Relations of Water Quality to Streamflow, Season, and Land Use for Four Tributaries to the Toms River, Ocean County, New Jersey, 1994-99

By Ronald J. Baker and Kathryn Hunchak-Kariouk

In cooperation with the
New Jersey Department of Environmental Protection

Scientific Investigations Report 2005-5274

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

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

U.S. Geological Survey, Reston, Virginia: 2006

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS--the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Contents

Figures

Tables

CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY AND HYDROLOGIC UNITS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft.)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
gallon (gal)	0.003785	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram

Water-quality abbreviations

mg/L- milligrams per liter

MPN/100 mL- most probable number of bacteria per 100 milliliters

μS/cm- microsiemens per centimeter at 25 degrees Celsius

$(lb/d)/mi^2$ - pounds per day per square mile

$(MPN/d)/mi^2$- most probable number per day per square mile

Temperature given in degrees Fahrenheit (º F) and Celsius (º C) may be converted to degrees Celsius (º C) and Kelvin (º K) by the following equations:

$$^\circ C = 5/9 \times (^\circ F-32)$$

$$^\circ F = 9/5 \times ^\circ C +32)$$

$$^\circ K = 273.16 + ^\circ C$$

Relations of Water Quality to Streamflow, Season, and Land Use for Four Tributaries to the Toms River, Ocean County, New Jersey, 1994-99

By Ronald J. Baker and Kathryn Hunchak-Kariouk

Abstract

The effects of nonpoint-source contamination on the water quality of four tributaries to the Toms River in Ocean County, New Jersey, have been investigated in a 5-year study by the U.S. Geological Survey (USGS), in cooperation with the New Jersey Department of Environmental Protection (NJDEP). The purpose of the study was to relate the extent of land development to loads of nutrients and other contaminants to these streams, and ultimately to Barnegat Bay. Volumetric streamflow (discharge) was measured at 6 monitoring sites during 37 stormflow and base-flow sampling events over a 5-year period (May 1994-September 1999). Concentrations and yields (area-normalized instantaneous load values) of nitrogen and phosphorus species, total suspended solids, and fecal coliform bacteria were quantified, and pH, dissolved oxygen, and stream stage were monitored during base-flow conditions and storms. Sufficient data were collected to allow for a statistical evaluation of differences in water quality among streams in subbasins with high, medium, and low levels of land development.

Long Swamp Creek, in a highly developed subbasin (64.2 percent developed); Wrangle Brook, in a moderately developed subbasin (34.5 percent); Davenport Branch, in a slightly developed subbasin (22.8 percent); and Jakes Branch, in an undeveloped subbasin (0 percent) are the subbasins selected for this study. No point-source discharges are known to be present on these streams. Water samples were collected and analyzed by the NJDEP, and discharge measurements and data analysis were conducted by the USGS.

Total nitrogen concentrations were lower in Davenport Branch than in Long Swamp Creek and Wrangle Brook during base flow and stormflow. Concentrations of total nitrogen and nitrate were highest in Wrangle Brook (as high as 3.0 mg/L and 1.6 mg/L, respectively) as a result of high concentrations of nitrate in samples collected during base flow; nitrate loading from ground-water discharge is much higher in Wrangle Brook than in any of the other streams, possibly as a result of an experimental wastewater-(secondary effluent) disposal site that was in operation during the 1980's. Ammonia concentrations were higher in samples from Long Swamp Creek than in those from the other two monitoring sites under all flow conditions, and ammonia yields were higher during stormflow than base flow at all monitoring sites.

Concentrations and yields of fecal coliform bacteria and total suspended solids were higher during stormflow than during base flow at all monitoring sites. Concentrations and yields were significantly higher in Long Swamp Creek, a highly developed subbasin and Wrangle Brook, a moderately developed subbasin than in Davenport Branch, a slightly developed subbasin. Concentrations and yields of phosphate species, which also are strongly related to stormflow, were higher during stormflow in Long Swamp Creek than in the other subbasins.

Base-flow separation techniques were used on hydrographs generated for storms to distinguish the fraction of discharge and constituent loading attributable to storm runoff (overland flow) from the fraction contributed by ground-water discharge. Precipitation records were used to determine the total annual volumes of ground-water discharge and runoff at each monitoring site. These volumes were used in conjunction with water-quality data to calculate total annual loads of each constituent at each monitoring site, separated into ground-water discharge and runoff fractions. It was determined that loads of ammonia, nitrate, organic nitrogen, total nitrogen, and orthophosphate in ground-water discharge were significantly higher in the moderately developed Wrangle Brook subbasin than in the highly developed Long Swamp Creek subbasin, and that no relation was apparent between the percent of land development and constituent loads from ground-water discharge. The loading of each constituent contributed by ground-water discharge is specific to each subbasin and is attributable to factors other than current levels of land development, such as hydrogeology and past land-use practices. In contrast, loads of total nitrogen, organic nitrogen, nitrate, ammonia, fecal coliform bacteria, and orthophosphate contributed by stormwater correlated significantly with the percentage of land development. These relations were used to extrapolate the increases in loads of these constituents from overland flow as

a function of future land development in the Toms River and Barnegat Bay drainage basins.

Introduction

The Toms River in southeastern New Jersey drains nearly one-half of the 450-mi^2 area that contributes drainage to Barnegat Bay, a 75-mi^2, environmentally sensitive estuary (fig. 1). Contributions of freshwater and water-quality constituents from the Toms River Basin can have a substantial effect on the ecological, commercial, and recreational value and viability of Barnegat Bay. The Barnegat Bay estuary (fig. 2) is classified as moderately eutrophic (Seitzinger and Pilling, 1992). Excessive nutrient loading can contribute to toxic or nuisance algal blooms and degrade estuarine water quality (Kennish, 1997). Turbidity in the water column resulting from phytoplankton production can reduce light penetration and degrade submerged aquatic vegetation and associated habitat functions. Despite reductions in point-source discharges mandated by environmental legislation and improved domestic wastewater treatment, concentrations of nutrients, sediment, and bacteria in the bay have increased in recent decades (New Jersey Department of Environmental Protection and Energy, 1993a).

Nonpoint source (NPS) discharges within the subbasin probably are partly responsible for altering the water quality of Barnegat Bay because there are no major point-source discharges to the Toms River and its tributaries (New Jersey Department of Environmental Protection and Energy, 1993b). Examples of NPS discharges include runoff from commercial and residential areas, and leachate from septic systems and underground storage tanks. Examples of point-source discharges are permitted discharges from municipal and industrial wastewater-treatment facilities. Constituents from NPS's are transported to streams by ground water and by storm runoff from diffuse areas or from areas where sources of constituents are not easily identified and quantified. NPS constituent loads in a surface-water body are greatly affected by land use in a subbasin. The amount of storm runoff is affected by the amount of impervious surface in the drainage basin, which in turn is proportional to the amount of development.

