapwallopen, Pa.	41 03 33	76 05 38	VRS	24	19.6	12.	61.0
01539000	Fishing Creek near Bloomsburg, Pa.	41 04 41	76 25 53	VRS	24	23.3	12.	52.9
01540500	Susquehanna River at Danville, Pa.	40 57 29	76 37 10	APS	24	17.8	9.3	54.4
01541000	West Branch Susquehanna River at Bower, Pa.	40 53 49	78 40 38	APS	24	23.8	11.	49.5
01541200	West Branch Susquehanna River near Curwensville, Pa.	40 57 41	78 31 10	APS	25	23.6	11.	48.5
01541303	West Branch Susquehanna River at Hyde, Pa.	41 00 16	78 27 25	APS	17	25.6	12.	52.6
01541500	Clearfield Creek at Dimeling, Pa.	40 58 18	78 24 22	APS	25	20.3	10.	53.8
01542000	Moshannon Creek at Osceola Mills, Pa.	40 50 58	78 16 05	APS	22	21.4	14.	64.2
01542500	West Branch Susquehanna River at Karthaus, Pa.	41 07 03	78 06 33	APS	25	22.8	12.	53.8

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitrogen record	Median total-flow total nitrogen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
APS	--	--	--	--	--	--	--	--	--	--	01534300
APS	--	--	--	--	--	--	--	--	--	--	01534500
VRS	15	0.94977	16	1.26089	0	--	15	76.124	0	--	01536000
APS	13	0.58464	16	1.05291	0	--	13	57.880	0	--	01536500
VRS	10	0.85613	11	1.31571	0	--	10	65.513	0	--	01537000
VRS	14	1.26545	16	1.51038	0	--	14	79.898	0	--	01538000
VRS	5	1.34934	6	1.92937	0	--	5	57.110	0	--	01539000
APS	37	0.74815	36	1.20108	23	2.1992	36	63.386	23	34.8940	01540500
APS	17	0.86805	16	1.75305	0	--	16	49.387	0	--	01541000
APS	12	0.78079	11	1.65867	0	--	11	48.855	0	--	01541200
APS	--	--	--	--	--	--	--	--	--	--	01541303
APS	5	0.54624	6	0.99636	0	--	5	52.787	0	--	01541500
APS	--	--	--	--	--	--	--	--	--	--	01542000
APS	--	--	--	--	--	--	--	--	--	--	01542500

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ″)	Longitude (° ′ ″)	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01542810	Waldy Run near Emporium, Pa.	41 34 44	78 17 34	APS	25	21.9	11.	49.7
01543000	Driftwood Branch Sinnemahoning Creek, Sterling Run, Pa.	41 24 48	78 11 50	APS	25	21.9	10.	47.4
01543500	Sinnemahoning Creek at Sinnemahoning, Pa.	41 19 02	78 06 12	APS	25	21.9	11.	49.4
01544000	First Fork Sinnemahoning Creek near Sinnemahoning, Pa.	41 24 06	78 01 28	APS	25	21.4	9.8	44.6
01544500	Kettle Creek at Cross Fork, Pa.	41 28 33	77 49 34	APS	25	22.5	12.	49.8
01545000	Kettle Creek near Westport, Pa.	41 19 10	77 52 27	APS	24	20.8	11.	52.5
01545500	West Branch Susquehanna River at Renovo, Pa.	41 19 28	77 45 03	APS	25	22.4	11.	53.4
01545600	Young Womans Creek near Renovo, Pa.	41 23 22	77 41 28	APS	25	21.8	12.	57.1
01546500	Spring Creek near Axemann, Pa.	40 53 23	77 47 40	VRC	24	14.1	12.	82.7
01547100	Spring Creek at Milesburg, Pa.	40 55 54	77 47 13	VRC	24	22.1	18.	85.7
01547200	Bald Eagle Creek below Spring Creek at Milesburg, Pa.	40 56 35	77 47 12	MIX	25	20.5	14.	64.8
01547500	Bald Eagle Creek at Blanchard, Pa.	41 03 06	77 36 17	VRS	24	18.2	11.	61.0
01547700	Marsh Creek at Blanchard, Pa.	41 03 34	77 36 22	VRS	25	17.9	9.5	47.5
01547950	Beech Creek at Monument, Pa.	41 06 42	77 42 09	APS	25	23.3	15.	61.6

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
APS	--	--	--	--	--	--	--	--	--	--	01542810
APS	5	0.30872	6	0.67821	0	--	5	39.922	0	--	01543000
APS	5	0.29687	8	0.67828	0	--	5	42.648	0	--	01543500
APS	5	0.38493	0	--	0	--	0	--	0	--	01544000
APS	--	--	--	--	--	--	--	--	--	--	01544500
APS	5	0.31548	6	0.75564	0	--	5	40.385	0	--	01545000
APS	--	--	--	--	--	--	--	--	--	--	01545500
APS	0	--	21	0.51221	13	1.1952	0	--	0	--	01545600
VRC	17	3.64409	16	4.08636	0	--	16	89.308	0	--	01546500
VRC	--	--	--	--	--	--	--	--	--	--	01547100
MIX	--	--	--	--	--	--	--	--	--	--	01547200
VRC	12	1.44156	16	2.12987	0	--	11	70.927	0	--	01547500
VRS	--	--	--	--	--	--	--	--	--	--	01547700
APS	5	0.29666	7	0.43680	0	--	5	56.203	0	--	01547950