Development is increasing in the Barnegat Bay drainage basin, particularly in the northeastern part (Lathrop and Bognar, 2001). Since the 1970's, the Toms River drainage basin has experienced rapid growth in population and urban development (Rogers, Golden, and Halpern, Inc., 1990). The lower one-third of the Toms River drainage basin (69 mi^2) is more developed (that is, contains more residential, commercial, and industrial land use) than the upper two-thirds and has the greatest potential for contributing NPS water-quality characteristics to the Toms River, the Toms River embayment, and Barnegat Bay. Contributions of constituents are quantified in terms of loads (mass per time) and yields (loads normalized to the area of contributing drainage in pounds per day per square mile), which are calculated from water-quality and streamflow data. Concentrations of water-quality constituents and streamflow measurements made since 1963 at the U.S. Geological Survey (USGS) water-quality and streamflow-gaging station on the Toms River near the community of Toms River, New Jersey, (USGS station number 01408500) represent the water quality in just the upper two-thirds of the basin (123 mi^2). Until the current study (1994-99), the lower third of the Toms River drainage basin was unmonitored, and NPS constituent loadings to the Toms River from the basin downstream from station 01408500 were unknown.

As part of NPS- and stormwater-management strategies for the Barnegat Bay drainage basin, the New Jersey Department of Environmental Protection (NJDEP) plans to implement best management practices (BMP's) within the Toms River drainage basin (New Jersey Department of Environmental Protection, 1999). BMP's are practices or a combination of practices that are determined by the State to be practical and effective in achieving and maintaining NPS loads at levels compatible with water-quality goals (Lynch and Corbett, 1990). The ability to project the degree to which further land development would increase NPS contaminant loading to a receiving water is essential in formulating effective BMPs. The Ocean County Soil Conservation District implemented several BMP's in the Toms River drainage basin in 1996.

From 1994 to 1999, the USGS, in cooperation with the NJDEP, conducted a study to determine the relation between land development and the quality of water in several tributaries to the Toms River and to estimate annual yields of selected nutrients to the Toms River embayment and Barnegat Bay. The objectives of this study were to (1) identify various subbasins of the Toms River Basin that have different levels of development and select appropriate streamgaging and water-quality sampling locations in each; (2) collect hydrological and water-quality data from each sampling location during base flow and during stormflow over five years; (3) statistically analyze the variation of each water-quality characteristic as a function of land development, season (growing and nongrowing), and hydrologic condition (base flow or stormflow); and (4) construct a simple model relating land development to contaminant loads and apply the model to selected subbasins draining into the Barnegat Bay.

Purpose and Scope

This report describes the results of a study to determine the relation between land development and the water quality of four tributaries to the Toms River--Long Swamp Creek, Wrangle Brook, Davenport Branch, and Jakes Branch--and presents estimates of annual yields of selected water-quality constituents for the Toms River embayment and Barnegat Bay. The constituent concentration and yield values presented in this report are based on water-quality and streamflow data collected at eight monitoring sites during base-flow and stormflow conditions during 1994-99. Concentrations and yields

Base from U.S. Geological Survey
digital line graph files, 1:24,000

Figure 1. Locations of water-quality-monitoring sites and subbasins in the Toms River drainage basin, New Jersey, 1995.

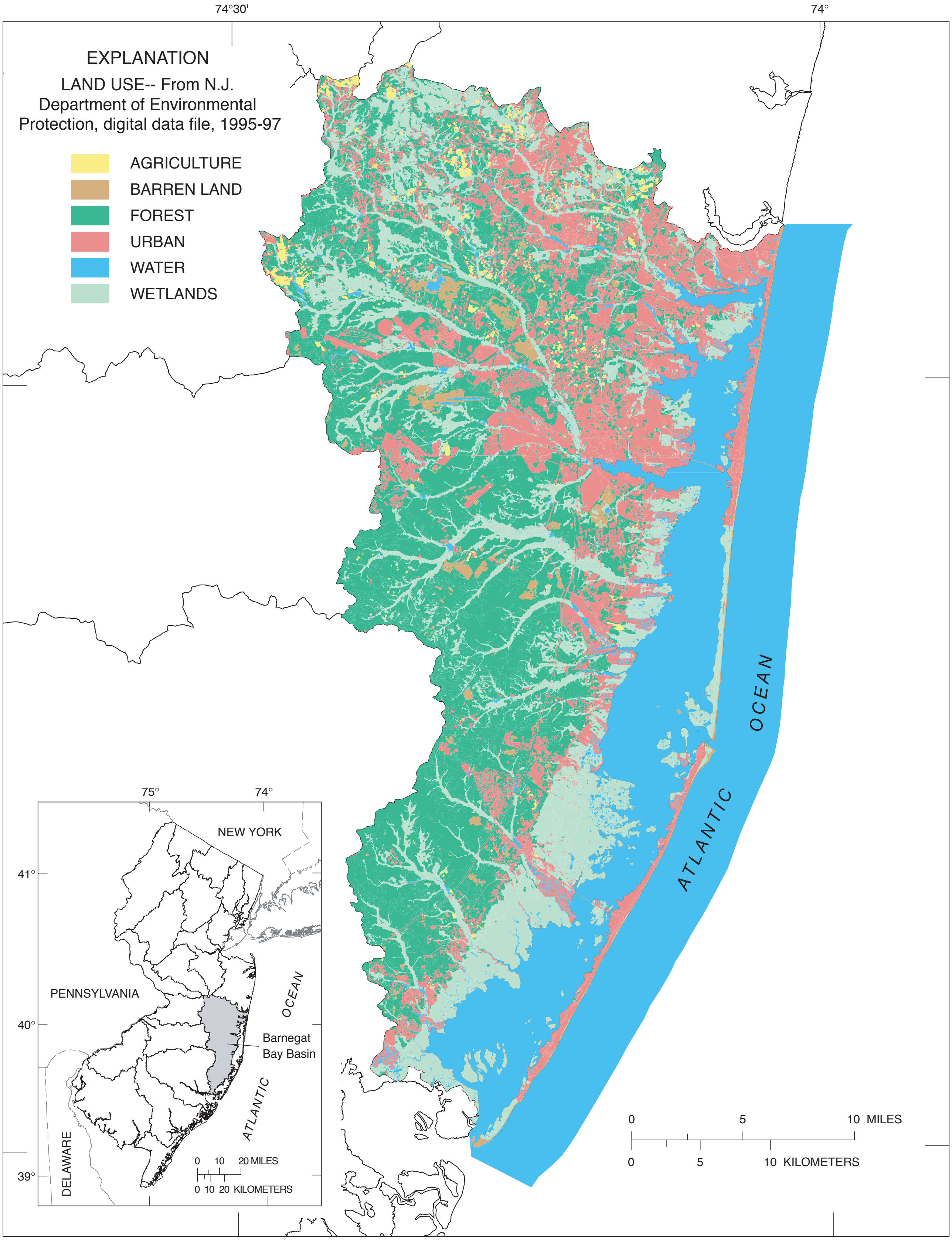


Figure 2. Land use in the Barnegat Bay Basin, Ocean County, New Jersey, 1995-97.

during periods of base flow and stormflow in the growing and nongrowing seasons are presented for monitoring sites on Long Swamp Creek, Wrangle Brook, and Davenport Branch; only concentrations during the growing season are presented for the monitoring site on Jakes Branch. The water-quality constituents for which concentrations and yields are reported are total nitrogen, ammonia, nitrate, organic nitrogen, orthophosphate, total suspended solids, and fecal coliform bacteria. Distributions of constituent concentrations and yields during base flow and stormflow in the growing and nongrowing seasons are shown in boxplots.

Previous Studies

The USGS, in cooperation with State and local agencies, has been conducting comprehensive water-quality studies in New Jersey since the early 1960's. Many of these studies have investigated NPS contributions from agricultural areas to ground water, but few have investigated NPS contributions from urban areas to surface water in the Coastal Plain (fig. 1). Two USGS NPS studies were conducted in the Coastal Plain of New Jersey, one in the Mill Creek Basin in Willingboro, Burlington County (Schornick and Fishel, 1980), and one in the Great Egg Harbor River Basin in Winslow Township, Camden County (Fusillo, 1981). Various studies investigated NPS contributions in the Coastal Plain outside New Jersey, but these focused primarily on contributions to ground water from agricultural areas.

Schornick and Fishel (1980) report that runoff from the nonresidential part of the study area in the upstream part of the drainage basin had a more substantial effect on the surface-water quality than did runoff from the residential area; the nonresidential area contributed more nutrients than the residential area. Fusillo (1981) reports that samples collected at surface-water monitoring sites in urban areas had higher values of specific conductance and pH than did those from monitoring sites in less developed areas. One USGS NPS study was conducted in the Musconetcong, Rockaway, and Whippany River Basins in northern New Jersey (Price and Schaefer, 1995). This study compared the estimated loads of selected constituents from permitted and nonpermitted (NPS and runoff) sources.

The water quality of the upper Oyster Creek was investigated by Fusillo and others (1980) and the water quality of McDonalds Branch by Johnsson and Barringer (1993) and Lord and others (1990). Both streams are located south of the Toms River drainage basin in Ocean and Burlington Counties. Zampella (1994) compared the surface-water quality of 14 New Jersey streams in the Pinelands Protection and Preservation Area along a drainage basin disturbance gradient and reports that pH, specific conductance, and nutrient concentrations increased with increasing intensity of land use.

The levels of volatile organic compounds (VOCs) and selected pesticides in samples from streams within and in the vicinity of the Toms River Basin were measured as part of the Ambient Stream Monitoring Network, a cooperative program of the USGS and the NJDEP, and the Long Island-New Jersey study unit of the USGS National Water Quality Assessment (NAWQA). None of 29 VOCs analyzed for were detected in samples collected from the Toms River and Shannoc Brook, a tributary to the Toms River (DeLuca and others, 1999), and only 1 of 34 VOCs analyzed for was detected in samples collected from the South Branch Metedeconk River, just north of the Toms River drainage basin (DeLuca and others, 2000). In other studies, various pesticides were detected at low to sub-parts per billion concentrations in samples collected from the Toms River, Wrangle Brook, Long Swamp Creek, Shannoc Brook, and South Branch Metedeconk River (Reed and others, 1998; DeLuca and others, 1999 and 2000; and Reiser and O'Brien, 1999).

Hunchak-Kariouk (1999) reports a preliminary analysis of water-quality and streamflow data collected during 1994-95 for Long Swamp Creek, Wrangle Brook, and Davenport Branch. A description of the study area, land uses in the subbasins, and the methods of sample collection and analysis with non-parametric statistical methods are presented. Hunchak-Kariouk (1999) also presents water-quality data for Long Swamp Creek, Wrangle Brook, and Davenport Branch in addition to water-quality data collected by Federal, State, and local agencies during 1960-98 for other streams draining into the Barnegat Bay. The data were later used by Hunchak-Kariouk and Nicholson (2001) to estimate nutrient loads to the Barnegat Bay.

Study Area

The study area lies entirely within the Atlantic Coastal Plain and includes the drainage basins of four tributaries to the Toms River--Long Swamp Creek, Wrangle Brook, Davenport Branch, and Jakes Branch--in the lower third of the Toms River drainage basin in Ocean County, New Jersey (figs. 1 and 2). Monitoring sites were established on the four streams; each drainage area has a different predominant land use. The study area and monitoring sites are described in detail in Hunchak-Kariouk (1999). The area to the south and west of the main stem of the Toms River is within the New Jersey Pinelands Protection and Preservation Area. Cranberry bogs, impoundments, and swamps are located throughout the study area; the predominant land use is forest plus wetlands (fig.1; table 1). Conversion of forested land to residential and commercial areas has increased since the early 1970's and is expected to increase even more in the future (New Jersey Department of Environmental Protection and Energy, 1993a). Land-use and land-cover digital data indicate that residential and commercial plus industrial uses have increased slightly over the last 10 years and account for slightly less than 25 percent of the development in the study area (U.S. Geological Survey, 1986 and Lathrop, 2000). Land use in each subbasin was classified by evaluating the percentage of land in each land-use category

Table 1. Land use in the Toms River drainage basin and selected subbasins, N.J., 1995-97

[USGS, U.S. Geological Survey; NJDEP, New Jersey Department of Environmental Protection; --, no station number or identifier]

U.S. Geological Survey station number (fig.1)	Station name	USGS station-name identifier (fig.1)	NJDEP station-name identifier	Drainage area, in square miles	Land use, in percent of drainage area[1]: Developed: Residential	Developed: Commercial plus Industrial[2]	Developed: Miscellaneous[3]	Developed: Total[4]	Undeveloped: Forests plus wetlands
01408500	Toms River near Toms River, N.J.	--	--	123	11.3	6.3	9.4	27	73
01408590	Wrangle Brook at Bimini Drive near South Toms River, N.J.	WB3	22	13.6	16.2	2	17.9	36.1	63.9
01408600	Wrangle Brook near Toms River, N.J.	WB1	4	19.5	27	4	6.3	37.4	62.6
01408620	Davenport Branch near Dover Forge, N.J.	DB	6	7.41	17.5	4.5	1.2	23.1	76.9
01408640	Wrangle Brook near South Toms River, N.J.	WB2	3	34	25.4	5.2	4.4	35	65
01408705	Jakes Branch near South Toms River, N.J.	JB	7	1.45	0	0	0	0	100
01408725	Long Swamp Creek near Toms River, N.J.	LSC1	2	3.54	37.2	20.1	7.1	64.4	35.6
01408728	Long Swamp Creek at Toms River, N.J.	LSC2	1	6.53	48.9	18.1	5.3	72.4	27.6
--	Toms River drainage basin at mouth	--	--	192	16.6	7.8	9.1	33.5	66.5
--	Toms River drainage basin downstream from 01408500	--	--	69	26.8	9.6	9.7	46.2	53.8

[1]Calculated from U.S. Geological Survey digital data (U.S. Geological Survey, 1997).