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01548005	Bald Eagle Creek near Beech Creek Station, Pa.	41 04 51	77 32 59	MIX	24	19.4	11.	61.1
01548408	Wilson Creek above Sand Run near Antrim, Pa.	41 38 51	77 18 26	APS	3	16.1	6.6	40.9
01548500	Pine Creek at Cedar Run, Pa.	41 31 18	77 26 52	APS	24	18.4	9.7	49.3
01549500	Blockhouse Creek near English Center, Pa.	41 28 25	77 13 52	APS	24	20.8	10.	52.1
01549700	Pine Creek below Little Pine Creek near Waterville Pa.	41 16 25	77 19 28	APS	24	19.0	10.	49.5
01550000	Lycoming Creek near Trout Run, Pa.	41 25 06	77 01 59	APS	24	21.9	12.	54.5
01551500	West Branch Susquehanna River at Williamsport, Pa.	41 14 10	76 59 49	APS	25	21.3	10.	51.7
01552000	Loyalsock Creek at Loyalsockville, Pa.	41 19 30	76 54 46	APS	23	22.8	11.	48.4
01552500	Muncy Creek near Sonestown, Pa.	41 21 25	76 32 06	APS	24	26.4	15.	57.2
01553500	West Branch Susquehanna River at Lewisburg, Pa.	40 58 03	76 52 36	APS	24	21.4	11.	51.9
01553700	Chillisquaque Creek at Washingtonville, Pa.	41 03 42	76 40 50	VRS	16	19.3	9.6	51.0
01554000	Susquehanna River at Sunbury, Pa.	40 51 15	76 48 21	APS	25	19.0	10.	53.5
01554500	Shamokin Creek near Shamokin, Pa.	40 48 37	76 35 04	VRS	44	21.2	17.	84.2

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
MIX	--	--	--	--	--	--	--	--	--	--	01548005
APS	--	--	--	--	--	--	--	--	--	--	01548408
APS	0	--	11	0.60831	0	--	0	--	0	--	01548500
APS	--	--	--	--	--	--	--	--	--	--	01549500
APS	19	0.29336	16	0.57357	0	--	16	46.873	0	--	01549700
APS	--	--	--	--	--	--	--	--	--	--	01550000
APS	18	0.54103	17	0.94935	0	--	17	50.529	0	--	01551500
APS	0	--	15	0.77434	0	--	0	--	0	--	01552000
APS	14	0.82470	11	1.48265	0	--	11	53.725	0	--	01552500
APS	15	0.56868	18	1.04969	18	1.9751	15	56.059	15	29.6086	01553500
VRS	8	1.37194	9	2.81967	0	--	8	47.019	0	--	01553700
APS	19	0.61779	23	1.17948	9	1.9986	19	54.236	8	31.3493	01554000
VRS	--	--	--	--	--	--	--	--	--	--	01554500

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01555000	Penns Creek at Penns Creek, Pa.	40 52 00	77 02 55	VRS	25	19.1	12.	61.3
01555500	East Mahantango Creek near Dalmatia, Pa.	40 36 40	76 54 44	VRS	24	18.5	10.	54.1
01556000	Frankstown Branch Juniata River at Williamsburg, Pa.	40 27 47	78 12 00	VRS	25	17.7	9.9	55.9
01557500	Bald Eagle Creek at Tyrone, Pa.	40 41 01	78 14 02	VRS	24	22.4	13.	57.3
01558000	Little Juniata River at Spruce Creek, Pa.	40 36 45	78 08 27	VRS	25	22.8	15.	64.2
01559000	Juniata River at Huntingdon, Pa.	40 29 05	78 01 09	VRS	24	18.3	10.	63.0
01560000	Dunning Creek at Belden, Pa.	40 04 18	78 29 34	VRS	25	17.6	9.2	49.3
01562000	Raystown Branch Juniata River at Saxton, Pa.	40 12 57	78 15 56	VRS	25	15.8	8.3	50.6
01563200	Rays Branch Juniata River below Rays Dam near Huntingdon, Pa.	40 25 44	77 59 29	VRS	25	16.0	8.1	54.6
01563500	Juniata River at Mapleton Depot, Pa.	40 23 32	77 56 07	VRS	24	16.4	8.9	56.8
01564500	Aughwick Creek near Three Springs, Pa.	40 12 45	77 55 32	VRS	25	15.3	7.5	49.9
01567000	Juniata River at Newport, Pa.	40 28 42	77 07 46	VRS	25	17.0	8.9	51.1
01567500	Bixler Run near Loysville, Pa.	40 22 15	77 24 09	VRS	24	16.2	10.	62.0
01568000	Sherman Creek at Shermans Dale, Pa.	40 19 24	77 10 09	VRS	24	18.6	10.	55.1
01568500	Clark Creek near Carsonville, Pa.	40 27 37	76 45 06	VRS	25	11.4	7.8	63.0
01569800	Letort Spring Run near Carlisle, Pa.	40 14 05	77 08 23	VRC	19	25.7	23.	91.5

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
VRS	--	--	--	--	--	--	--	--	--	--	01555000
VRS	--	--	--	--	--	--	--	--	--	--	01555500
VRS	--	--	--	--	--	--	--	--	--	--	01556000
VRS	--	--	--	--	--	--	--	--	--	--	01557500
VRS	21	1.41563	16	2.15356	0	--	16	66.251	0	--	01558000
VRS	--	--	--	--	--	--	--	--	--	--	01559000
VRS	--	--	--	--	--	--	--	--	--	--	01560000
VRS	26	1.12653	26	2.03034	10	2.0249	26	50.237	10	44.8407	01562000
VRS	--	--	--	--	--	--	--	--	--	--	01563200
VRS	--	--	--	--	--	--	--	--	--	--	01563500
VRS	--	--	--	--	--	--	--	--	--	--	01564500
VRS	--	--	--	--	--	--	--	--	--	--	01567000
VRS	--	--	--	--	--	--	--	--	--	--	01567500
VRS	18	0.91261	25	1.57808	18	2.1444	18	54.645	18	30.7025	01568000
VRS	--	--	--	--	--	--	--	--	--	--	01568500
VRC	--	--	--	--	--	--	--	--	--	--	01569800