[2]Includes commercial and services, transportation, communications, utilities, and recreational land uses.

[3]Includes agricultural land, barren land, and water bodies (river channels, lakes, ponds, reservoirs, bays, estuaries, and cranberry bogs).

[4]Sum of residential, commercial plus industrial, and miscellaneous land-use percentages.

and the physical characteristics of the residential and commercial plus industrial land uses (table 1).

Site descriptions and identifiers, and a summary of the land-use distributions in the basins upstream from each monitoring site are listed in table 1. The Long Swamp Creek drains an area of 6.71 mi^2 and was not given a designated use classification under the surface-water quality standards for New Jersey (New Jersey Department of Environmental Protection, 1998). The entire basin is developed; the greatest amount of residential and commercial development is in the lower half of the basin (fig. 1). Two monitoring sites are located on Long Swamp Creek--LSC1 near Toms River and LSC2 at Toms River. Water sampling at monitoring site LSC1 was discontinued after the first year of the study[1]. Land in the basin upstream from monitoring site LSC2 is classified as highly developed; greater than 50 percent of the land in the contributing drainage area is developed. See "Methods of Study" section for an expanded description of land-use classification. Surface runoff volumes during precipitation at monitoring site LSC2 (a highly developed area) probably are greater than they were before the subbasin was extensively developed because the large area of imperious surface reduces infiltration and increases runoff. The Wrangle Brook drains an area of 34.4 mi^2 and is designated as FW2-NT for most of its length. The

[1] All data from site LSC1 are reported and discussed in Hunchak-Kariouk (1999).

designation FW2 is the general surface-water classification[2] applied to those freshwater bodies that are not designated as FW1 or PL; NT represents non-trout waters. Most development is in the downstream third of the basin (fig. 2); a State fish and wildlife management area occupies almost half of the undeveloped area in the upper third of the Wrangle Brook basin. Three monitoring sites are located on Wrangle Brook, WB1 and WB3 near Toms River, and WB2 near South Toms River, all in moderately developed areas. The land in the basins upstream from the three monitoring sites is moderately developed; 25 to 50 percent of the land is developed. Most of this development consists of large-scale housing communities of 1,000 to 2,500 single-family units with approximately one-eighth acre lots. This development represents a more recent suburban land-use pattern compared to the older urban land use typical of the Long Swamp Creek subbasin. The methods of construction of these communities resulted in extensive soil compaction and high-maintenance lawns (David Friedman, Ocean County Soil Conservation District, oral commun., 1997). Soil compaction can decrease soil permeability, thereby affecting ground-water flow and storm runoff. Before the residential development of the early 1970's, various poultry farms were located within the Wrangle Brook subbasin. Site descriptions and identifiers, and a summary of the land-use distributions in the basins upstream from the monitoring sites are listed in table 1.

The entire reach upstream from the monitoring site on the Davenport Branch near Dover Forge (Site DB) is designated PL; downstream from this monitoring site the stream is designated FW2 (New Jersey Department of Environmental Protection, 1998). Land in the basin upstream from this monitoring site is classified as slightly developed; 10 to 25 percent of the land in the contributing drainage area is developed. Most development is in the lower third of the subbasin and it is suburban in nature, similar to that in the Wrangle Brook subbasin. The presence of large ponds in the basin (former cranberry bogs) can reduce the variability of streamflow by retaining stormwater runoff. The site description and identifier, and a summary of the land-use distribution in the basin upstream from the monitoring site are listed in table 1.

The entire length of Jakes Branch is designated as a PL stream (New Jersey Department of Environmental Protection, 1998). The monitoring site is located on Jakes Branch near South Toms River (JB). Land in the basin upstream from the site is classified as undeveloped because it is solely forest plus wetlands and is entirely within the boundaries of the Pinelands Protection and Preservation Area (fig. 1). The site description and identifier, and a summary of the land-use distribution in the basin upstream from the site are listed in table 1.

[2] Most waterbodies within New Jersey are assigned a surface-water quality classification (New Jersey Department of Environmental Protection, 1998). FW1 are those freshwater bodies that originate in and lie wholly within Federal or State parks, forests, fish and wildlife lands, and other special holdings, and that are to be maintained in their natural state of quality and not subjected to any manmade wastewater discharges. PL are all freshwater bodies that lie within the boundaries of the New Jersey Pinelands Protection and Preservation Area; the surface-water-quality criteron for PL waters is that these waters shall be maintained at the quality of their present state or that quality necessary to attain or protect the designated uses, whichever is more stringent. Designated uses for FW2 waters are maintenance, migration and propagation of the natural and established biota, primary and secondary contact recreation (swimming, boating, and fishing), industrial and agricultural water supply, and public water supply after conventional filtration treatment.

Methods of Study

The following section describes the methods used in the collection and analysis of surface-water quality and streamflow data. Constituents carried to a stream by stormwater runoff were quantified in samples collected during precipitation, and constituents carried to a stream by ground water were quantified in samples collected during base flow. In addition, data were categorized as being collected during the growing and nongrowing seasons. The determination of instantaneous streamflows and the calculation of area-normalized instantaneous loads (referred to as yields) are described, as are the methods used to estimate annual yields of selected constituents to the Toms River embayment and the Barnegat Bay.

Data Collection

Surface-water samples used to obtain water-quality and streamflow data were collected 37 times in the growing and nongrowing seasons during periods of base flow and stormflow from May 1994 to September 1999. Detailed descriptions of the criteria for site selection, methods for surface-water sampling, and analysis of water samples are documented in Hunchak-Kariouk (1999) and Connell and Schuster (1996), and in standard operating procedures of the NJDEP Bureau of Marine Water Classification and Analysis Laboratory, Leeds Point, N.J.

Monitoring sites used for streamflow measurement and surface-water quality sampling are located on streams draining areas with two or more predominant land uses, one of which is forest plus wetlands. For this study, land development in the basins was classified as highly, moderately, slightly, or undeveloped. In a highly developed area, more than 50 percent of the land in the drainage area is developed; residential is the predominant land use, and forest plus wetlands is the secondary land use. In a moderately developed area, 25 to 50 percent of the land in the drainage area is developed, and in a slightly developed area, 10 to less than 25 percent of the land in the drainage area is developed. In moderately and slightly developed areas, forest plus wetlands is the predominant land use, and residential is the secondary land use. In an undeveloped area, less than 10 percent of the land in the drainage area is developed.

For base-flow sampling, a maximum-rainfall criterion of less than 0.1 in. during the 7 days prior to sampling was used. The minimum-rainfall criteria for stormflow sampling during the growing season and nongrowing season, 1 in. and 0.5 in., respectively, are based on an analysis of precipitation data collected at Toms River, N.J., (National Oceanic and Atmospheric Administration, 1991, 1992) and streamflow data collected during 1991-92 from nearby USGS streamflow-gaging stations. Larger total-rainfall amounts were required during the growing season than the nongrowing season because of greater water loss by evapotranspiration, lower stream and groundwater levels, and longer dry spells between storms. The dates for the growing season, April 1 to October 31, and nongrowing season, November 1 to March 31, were based on the average times of the first and final frosts in New Jersey (Ruffner and Bair, 1977).