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ″)	Longitude (° ′ ″)	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01570000	Conodoguinet Creek near Hogestown, Pa.	40 15 08	77 01 17	VRS	25	16.0	9.2	59.4
01570500	Susquehanna River at Harrisburg, Pa.	40 15 17	76 53 11	APS	25	18.8	10.	57.2
01571000	Paxton Creek near Penbrook, Pa.	40 18 30	76 51 00	VRS	16	18.4	9.0	43.3
01571500	Yellow Breeches Creek near Camp Hill, Pa.	40 13 29	76 53 54	MIX	24	17.6	13	75.7
01572000	Lower Little Swatara Creek at Pine Grove, Pa.	40 32 15	76 22 40	VRS	3	23.4	12	49.3
01573000	Swatara Creek at Harper Tavern, Pa.	40 24 09	76 34 39	VRS	24	22.7	11.	51.3
01573160	Quittapahilla Creek near Bellegrove, Pa.	40 20 34	76 33 46	VRC	18	18.4	14.	80.7
01573560	Swatara Creek near Hershey, Pa.	40 17 54	76 40 05	VRS	20	20.3	11.	54.1
01573810	Branch Run, Site 2, near McSherrystown, Pa.	39 49 06	77 06 26	ML	6	18.9	2.9	15.5
01574000	West Conewago Creek near Manchester, Pa.	40 04 56	76 43 13	ML	24	15.4	6.6	44.5
01574500	Codorus Creek at Spring Grove, Pa.	39 52 43	76 51 13	PCR	25	13.5	8.8	71.7
01575000	South Branch Codorus Creek near York, Pa.	39 55 14	76 44 57	PCR	24	12.8	7.4	56.0
01575500	Codorus Creek near York, Pa.	39 56 46	76 45 20	PCR	25	12.6	8.2	64.8
01575585	Codorus Creek at Pleasureville, Pa.	40 01 07	76 41 36	PCR	5	13.0	8.6	66.3
01576000	Susquehanna River at Marietta, Pa.	40 03 16	76 31 52	APS	25	19.0	10.	55.6

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
VRS	20	2.39572	16	3.91864	0	--	16	61.208	0	--	01570000
APS	35	0.81751	37	1.37995	0	--	35	58.476	0	--	01570500
VRS	4	0.56140	4	1.14912	4	2.5132	4	48.916	4	21.8921	01571000
MIX	21	1.96200	17	2.44074	0	--	17	81.425	0	--	01571500
VRS	0	--	3	3.31089	3	4.6370	0	--	0	--	01572000
VRS	--	--	--	--	--	--	--	--	--	--	01573000
VRC	--	--	--	--	--	--	--	--	--	--	01573160
VRS	23	2.63059	22	4.89868	10	6.1447	22	56.926	10	49.2701	01573560
ML	0	--	6	5.39474	6	11.9737	0	--	0	--	01573810
ML	22	1.90797	19	2.88982	10	3.8066	19	57.144	10	51.5084	01574000
PCR	--	--	--	--	--	--	--	--	--	--	01574500
PCR	11	1.86112	16	4.01500	0	.	11	50.776	0	.	01575000
PCR	22	2.07759	21	3.24782	10	3.8851	21	64.378	10	49.7713	01575500
PCR	5	2.43058	5	3.14559	5	5.3588	5	77.269	5	45.3790	01575585
APS	14	0.89085	15	1.56490	0	--	14	55.645	0	--	01576000

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
0157608335	Little Conestoga Creek, Site 3A near Morgantown, PA.	40 08 47	75 55 37	MIX	7	10.9	7.0	64.2
01576085	Little Conestoga Creek near Churchtown, Pa.	40 08 41	75 59 20	MIX	13	15.8	9.2	60.5
01576500	Conestoga River at Lancaster, Pa.	40 03 00	76 16 39	MIX	24	16.3	10.	62.2
01576754	Conestoga River at Conestoga, Pa.	39 56 47	76 22 05	PCA	11	18.1	11.	65.2
01576788	Pequea Creek Tributary near Mt. Nebo, Pa.	39 53 27	76 18 13	PCR	6	19.7	16.	82.3
01577400	Bald Eagle Creek near Fawn Grove, Pa.	39 44 54	76 27 50	PCR	4	11.8	8.3	73.9
01578310	Susquehanna River at Conowingo, Md.	39 39 28	76 10 29	APS	25	20.2	8.9	42.1
01580000	Deer Creek at Rocks, Md.	39 37 49	76 24 13	PCR	25	17.6	13.	73.5
01581700	Winters Run near Benson, Md.	39 31 12	76 22 24	PCR	25	19.3	14.	66.8
01582000	Little Falls at Blue Mount, Md.	39 36 16	76 37 16	PCR	25	16.8	12.	76.3
01583500	Western Run at Western Run, Md.	39 30 38	76 40 37	PCR	25	14.7	10.	74.8
01583600	Beaverdam Run at Cockeysville, Md.	39 29 13	76 38 42	PCR	14	19.1	12.	68.7
01584050	Long Green Creek at Glen Arm, Md.	39 27 17	76 28 45	PCR	21	17.6	12.	73.3
01585500	Cranberry Branch near Westminster, Md.	39 35 35	76 58 05	PCR	25	12.1	8.5	60.4
01586000	North Branch Patapsco River at Cedarhurst, Md.	39 30 00	76 53 00	PCR	24	14.1	9.7	67.2

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
MIX	7	4.78261	7	4.63768	7	8.4783	7	104.938	7	56.0000	0157608335
PCA	9	6.09966	10	6.15120	10	11.3058	9	94.460	9	52.3729	01576085
PCA	0	--	10	8.42682	0	--	0	--	0	--	01576500
PCA	16	6.94711	16	9.10331	16	11.2680	16	79.883	16	64.4868	01576754
PCR	--	--	--	--	--	--	--	--	--	--	01576788
PCR	0	--	4	3.10000	4	6.0000	0	--	0	--	01577400
APS	0	--	21	1.72647	21	2.5711	0	--	0	--	01578310
PCR	--	--	--	--	--	--	--	--	--	--	01580000
PCR	--	--	--	--	--	--	--	--	--	--	01581700
PCR	--	--	--	--	--	--	--	--	--	--	01582000
PCR	4	1.82113	0	--	0	--	0	--	0	--	01583500
PCR	--	--	--	--	--	--	--	--	--	--	01583600
PCR	--	--	--	--	--	--	--	--	--	--	01584050
PCR	--	--	--	--	--	--	--	--	--	--	01585500
PCR	19	2.60515	0	--	7	3.9858	0	--	7	79.6236	01586000