All water-quality analyses and quality-assurance testing were conducted by NJDEP personnel either on-site at the time of sample collection or at the NJDEP Bureau of Marine Water Classification and Analysis Laboratory, Leeds Point, New Jersey (Connell and Schuster, 1996). Water stage was measured by NJDEP personnel concurrent with sample collection. USGS personnel measured water stage and streamflow and developed stage-to-streamflow relations. At five monitoring sites, samples were collected for water-quality analysis, and water stage and streamflow were measured. At two monitoring sites, samples were collected for water-quality analysis only. At one monitoring site, only water stage and streamflow were measured. The types of data collected at each site are listed in table 2.

The types of measurements made (streamflow and (or) water-quality) and season of sample collection at the monitoring sites during the 37 sampling events conducted during 1994-99 are listed in table 3. During most base-flow samplings, water samples were collected manually (discrete measurements). Stormwater samples were collected manually and with automatic samplers at 1- or 2-hour intervals throughout each storm to ensure that critical times relating to the rise, peak, and fall on hydrographs were analyzed for each storm. Stream-stage measurements were made automatically by using pressure transducers and a relation between water depth and pressure, and stored automatically in the water-quality-monitoring devices (sondes). After analyzing the hydrographs for each site, field personnel selected 1 to 12 samples for analysis. Automatic samplers and sensors were not used at all sites during all storms.

Sample collection at monitoring site LSC1 was discontinued in August 1994 because the streamflow was found to be highly ephemeral, and sampling was initiated at monitoring

Table 2. Types of data collected at surface-water monitoring sites in the Toms River drainage basin, N.J., 1994-99

[y, data were collected; --, data were not collected]

U.S. Geological Survey station number (fig. 1)	Site name (Identifier)	Abreviation (fig. 1)	Type of data collected		
			Water stage	Streamflow	Water quality
01408590	Wrangle Brook near South Toms River at Bimini Drive	WB3	y	y	y
01408600	Wrangle Brook near Toms River	WB1	y	y	y
01408620	Davenport Branch near Dover Forge	DB	y	y	y
01408630	Davenport Branch near Toms River	--	[1]y	[1]y	--
01408640	Wrangle Brook near South Toms River	WB2	[2]--	[2]--	y
01408705	Jakes Branch near South Toms River	JB	--	--	[3]y
01408725	Long Swamp Creek near Toms River	LSC1	y	y	y
01408728	Long Swamp Creek at Toms River	LSC2	y	y	y

[1] Data collection was discontinued when site was disturbed by road construction in October 1995.

[2] Streamflow and stage were measured once (at different times) to verify streamflow estimates.

[3] Data were collected only once during base flow in the growing season.

Table 3. Sampling dates and types of data collected at surface-water measurement sites in the Toms River drainage basin, N.J., May 1994 to September 1999.

[Sites are listed in order of decreasing intensity of land development in the contributing drainage area. LSC2, Long Swamp Creek at Toms River; WB1, Wrangel Brook near Toms River; WB2, Wrangel Brook near South Toms River; LSC1, Long Swamp Creek near Toms River; DB, Davenport Branch; JB, Jakes Branch; WQ, water quality; W, winter season (January through March); Sp, spring season (April through June); Su, summer season (July through September); F, fall season (October through December); G, growing season (April through October); NG, nongrowing season (November through March); Q, samples were collected for water-quality analysis; --, no sample was collected for water-quality analysis or no streamflow or stream-stage measurement was made; M, stream stage was measured manually; A, stream stage was measured by stage sensor of automatic sampler; site locations are shown in Fig. 1]

Event[1]	Flow	Sampling date	Season		Sample collection and type of measurement										
					Site LSC2		Site WB1		Site WB2		Site LSC1		Site DB		Site JB
					WQ	Stream stage	WQ	Stream stage	WQ	Stream stage	WQ	Stream stage	WQ	Stream stage	WQ
1	Base flow	05/25/94	G	Sp	Q	M	Q	M	Q	--	--	--	--	--	--
2	Base flow	06/02/94	G	Sp	Q	M	Q	M	Q	--	--	--	--	--	--
3	Stormflow	07/14/94	G	Su	Q	M	Q	M	Q	--	--	--	--	--	--
4	Base flow	09/08/94	G	Su	Q	M	Q	M	Q	--	--	--	Q	M	--
5	Stormflow	09/22/94	G	Su	Q	A, M	Q	M	Q	--	--	--	Q	A, M	--
7	Stormflow	11/27/94	NG	F	Q	A, M	Q	A, M	Q	--	--	--	Q	A	--
8	Stormflow	01/06/95	NG	W	Q	A, M	Q	A, M	Q	--	--	--	Q	A, M	--
9	Base flow	03/07/95	NG	W	Q	M	Q	M	Q	--	--	--	Q	M	--
10	Stormflow	03/08/95	NG	W	Q	A, M	Q	A, M	Q	A	--	--	Q	A, M	--
11	Base flow	04/20/95	G	Sp	Q	M	Q	M	Q	--	--	--	Q	M	Q
12	Base flow	08/30/95	G	Su	Q	M	Q	M	Q	--	--	--	Q	M	--
13	Stormflow	09/17/95	G	Su	Q	A, M	Q	A, M	--	--	--	--	Q	A, M	--
14	Base flow	10/04/95	G	F	Q	A, M	Q	A, M	--	--	--	--	Q	A, M	--
15	Stormflow	10/05/95	G	F	Q	A, M	Q	A, M	--	--	--	--	Q	A, M	--
16	Stormflow	12/09/95	NG	F	Q	A	Q	A	Q	--	--	--	Q	A	--
17	Stormflow	03/18/96	NG	W	Q	A,M	Q	A,M	Q	--	--	--	Q	A,M	--
18	Base flow	03/28/96	NG	W	Q	M	Q	M	Q	--	--	--	Q	M	--
20	Stormflow	04/15/96	G	Sp	Q	A,M	Q	A,M	Q	--	--	--	Q	A,M	Q
21	Base flow	06/28/96	G	Sp	Q	M	Q	M	Q	--	--	--	Q	M	--
22	Stormflow	07/30/96	G	Su	Q	A,M	Q	A,M	Q	--	--	--	Q	A,M	--
23	Stormflow	11/25/96	NG	F	Q	A,M	Q	A,M	Q	--	--	--	Q	A,M	--
24	Base flow	04/11/97	G	Sp	Q	M	Q	M	Q	--	--	--	Q	M	--
25	Base flow	08/05/97	G	Su	Q	M	Q	M	Q	--	--	--	Q	M	--
26	Stormflow	08/20/97	G	Su	Q	A,M	Q	A,M	Q	--	--	--	Q	A,M	--
27	Stormflow	10/24/97	G	F	Q	A,M	Q	A,M	Q	--	--	--	Q	A,M	--
28	Stormflow	12/29/97	NG	F	Q	A,M	Q	A,M	Q	--	--	--	Q	A,M	--
29	Base flow	11/21/97	NG	F	Q	M	Q	M	Q	--	--	--	Q	M	--