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01586210	Beaver Run near Finksburg, Md.	39 29 22	76 54 12	PCR	14	15.0	11.	74.6
01586610	Morgan Run near Louisville, Md.	39 27 07	76 57 20	PCR	14	15.7	11.	75.4
01589000	Patapsco River at Hollofield, Md.	39 18 36	76 47 34	PCR	21	6.8	4.4	63.1
01589300	Gwynns Falls at Villa Nova, Md.	39 20 45	76 44 01	PCR	17	13.4	7.0	50.5
01589440	Jones Falls at Sorrento, Md.	39 23 30	76 39 42	PCR	17	15.3	10.	72.4
01589500	Sawmill Creek at Glen Burnie, Md.	39 10 12	76 37 51	CPU	13	11.6	8.1	64.6
01591000	Patuxent River near Unity, Md.	39 14 18	77 03 23	PCR	25	14.0	9.4	67.8
01591700	Hawlings River near Sandy Spring, Md.	39 10 29	77 01 22	PCR	17	13.5	8.6	62.1
01592500	Patuxent River near Laurel, Md.	39 06 56	76 52 27	PCR	25	7.8	4.1	58.3
01593500	Little Patuxent River at Guilford, Md.	39 10 04	76 51 07	PCR	24	14.3	7.8	49.5
01594000	Little Patuxent River at Savage, Md.	39 08 06	76 48 58	PCR	16	13.6	8.2	60.3
01594440	Patuxent River near Bowie, Md.	38 57 21	76 41 36	PCR	19	14.0	7.9	57.8
01594526	Western Branch at Upper Marlboro, Md.	38 48 50	76 44 50	CPD	7	11.5	5.9	49.8
01594670	Hunting Creek near Huntingtown, Md.	38 35 02	76 36 20	CPU	8	17.1	10.	64.5

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
PCR	--	--	--	--	--	--	--	--	--	--	01586210
PCR	--	--	--	--	--	--	--	--	--	--	01586610
PCR	10	0.65102	0	--	6	1.3492	0	--	6	56.7759	01589000
PCR	14	1.18587	0	--	0	--	0	--	0	--	01589300
PCA	15	1.46767	0	--	3	1.8366	0	--	3	58.5313	01589440
CPU	--	--	--	--	--	--	--	--	--	--	01589500
PCR	19	1.54894	14	2.41702	14	2.9007	14	78.817	14	64.2284	01591000
PCR	--	--	--	--	--	--	--	--	--	--	01591700
PCR	19	0.27951	0	--	7	1.0256	0	--	7	42.4057	01592500
PCR	--	--	--	--	--	--	--	--	--	--	01593500
PCR	7	1.10105	7	1.41142	7	2.2591	7	78.010	7	48.7387	01594000
PCR	24	1.41980	23	1.86725	23	2.8976	23	77.538	23	49.8077	01594440
MIX	3	0.17633	3	0.47910	3	1.0258	3	36.969	3	20.8768	01594526
CPU	0	--	3	0.11803	3	0.4721	0	--	0	--	01594670

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01594710	Killpeck Creek at Huntersville, Md.	38 28 37	76 44 08	CPD	10	15.4	10.	70.8
01594936	North Fork Sand Run near Wilson, Md.	39 15 36	79 24 36	APS	16	31.8	19.	62.3
01595000	North Branch Potomac Run at Steyer, Md.	39 18 07	79 18 26	APS	25	32.4	17.	57.3
01595200	Stony River near Mount Storm, W. Va.	39 16 10	79 15 45	APS	25	27.1	13.	51.2
01595500	North Branch Potomac River at Kitzmiller, Md.	39 23 38	79 10 55	APS	14	27.6	15.	56.8
01596500	Savage River near Barton, Md.	39 34 05	79 06 10	APS	25	20.9	10.	50.1
01597500	Savage River below Savage River Dam near Bloomington, Md.	39 30 05	79 07 25	APS	25	21.7	10.	54.4
01598500	North Branch Potomac Run at Luke, Md.	39 28 45	79 03 55	APS	25	24.2	13.	58.3
01599000	Georges Creek at Franklin, Md.	39 29 38	79 02 42	APS	25	15.4	8.6	58.3
01600000	North Branch Potomac River at Pinto, Md.	39 33 59	78 50 25	APS	28	20.3	10.	56.2
01601500	Wills Creek near Cumberland, Md.	39 40 07	78 47 18	APS	25	17.7	8.8	50.1
01603000	North Branch Potomac River near Cumberland, Md.	39 37 18	78 46 24	APS	25	19.4	10.	57.8
01604500	Patterson Creek near Headsville, W. Va.	39 26 35	78 49 20	VRS	25	10.7	4.7	52.1

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
CPD	6	1.14035	7	1.11111	7	1.6959	6	100.163	6	57.6389	01594710
APS	--	--	--	--	--	--	--	--	--	--	01594936
APS	--	--	--	--	--	--	--	--	--	--	01595000
APS	--	--	--	--	--	--	--	--	--	--	01595200
APS	--	--	--	--	--	--	--	--	--	--	01595500
APS	--	--	--	--	--	--	--	--	--	--	01596500
APS	10	0.58038	0	--	0	--	0	--	0	--	01597500
APS	--	--	--	--	--	--	--	--	--	--	01598500
APS	11	0.66639	0	--	0	--	0	--	0	--	01599000
APS	--	--	--	--	--	--	--	--	--	--	01600000
APS	16	0.71564	0	--	0	--	0	--	0	--	01601500
APS	6	0.83182	0	--	0	--	0	--	0	--	01603000
VRS	--	--	--	--	--	--	--	--	--	--	01604500

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01606500	South Branch Potomac River near Petersburg, W. Va.	38 59 28	79 10 34	VRS	25	15.4	8.1	51.5
01608000	South Fork South Branch Potomac River near Moorefield, W. Va.	39 00 44	78 57 23	VRS	25	10.6	4.9	43.8
01608500	South Branch Potomac River near Springfield, W. Va.	39 26 49	78 39 16	VRS	25	11.7	5.8	48.1
01610000	Potomac River at Paw Paw, W. Va.	39 32 20	78 27 24	VRS	25	14.1	7.3	53.0
01611500	Cacapon River near Great Cacapon, W. Va.	39 34 43	78 18 34	VRS	24	11.1	5.2	49.3
01613000	Potomac River at Hancock, Md.	39 41 49	78 10 39	VRS	25	13.4	6.4	48.3
01614500	Conococheague Creek at Fairview, Md.	39 42 57	77 49 28	VRS	24	15.6	9.3	58.8
01615000	Opequon Creek near Berryville, Va.	39 10 40	78 04 20	VRS	25	9.8	4.3	43.9
01616000	Abrams Creek near Winchester, Va.	39 10 40	78 05 10	VRC	14	16.6	12.	77.2
01617800	Marsh Run at Grimes, Md.	39 30 53	77 46 38	VRC	24	8.5	7.3	86.9
01618000	Potomac River at Shepherdstown, W. Va.	39 26 04	77 48 07	VRS	23	14.5	7.3	51.0
01619500	Antietam Creek near Sharpsburg, Md.	39 27 01	77 43 52	VRC	25	13.0	10.	78.5
01620500	North River near Stokesville, Va.	38 20 15	79 14 25	VRS	24	21.8	10.	48.6