Table 3. Sampling dates and types of data collected at surface-water measurement sites in the Toms River drainage basin, N.J., May 1994 to September 1999.—Continued

[Sites are listed in order of decreasing intensity of land development in the contributing drainage area. LSC2, Long Swamp Creek at Toms River; WB1, Wrangel Brook near Toms River; WB2, Wrangel Brook near South Toms River; LSC1, Long Swamp Creek near Toms River; DB, Davenport Branch; JB, Jakes Branch; WQ, water quality; W, winter season (January through March); Sp, spring season (April through June); Su, summer season (July through September); F, fall season (October through December); G, growing season (April through October); NG, nongrowing season (November through March); Q, samples were collected for water-quality analysis; --, no sample was collected for water-quality analysis or no streamflow or stream-stage measurement was made; M, stream stage was measured manually; A, stream stage was measured by stage sensor of automatic sampler; site locations are shown in Fig. 1]

Event[1]	Flow	Sampling date	Season		Sample collection and type of measurement										
					Site LSC2		Site WB1		Site WB2		Site LSC1		Site DB		Site JB
					WQ	Stream stage	WQ	Stream stage	WQ	Stream stage	WQ	Stream stage	WQ	Stream stage	WQ
30	Stormflow	02/23/98	NG	W	Q	A,M	Q	A,M	Q	M	--	--	Q	A,M	--
32	Base flow	03/31/98	NG	W	Q	M	Q	M	Q	--	--	--	Q	M	--
33	Base flow	06/22/98	G	Sp	Q	M	Q	M	Q	--	--	--	Q	M	--
34	Base flow	09/30/98	G	Su	Q	M	Q	M	Q	--	--	--	Q	M	--
35	Base flow	11/05/98	NG	F	Q	M	Q	M	Q	--	--	--	Q	M	--
36	Stormflow	02/28/99	NG	W	Q	A,M	Q	M	--	--	--	--	Q	A	--
37	Base flow	03/31/99	NG	W	Q	M	Q	M	--	--	Q	M	Q	M	--
38	Stormflow	04/09/99	G	Sp	Q	A	Q	A	Q	--	Q	A	--	--	--
39	Base flow	06/03/99	G	Sp	Q	M	Q	M	Q	--	Q	M	--	--	--
41	Stormflow	08/20/99	G	Su	Q	A	Q	A	--	--	Q	A	--	--	--
42	Base flow	09/28/99	G	Su	Q	M	Q	M	--	--	Q	M	--	--	--
					Total number of sampling events										
	Base flow		G		13		13		10		2		7		1
	Base flow		NG		6		6		5		1		6		0
	Stormflow		G		10		10		7		2		7		1
	Stormflow		NG		9		9		8		0		8		0

[1] Events 6, 19, and 40 are not listed because no water-quality samples were collected during these events.

site DB in mid-September 1994. Sample collection at monitoring site WB3 was initiated in April 1999; monitoring site WB3 was considered a possible replacement for monitoring site DB where data collection became difficult as a result of dam building by beavers. Monitoring site WB2 was moved 1,000 ft. upstream from the original location because of vandalism to equipment.

Samples were collected 18 times during base-flow conditions; of these sampling events, 12 were conducted in the growing season and 6 were conducted in the nongrowing season. Samples were collected 19 times during stormflow; of these, 10 were collected in the growing season and 9 in the nongrowing season. Water samples were collected only twice at monitoring site JB (once each during base flow and stormflow in the growing season) and five times at monitoring site WB3 (three times during base flow, twice in the growing season and once in the nongrowing season; and twice during stormflow in the growing season). All samples for bacteria analysis were collected manually. As a result of equipment and weather conditions, the number of water samples collected for analysis of all constituents is different at each monitoring site.

During most base-flow samplings, one set of water samples was collected. On the afternoon of October 4, 1995, field personnel anticipated a storm and deployed the automatic samplers and sensors. Streamflow at the time of measurement and sample collection, prior to the storm (event 15), was considered to be base flow (event 14) because the storm did not begin until the morning of October 5.

Duplicate samples were collected once each at monitoring sites WB1 and WB2 during base-flow conditions (event 9) to evaluate sampling effectiveness. Samples were collected once at monitoring site WB2 during base flow (event 12) to verify that water quality at that site and at a location 1,000 ft. upstream from the site were similar. At the beginning of the September 1995 storm (event 13), one set of composite samples was collected at each of monitoring sites WB1, WB2, and DB, and one set of grab samples was collected manually at monitoring site LSC2 for comparison with samples collected with automatic samplers. Grab samples were collected at monitoring site LSC2 because the stream is narrow and well mixed at the sampling location.

Data Management

The water-quality and water-stage data collected during December 1995 to September 1999 were received by the USGS from the NJDEP as a Microsoft Access table. Each record contained all recorded information about a single measurement, for example, the nitrate concentration at a specific date and time of collection at a sampling site. Although an efficient way to archive data, this format is not suitable for data analysis. Therefore, a Microsoft Access relational database was constructed, where information on sites, events, samples, and results was separated into related tables. Data collected during May 1994 to October 1995 and described by Hunchak-Kariouk (1999) were added to the database; therefore, the completed project database contains all data collected from May 1994 through September 1999.

The relational database is composed of tables; the names of the tables appear here in parentheses. The database structure is based on a core model of events (tbsEvent) as discrete time periods during which sampling took place, sites (tbsSite) with one or more samples, and samples (tbsSample) with one or more reported results (tbsResult) for individual constituents. The site table contains fields with a monitoring site description, site area, alternative site names, codes, and other information related to the site. The event table has an event code that uniquely identifies each sampling event, where a sampling event is defined as a set of sampling, measurement, and analytical activities undertaken during a storm or base-flow time period to characterize water quality and discharge at one or more monitoring sites. Other fields in the event table show the starting and ending dates and times of the event, duration, season, and whether the event took place during the growing or nongrowing part of the year. The sample table uniquely specifies a point in time when one or more water-quality or -quantity characteristics were measured at a monitoring site during an event. Calculated discharge values at the time of sampling are included in a field in this table. The result table contains individual chemical and physical observations associated with each sample, where each result is described by a characteristic name, reporting units, filter condition, determination method (manual or automated sampling), and whether the reported value requires a qualifying flag, such as "< (less than)" reflecting a detection limit value. Five additional tables were created to provide information about sample filtration, methods of detection, and other water-quality data characteristics. Various queries were created to assist in data-quality assessment and assurance.

Data Analysis

The following sections describe the analysis of the hydrologic and water-quality data. Hydrologic data consist of stream stage and streamflow measurements. Stage-to-streamflow relations (rating curves) prepared from stream-gaging measurements (simultaneous discharge and stream-stage measurements) were used to convert stream-stage values to discharge values at the time of sample collection. Stream stage was measured manually from staff plates or reference marks or by pressure transducers in the sondes. Water-quality data consist of concentration values of selected water-quality characteristics from which yields (area-normalized instantaneous load values) were calculated by using the estimated instantaneous streamflows at the time of sample collection. Water-quality constituent concentrations and yields were evaluated by using parametric statistical methods to determine relations between water quality and streamflow, season, and percentage of development in the subbasins studied.