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
VRS	--	--	--	--	--	--	--	--	--	--	01606500
VRS	--	--	--	--	--	--	--	--	--	--	01608000
VRS	--	--	--	--	--	--	--	--	--	--	01608500
VRS	16	0.48557	0	--	0	--	0	--	0	--	01610000
VRS	--	--	--	--	--	--	--	--	--	--	01611500
VRS	11	0.46463	0	--	7	1.4168	0	--	7	39.8476	01613000
VRS	11	2.52905	0	--	7	4.2884	0	--	7	57.6639	01614500
VRS	--	--	--	--	--	--	--	--	--	--	01615000
VRC	0	--	8	3.70293	0	--	0	--	0	--	01616000
VRC	--	--	--	--	--	--	--	--	--	--	01617800
VRS	19	0.79499	0	--	7	2.0118	0	--	7	47.6031	01618000
VRC	11	3.28023	0	--	7	4.7761	0	--	7	71.9339	01619500
VRS	--	--	--	--	--	--	--	--	--	--	01620500

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ″)	Longitude (° ′ ″)	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01622000	North River near Burketown, Va.	38 20 25	78 54 50	VRS	21	12.8	7.3	53.8
01624800	Christians Creek near Fisherville, Va.	38 07 42	78 59 41	VRC	24	15.0	8.8	65.1
01625000	Middle River near Grottoes, Va.	38 15 42	78 51 44	VRC	24	11.0	6.7	62.4
01626000	South River near Waynesboro, Va.	38 03 27	78 54 30	MIX	25	15.8	9.8	61.8
01626850	South River near Dooms, Va.	38 05 19	78 52 38	MIX	22	20.1	12.	64.7
01627500	South River at Harriston, Va.	38 13 07	78 50 13	MIX	25	15.9	10.	63.7
01628060	White Oak Run near Grottoes, Va.	38 15 01	78 44 57	BR	16	20.3	7.1	37.1
01629500	South Fork Shenandoah River near Luray, Va.	38 38 46	78 32 06	VRC	16	12.4	7.2	57.8
01631000	South Fork Shenandoah River at Front Royal, Va.	38 54 50	78 12 40	MIX	25	12.1	7.2	57.8
01632000	North Fork Shenandoah River at Cootes Store, Va.	38 38 13	78 51 11	VRS	24	11.8	4.8	38.1
01632900	Smith Creek near New Market, Va.	38 41 36	78 38 35	VRC	25	10.1	6.6	64.3
01633000	North Fork Shenandoah River at Mount Jackson, Va.	38 44 44	78 38 21	VRS	25	9.7	5.0	47.1
01634000	North Fork Shenandoah River near Strasburg, Va.	38 58 36	78 20 11	VRS	24	10.0	5.5	56.0
01634500	Cedar Creek near Winchester, Va.	39 04 52	78 19 47	VRS	24	11.4	5.9	47.3
01635500	Passage Creek near Buckton, Va.	38 57 29	78 16 01	VRS	24	10.3	5.0	48.9
01636500	Shenandoah River at Millville, W. Va.	39 16 55	77 47 22	MIX	25	5.7	3.3	54.7

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
VRS	--	--	--	--	--	--	--	--	--	--	01622000
VRC	--	--	--	--	--	--	--	--	--	--	01624800
VRC	--	--	--	--	--	--	--	--	--	--	01625000
MIX	--	--	--	--	--	--	--	--	--	--	01626000
MIX	--	--	--	--	--	--	--	--	--	--	01626850
MIX	--	--	--	--	--	--	--	--	--	--	01627500
BR	--	--	--	--	--	--	--	--	--	--	01628060
VRC	--	--	--	--	--	--	--	--	--	--	01629500
VRC	0	--	7	0.90323	0	--	0	--	0	--	01631000
VRS	--	--	--	--	--	--	--	--	--	--	01632000
VRC	--	--	--	--	--	--	--	--	--	--	01632900
VRS	--	--	--	--	--	--	--	--	--	--	01633000
VRC	0	--	2	1.08391	0	--	0	--	0	--	01634000
VRS	0	--	5	0.42765	0	--	0	--	0	--	01634500
VRS	--	--	--	--	--	--	--	--	--	--	01635500
MIX	--	--	--	--	--	--	--	--	--	--	01636500

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01637500	Catoctin Creek near Middletown, Md.	39 25 35	77 33 25	BR	25	14.2	8.6	57.3
01638480	Catoctin Creek at Taylorstown, Va.	39 15 16	77 34 36	PCR	25	15.5	7.3	53.7
01638500	Potomac River at Point of Rocks, Md.	39 16 25	77 32 35	VRS	25	12.6	6.8	53.2
01639000	Monocacy River at Bridgeport, Md.	39 40 43	77 14 06	ML	25	15.1	5.6	35.5
01639500	Big Pipe Creek at Bruceville, Md.	39 36 45	77 14 10	PCR	25	14.1	8.7	59.6
01640965	Hunting Creek near Foxville, Md.	39 37 10	77 28 00	BR	13	20.0	12.	62.2
01643000	Monocacy River at Jug Bridge near Frederick, Md.	39 23 13	77 21 58	MIX	25	14.5	7.3	48.7
01643020	Monocacy River at Reichs Ford Bridge near Frederick, Md.	39 23 16	77 22 40	--	--	--	--	--
01643500	Bennett Creek at Park Mills, Md.	39 17 40	77 24 30	PCR	25	14.5	8.8	62.9
01643700	Goose Creek near Middleburg, Va.	38 59 11	77 47 49	BR	25	13.1	8.0	54.5
01645000	Seneca Creek at Dawsonville, Md.	39 07 41	77 20 13	PCR	25	13.4	8.4	60.8
01646000	Difficult Run near Great Falls, Va.	38 58 33	77 14 46	PCR	24	13.2	7.3	52.0
01646500	Potomac River near Washington, D.C. Little Falls Pump Station	38 56 58	77 07 40	MIX	25	12.4	6.5	51.5
01646580	Potomac River at Chain Bridge, at Washington, D.C.	38 55 46	77 07 02	--	--	--	--	--

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
BR	3	1.10432	0	--	7	2.4799	0	--	0	--	01637500
PCR	--	--	--	--	--	--	--	--	--	--	01638480
VRS	19	0.98522	0	--	7	2.0705	0	--	7	49.9635	01638500
ML	20	1.24233	13	2.43138	16	3.3978	10	52.293	13	38.6613	01639000
PCR	11	1.94895	0	--	7	4.0857	0	--	7	50.7402	01639500
BR	--	--	--	--	--	--	--	--	--	--	01640965
MIX	14	1.48464	0	--	7	3.5949	0	--	7	41.4701	01643000
MIX	0	--	8	2.60264	15	3.6435	0	--	0	--	01643020
PCR	--	--	--	--	--	--	--	--	--	--	01643500
BR	--	--	--	--	--	--	--	--	--	--	01643700
PCR	--	--	--	--	--	--	--	--	--	--	01645000
PCR	0	.	5	0.93308	0	--	0	--	0	--	01646000
MIX	18	0.81643	0	--	7	2.0573	0	--	7	52.5335	01646500
MIX	3	0.94891	3	2.16745	3	3.0757	3	51.026	3	31.2780	01646580

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01647720	North Branch Rock Creek near Norbeck, Md .	39 06 59	77 06 09	PCR	12	14.0	7.7	53.7
01648000	Rock Creek at Sherrill Drive Washington, D.C.	38 58 21	77 02 25	PCR	25	13.3	7.4	50.2
01649500	Northeast Branch Anacostia River at Riverdale, Md.	38 57 37	76 55 34	CPD	25	14.6	6.9	41.9
01650450	Bel Pre Creek at Layhill, Md.	39 05 27	77 03 11	PCR	3	14.2	4.0	26.0
01651000	Northwest Branch Anacostia River near Hyattsville, Md.	38 57 09	76 58 00	PCR	24	12.6	5.3	43.8
01653600	Piscataway Creek at Piscataway, Md.	38 42 20	76 58 00	MIX	25	15.3	7.8	48.7
01656100	Cedar Run near Aden, Va.	38 36 58	77 33 16	ML	15	14.4	4.3	26.7
01656500	Broad Run at Buckland, Va.	38 46 50	77 40 22	PCR	14	13.2	6.5	48.9
01656650	Broad Run near Bristow, Va.	38 44 56	77 33 50	PCR	12	15.0	6.0	41.0
01656700	Occoquan River near Manassas, Va.	38 42 19	77 26 46	ML	9	17.3	4.7	29.4
01656725	Bull Run near Catharpin, Va.	38 53 21	77 34 14	ML	15	18.5	6.6	38.7
01656960	Cub Run near Bull Run, Va.	38 49 16	77 27 57	ML	14	14.0	4.2	26.1
01657415	Bull Run near Clifton, Va .	38 45 59	77 24 52	ML	12	17.4	6.1	36.3
01657655	Hooes Run near Occoquan, Va.	38 40 48	77 17 25	ML	7	15.3	8.5	43.4
01658500	South Fork Quantico Creek near Independent Hill, Va.	38 35 14	77 25 44	PCR	25	10.9	5.2	43.2
01660400	Aquia Creek near Garrisonville, Va.	38 29 25	77 26 02	PCR	24	12.8	6.4	47.2

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
PCR	--	--	--	--	--	--	--	--	--	--	01647720
PCR	--	--	--	--	--	--	--	--	--	--	01648000
CPD	--	--	--	--	--	--	--	--	--	--	01649500
PCR	--	--	--	--	--	--	--	--	--	--	01650450
PCR	--	--	--	--	--	--	--	--	--	--	01651000
MIX	--	--	--	--	--	--	--	--	--	--	01653600
ML	--	--	--	--	--	--	--	--	--	--	01656100
PCR	--	--	--	--	--	--	--	--	--	--	01656500
PCR	--	--	--	--	--	--	--	--	--	--	01656650
ML	--	--	--	--	--	--	--	--	--	--	01656700
ML	--	--	--	--	--	--	--	--	--	--	01656725
ML	--	--	--	--	--	--	--	--	--	--	01656960
ML	--	--	--	--	--	--	--	--	--	--	01657415
ML	--	--	--	--	--	--	--	--	--	--	01657655
PCR	--	--	--	--	--	--	--	--	--	--	01658500
PCR	--	--	--	--	--	--	--	--	--	--	01660400

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01660920	Zekiah Swamp Run near Newton, Md.	38 29 26	76 55 37	CPU	13	14.1	8.0	53.3
01661050	St. Clement Creek near Clements, Md.	38 20 00	76 43 31	CPU	24	12.8	7.0	57.1
01661500	St. Marys River at Great Mills, Md.	38 14 36	76 30 13	CPU	24	13.0	6.3	50.4
01662800	Battle Run near Laurel Mills, Va.	38 39 20	78 04 27	BR	23	12.1	7.7	62.6
01664000	Rappahannock River at Remington, Va.	38 31 50	77 48 50	BR	24	13.8	8.0	51.7
01665000	Mount Run near Culpeper, Va.	38 28 50	78 03 10	PCR	24	14.4	8.3	56.9
01665500	Rapidan River near Ruckersville, Va.	38 16 50	78 20 25	BR	23	18.2	11.	60.2
01666500	Robinson River near Locust Dale, Va.	38 19 30	78 05 45	PCR	24	16.3	9.6	58.1
01667500	Rapidan River near Culpeper, Va.	38 21 01	77 58 31	MIX	24	15.3	8.5	54.7
01668000	Rappahannock River near Fredericksburg, Va.	38 19 20	77 31 05	PCR	25	13.8	7.1	47.7
01669000	Piscataway Creek near Tappahannock, Va.	37 52 37	76 54 03	CPD	24	14.2	10.	73.1
01669520	Dragon Swamp at Mascot, Va.	37 38 01	76 41 48	CPU	15	14.6	9.3	65.9
01670400	North Anna River near Partlow, Va.	38 00 46	77 42 05	PCR	17	11.5	3.9	37.3
01671020	North Anna River at Hart Corner near Doswell, Va.	37 51 00	77 25 41	PCR	16	11.1	4.8	43.3
01671100	Little River near Doswell, Va.	37 52 21	77 30 48	PCR	24	12.2	6.1	51.9
01672500	South Anna River near Ashland, Va.	37 47 48	77 32 57	PCR	25	12.3	6.1	48.3
01673000	Pamunkey River near Hanover, Va.	37 46 03	77 19 57	PCR	25	12.5	6.2	46.1