Hydrologic Data

Stream stage and streamflow were measured at eight monitoring sites over a range of flow conditions (table 3). During base flow, stream stages were measured manually from staff plates and reference marks at the time of water-sample collection at monitoring sites LSC1, LSC2, WB1, WB3, and DB. During stormflow at these monitoring sites, stream stages were measured manually from staff plates and reference marks at the start, middle, and end of most storms and at the time of streamflow measurement. In addition, during most storms, stream stage at monitoring sites LSC2, WB1, WB3, and DB was recorded every 10 minutes by the stage sensor of the automatic samplers. These measurements were sometimes retained by the microprocessor of the stage sensor as hourly averages or hourly maximums and minimums. Stream stages were measured manually at Davenport Branch near Toms River about the time of water-sample collection at monitoring site WB2 until the site was altered by road construction during 1996.

At monitoring site WB1, stream stages measured manually were in close agreement with those recorded by the stage sensor because the bed slope between the staff plate and sensor was slight. At monitoring site LSC2, water stages measured manually were not always in close agreement with those recorded by the stage sensor because standing waves formed during stormflow, resulting in inaccurate stage readings from the pressure transducer in the data sonde. During the study at monitoring site DB, beavers built a large dam in the culvert just upstream from the stream-stage reference mark. The stream-stage reference mark used for the rating curve was transferred to a new location downstream from the dam. Streamflow was still substantially affected by the dam, and the rating curve developed for monitoring site DB was poor.

Stage Correction

Instantaneous streamflows, which were used to calculate yields (area-normalized instantaneous loads of contaminants), were determined from rating curves by using measured stream-stage values or estimated values for the time of sample collection. Stream stages during base-flow and the first stormflow samplings were measured manually for use in determining instantaneous streamflows. Stream stages during all other stormflow samplings were estimated by linearly interpolating values between hourly averages of stream stages measured by the stage sensor prior to and after the actual sampling or measurement time. Streamflows determined from estimated stream stages are used with caution, especially when only hourly averaged stage values are available, because the estimated and actual streamflows might be different for these streams. This section describes the correction of raw stream-stage data and the calculation of discharge rates from corrected stream-stage data.

Stream stages measured by the pressure transducer in the sonde (automated measurements) were found to differ, sometimes substantially, from manually collected stream-stage data. Stream-stage measurements obtained by directly reading the stage from a staff plate or reference mark (manual measurements) are considered more reliable than automated measurements. Methods were developed to redraw hydrographs for storm events using all available manual stream-stage data and automated data when the automated data were consistent with the manual data. Where systematic error in the automated data was apparent (a uniform discrepancy between manual and automated measurements during a portion of a storm event), a mathematical formula was applied to shift the automated stream-stage data into agreement with the manual data. During some sampling events, manual measurements were not made, and the automated data were used without adjustment.

Stream-stage measurements from event 17 (March 18-20, 1996) at the monitoring site LSC2 are used to demonstrate the stage correction procedures. Nine manual measurements were made. The first two manual measurements were consistent with automated measurements, and no adjustment was necessary. The third and fourth manual measurements, however, were substantially higher than the automated measurements. A corrected point was generated to replace each automated measurement by interpolation, using the error of the two closest automated measurements with simultaneous manual measurements that bracket the automated measurements being corrected. The correction was proportionally weighted and can be expressed mathematically as

$$G_{C,i} = G_{S,i} + [(t_i - t_1)(G_{M,2} - G_{S,2})/(t_2 - t_1)] + [(t_2 - t_i)(G_{M,1} G_{S,1})/(t_2 - t_1)], \qquad (1)$$

where,

$G_{C,i}$ = corrected gage height,
$G_{S,i}$ = data-sonde-gage height at time t_i,
t_1 = time of the previous manual gage measurement,
t_2 = time of the next manual gage measurement,
$G_{M,1}$ = manual gage measurement at t_1,
$G_{M,2}$ = manual gage measurement at t_2,
$G_{S,1}$ = data-sonde gage measurement at t_1,

and

$G_{S,2}$ = data-sonde-gage measurement at t_2.

The manual and automated stream-stage measurements and corrected stage values from event 17 (March 18-20, 1996) at monitoring site LSC2 are shown in figure 3. The resulting hydrograph passes through all manual stage measurements and uses all automated measurements to generate corrected stage values. This corrected hydrograph is a hybrid of the hydrograph drawn using only manual stream-stage measurements and the one drawn using only uncorrected automated measurements, and probably is more representative of actual hydrologic conditions than either the manual or automated measurement method.