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
CPU	--	--	--	--	--	--	--	--	--	--	01660920
CPU	--	--	--	--	--	--	--	--	--	--	01661050
CPU	--	--	--	--	--	--	--	--	--	--	01661500
BR	--	--	--	--	--	--	--	--	--	--	01662800
BR	0	--	9	0.64858	0	--	0	--	0	--	01664000
PCR	--	--	--	--	--	--	--	--	--	--	01665000
BR	--	--	--	--	--	--	--	--	--	--	01665500
PCR	--	--	--	--	--	--	--	--	--	--	01666500
MIX	--	--	--	--	--	--	--	--	--	--	01667500
MIX	0	--	6	0.49083	8	1.2637	0	--	0	--	01668000
CPD	--	--	--	--	--	--	--	--	--	--	01669000
CPU	--	--	--	--	--	--	--	--	--	--	01669520
PCR	--	--	--	--	--	--	--	--	--	--	01670400
PCR	--	--	--	--	--	--	--	--	--	--	01671020
PCR	--	--	--	--	--	--	--	--	--	--	01671100
PCR	--	--	--	--	--	--	--	--	--	--	01672500
PCR	0	--	19	0.18667	17	0.7937	0	--	0	--	01673000

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ″)	Longitude (° ′ ″)	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
01673550	Totopotomoy Creek near Studley, Va.	37 39 45	77 15 29	CPU	19	12.0	8.6	65.9
01673800	Po River near Spotsylvania, Va.	38 10 17	77 35 42	PCR	24	11.1	5.3	43.6
01674000	Mattaponi River near Bowling Green, Va.	38 03 42	77 23 10	PCR	24	11.8	5.9	49.7
01674500	Mattaponi River near Beulahville, Va.	37 53 16	77 09 48	MIX	23	12.6	7.9	60.0
01677000	Ware Creek near Toano, Va.	37 26 17	76 47 12	MIX	15	13.1	8.7	65.9
02011400	Jackson River near Bacova, Va.	38 02 32	79 52 54	VRC	22	15.5	8.5	55.8
02011460	Back Creek near Sunrise, Va.	38 14 43	79 46 08	VRS	22	21.4	10.	46.4
02011500	Back Creek near Mountain Grove, Va.	38 04 10	79 53 50	VRS	25	18.8	8.9	46.1
02011800	Jackson River below Gathright Dam near Hot Springs, Va.	37 56 54	79 56 58	VRS	23	18.8	10.	57.3
02012500	Jackson River at Falling Spring, Va.	37 52 36	79 58 39	VRS	12	16.6	8.7	51.3
02013000	Dunlap Creek near Covington, Va.	37 48 10	80 02 50	VRS	25	13.9	6.6	47.6
02013100	Jackson River below Dunlap Creek at Covington, Va.	37 47 19	80 00 03	VRS	22	16.7	9.4	56.6
02014000	Potts Creek near Covington, Va.	37 43 44	80 02 33	VRC	25	15.8	9.0	54.2
02015700	Bullpasture River at Williamsville, Va.	38 11 43	79 34 14	VRC	24	19.4	10.	58.3

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
CPU	--	--	--	--	--	--	--	--	--	--	01673550
PCR	--	--	--	--	--	--	--	--	--	--	01673800
PCR	--	--	--	--	--	--	--	--	--	--	01674000
MIX	0	--	3	0.06953	3	0.2980	0	--	0	--	01674500
MIX	--	--	--	--	--	--	--	--	--	--	01677000
VRC	--	--	--	--	--	--	--	--	--	--	02011400
VRS	--	--	--	--	--	--	--	--	--	--	02011460
VRS	--	--	--	--	--	--	--	--	--	--	02011500
VRS	--	--	--	--	--	--	--	--	--	--	02011800
VRC	11	0.17191	11	0.34261	0	--	8	35.265	0	--	02012500
VRC	--	--	--	--	--	--	--	--	--	--	02013000
VRC	0	--	4	0.23831	0	--	0	--	0	--	02013100
VRC	--	--	--	--	--	--	--	--	--	--	02014000
VRC	--	--	--	--	--	--	--	--	--	--	02015700

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
02016000	Cowpasture River near Clifton Forge, Va.	37 47 30	79 45 35	VRS	25	16.0	7.6	45.4
02016500	James River at Lick Run, Va.	37 46 25	79 47 05	VRS	25	16.6	8.2	49.3
02017500	Johns Creek at New Castle, Va.	37 30 22	80 06 25	VRS	25	17.1	9.2	51.5
02018000	Craig Creek at Parr, Va.	37 39 57	79 54 42	VRS	25	16.6	7.8	50.6
02018500	Catawba Creek near Catawba, Va.	37 28 05	80 00 20	VRC	25	14.6	7.5	50.2
02019500	James River at Buchanan, Va.	37 31 50	79 40 45	VRS	25	16.5	8.5	50.9
02020500	Calfpasture River above Mill Creek at Goshen, Va.	37 59 16	79 29 38	VRS	25	16.2	6.5	40.2
02021500	Maury River at Rockbridge Baths, Va.	37 54 26	79 25 20	VRS	25	16.3	6.9	41.7
02024000	Maury River near Buena Vista, Va.	37 45 45	79 23 30	VRC	25	14.3	7.5	52.5
02025500	James River at Holcomb Rock, Va.	37 30 04	79 15 46	MIX	25	15.5	8.2	50.1
02026000	James River at Bent Creek, Va.	37 32 10	78 49 47	MIX	25	15.9	8.3	53.1
02027000	Tye River near Lovingston, Va.	37 42 55	78 58 55	BR	24	23.0	14.	62.8
02027500	Piney River at Piney River, Va.	37 42 08	79 01 40	BR	24	27.0	15.	61.7
02027800	Buffalo River near Tye River, Va.	37 36 20	78 55 25	PCR	24	14.9	10.	66.0
02028500	Rockfish River near Greenfield, Va.	37 52 10	78 49 25	BR	24	21.0	12.	61.2
02029000	James River at Scottsville, Va.	37 47 50	78 29 30	MIX	25	15.6	8.1	53.9

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
VRC	0	--	3	0.25108	0	--	0	--	0	--	02016000
VRS	--	--	--	--	--	--	--	--	--	--	02016500
VRC	0	--	3	0.17169	0	--	0	--	0	--	02017500
VRS	--	--	--	--	--	--	--	--	--	--	02018000
VRC	--	--	--	--	--	--	--	--	--	--	02018500
VRC	11	0.15218	8	0.38456	0	--	8	45.514	0	--	02019500
VRS	--	--	--	--	--	--	--	--	--	--	02020500
VRS	0	--	4	0.18904	0	--	0	--	0	--	02021500
VRC	--	--	--	--	--	--	--	--	--	--	02024000
MIX	--	--	--	--	--	--	--	--	--	--	02025500
VRC	0	--	6	0.43974	0	--	0	--	0	--	02026000
BR	--	--	--	--	--	--	--	--	--	--	02027000
BR	--	--	--	--	--	--	--	--	--	--	02027500
PCR	--	--	--	--	--	--	--	--	--	--	02027800
BR	--	--	--	--	--	--	--	--	--	--	02028500
MIX	--	--	--	--	--	--	--	--	--	--	02029000

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
02030000	Hardware River below Briery Run near Scottsville, Va.	37 48 45	78 27 20	PCR	24	14.5	9.3	60.9
02030500	Slate River near Arvonia, Va.	37 42 10	78 22 40	PCR	24	13.3	7.0	54.0
02031000	Mechums River near White Hall, Va.	38 06 09	78 35 35	BR	16	15.0	9.7	58.3
02032250	Moormans River near Free Union, Va.	38 08 26	78 33 22	BR	16	18.5	9.0	48.3
02032400	Buck Mountain Creek near Free Union, Va.	38 09 16	78 32 22	BR	17	16.1	9.0	52.1
02032515	South Fork Rivanna River near Charlottesville, Va.	38 06 06	78 27 39	BR	17	15.0	7.4	50.2
02034000	Rivanna River at Palmyra, Va.	37 51 28	78 15 58	PCR	25	14.7	7.6	47.6
02035000	James River at Cartersville, Va.	37 40 15	78 05 10	MIX	25	14.9	8.0	52.9
02036500	Fine Creek at Fine Creek Mills, Va.	37 35 52	77 49 12	PCR	24	11.2	6.7	55.0
02037500	James River near Richmond, Va.	37 33 47	77 32 50	MIX	24	13.7	6.8	54.2
02038850	Holiday Creek near Andersonville, Va.	37 24 55	78 38 10	PCR	25	12.2	7.5	59.6
02039000	Buffalo Creek near Hampden Sydney, Va.	37 15 25	78 29 12	PCR	25	13.0	7.8	60.5
02039500	Appomattox River at Farmville, Va	37 18 25	78 23 20	PCR	25	12.7	6.6	51.4
02040000	Appomattox River at Mattoax, Va.	37 25 17	77 51 33	PCR	25	12.7	6.4	50.3

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
PCR	--	--	--	--	--	--	--	--	--	--	02030000
PCR	--	--	--	--	--	--	--	--	--	--	02030500
BR	--	--	--	--	--	--	--	--	--	--	02031000
BR	--	--	--	--	--	--	--	--	--	--	02032250
BR	--	--	--	--	--	--	--	--	--	--	02032400
BR	--	--	--	--	--	--	--	--	--	--	02032515
PCR	--	--	--	--	--	--	--	--	--	--	02034000
MIX	27	0.21069	29	0.39766	29	1.0467	25	51.030	25	17.1875	02035000
PCR	--	--	--	--	--	--	--	--	--	--	02036500
MIX	0	--	4	0.32176	0	--	0	--	0	--	02037500
PCR	--	--	--	--	--	--	--	--	--	--	02038850
PCR	--	--	--	--	--	--	--	--	--	--	02039000
PCR	--	--	--	--	--	--	--	--	--	--	02039500
PCR	--	--	--	--	--	--	--	--	--	--	02040000

Appendix. *Streamflow, base-flow, and nitrogen-yield data for basins within the Chesapeake Bay watershed, 1972-96*--Continued

Station identification no.	Station name	Latitude (° ′ ")	Longitude (° ′ ")	Dominant HGMR used for analysis of ground-water discharge	Years of record used	Total flow: median annual stream-flow (inches)	Base flow: median annual stream-flow (inches)	Ratio of base flow to total flow (base-flow index)
02041000	Deep Creek near Mannboro, Va.	37 16 59	77 52 12	PCR	25	11.4	5.8	49.0
02041650	Appomattox River at Matoaca, Va.	37 13 30	77 28 32	PCR	25	13.5	5.9	45.9
02042500	Chickahominy River near Providence Forge, Va.	37 26 30	77 02 55	MIX	25	13.1	7.7	56.3

Dominant HGMR used for analysis of base-flow loads	Years of base-flow nitrate record	Median base-flow nitrate yield for station	Years of total-flow nitrate record	Median total-flow nitrate yield for station	Years of total-flow nitro-gen record	Median total-flow total nitro-gen yield for station	Years of base-flow nitrate index record	Percent of base-flow nitrate yield to total-flow nitrate yield (BFNI)	Years of base-flow total-nitrogen index record	Percent of base-flow nitrate yield to total-flow total-nitrogen yield (BFTI)	Station identification no.
PCR	--	--	--	--	--	--	--	--	--	--	02041000
PCR	12	0.09544	12	0.17128	12	0.4523	12	48.008	12	18.3424	02041650
MIX	--	--	--	--	--	--	--	--	--	--	02042500

Ground-Water Discharge and Base-Flow Nitrate Loads of Nontidal Streams, and Their Relation to a Hydrogeomorphic Classification of the Chesapeake Bay Watershed, Middle Atlantic Coast / Water-Resources Investigations Report 98-4059

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