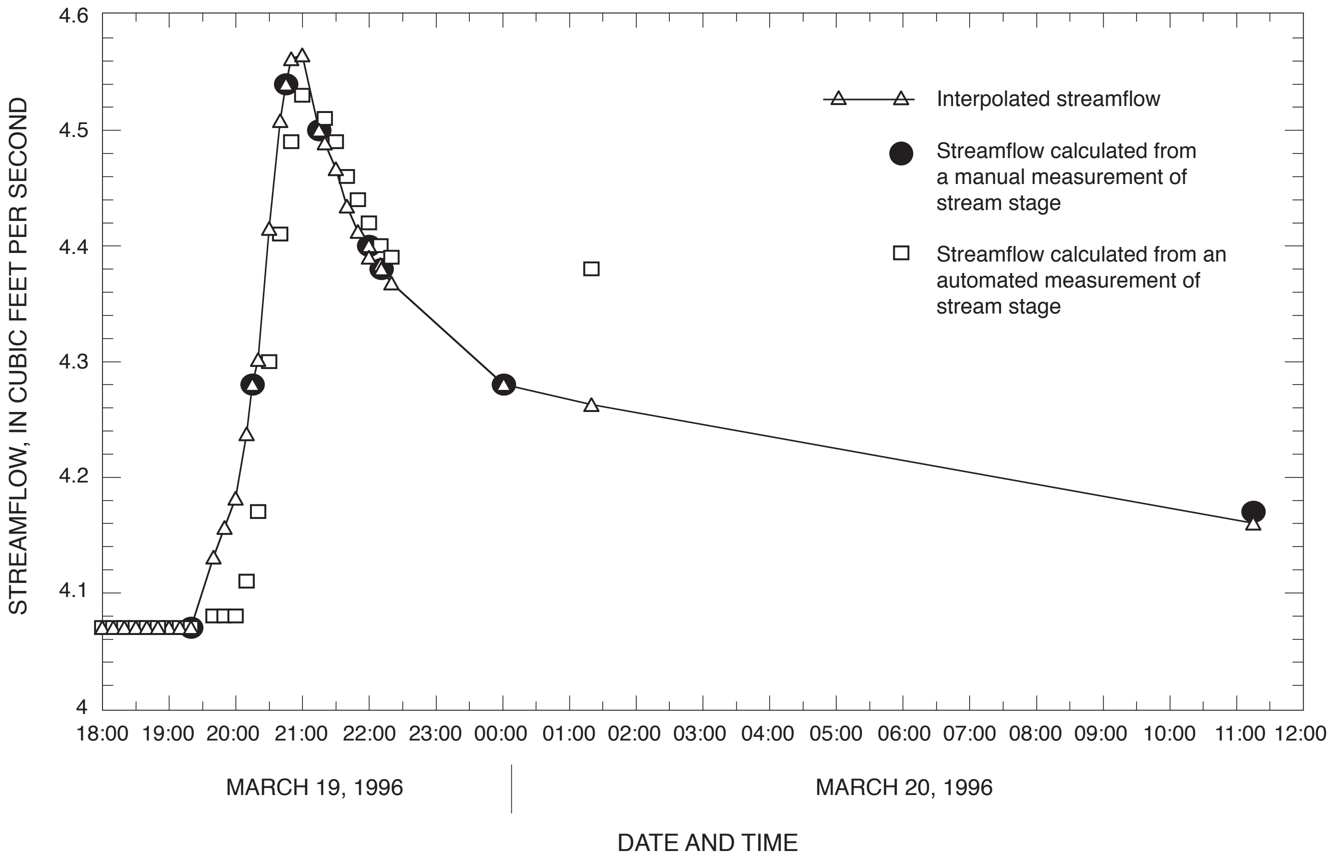


Figure 3. Hydrograph of precipitation event on March 18, 1996, at Long Swamp Creek at Toms River, N.J.(Site LSC2, see figure 1.)

Determination of Instantaneous Streamflows

Instantaneous streamflow (discharge) values were determined from stream-stage values by using rating curves, which are offset log-log relations between stage and discharge measurements. Discharge calculations are based on standard USGS methods as presented by Kennedy (1984). The USGS Automated Data Processing System (ADAPS) was used to generate initial rating curves. The process was refined further in Microsoft Excel spreadsheets, which facilitated rapid conversion of stage, measured in feet (ft), to discharge (ft^3/s) once the proper rating equations were determined.

The relation between the log (discharge) and log (stage) at a location on a stream is often linear if the appropriate Y-axis (stage) offset is used. The offset, slope, and Y intercept can be determined mathematically. Three values of discharge (Q) and stage (G) at a site on the stream are required. The lowest (Q_2, G_2) and highest (Q_1,G_1) values are obtained by stream gaging, where stage and discharge are measured simultaneously. An intermediate discharge value (Q_3) is the geometric mean of Q_1 and Q_2 as

$$Q_3 = (Q_1 \text{ x } Q_2)^{0.5}. \quad (2)$$

G_3 is the gage height corresponding to Q_3 and is obtained directly from the initial rating curve drawn by ADAPS. Alternatively, a third point (Q_3,G_3) can be any measured discharge and corresponding stage values that fall between (Q_1,G_1) and (Q_2,G_2), preferably a point where Q is close to $(Q_1 \text{ x } Q_2)^{0.5}$. The Y-axis offset (e) is a constant for which the plot of log(Q) in relation to log (G-e) yields a straight line. The value of e is often the gage height of zero flow. Calculation of e and the slope (b) are as follows:

$$e = [(G_1 x G_2)-(G_3)^2]/(G_1+G_2-2G_3), \quad (3)$$

$$b = [\log Q_1 - \log Q_2]/[\log (G_1-e) - \log (G_2-e)]. \quad (4)$$

The Y-intercept (P) and discharge can then be calculated as

$$P = Y \text{ intercept} = Q/(G-e)^b, \quad (5)$$

$$Q = P(G-e)^b. \quad (6)$$

The rating curve function for a given station may not be constant for all discharge values. Under low-flow conditions, a flow-restricted section of the channel downstream from the station commonly defines a predictable stage-discharge relation. This condition is referred to as section control. At higher flow, channel control defines the relation and is governed by size, shape, slope, roughness, straightness, and other characteristics of the entire channel. A third stage-discharge relation can be defined for conditions where the stream overflows its bank (combined channel and flood-plain control). Each of these conditions can have a different offset and slope. Therefore, a stream can have two or more ratings.

The rating curve for monitoring site LSC2 under high-flow conditions (above about 2 ft^3/s) is shown in figure 4. The rating curve is linear and stable, and discharge can be determined accurately from stage values. Under low-flow conditions, however, the discharge-stage relation at this monitoring site is not useful. The possibility that the linear rating changed over time (vertical shift) was considered, but the stage for a given discharge value appeared to be randomly distributed with respect to time. Low-flow correlations with other streams in southern New Jersey were calculated as an alternative method of determining discharge under base-flow conditions using a Move.1 regression (Maintenance of Variance Extension, Type 1) (Hirsch, 1982). The highest correlation coefficient between monitoring site LSC2 and 23 potential index sites was 0.67. This result was not considered satisfactory for providing accurate estimates of discharge for monitoring site LSC2 (site 1). All base-flow sampling and stream gaging times for monitoring site LSC2, estimated discharge values, and the quality of the estimate (excellent, good, fair, or poor, as described by Buchanan and Somers, 1969) are shown in table 4.

The rating curve for monitoring site WB1 is shown in figure 5. The curve is linear for the entire range of gage heights encountered. The rating at this station appears to be changing over time; the stage value for a given discharge is gradually increasing, indicating additional flow restriction downstream as a result of an obstruction or silting. One or more additional rating curves could be needed for future stream-stage data.

Two rating curves were needed for monitoring site DB. The upper curve in figure 6 is appropriate from December 1995 to September 1997; the lower curve was used thereafter, except for a brief period (July 1998) when the upper curve was used. The presence of beaver dams in a downstream culvert and under a bridge, and varying amounts of vegetation and debris in the channel, could have caused the rating to change.

Stream gaging was not conducted at monitoring site WB2. Discharge at this site was estimated from monitoring site WB1 (site 4) discharge data (Hunchak-Kariouk, 1999) using the relation

$$Q_{site3} = Q_{site4}\ x\ [(2/3A_{site5}+A_{site4}+A_{um})/A_{site4}]^{n}\ , \qquad (7)$$

where,

Q_{site3} = streamflow estimated for site WB2,
Q_{site4} = streamflow estimated for site WB1,
A_{site5} = drainage area of site 5 (Davenport Branch near Toms River, DB2, USGS station number 01408630, 12.15 mi^2),
A_{site4} = drainage area of site WB1 (19.5 mi^2),
A_{um} = unmonitored drainage area of site WB2 (2.5 mi^2),

and

n = a constant equal to 0.93 for drainage in the Atlantic Coastal Plain.

Because the drainage areas and *n* are known, equation (6) can be simplified to

$$Q_{site3} = Q_{site4}\ x\ 1.4958. \qquad (8)$$

The validity of equation (8) was verified by comparing a calculated Q_{site4} value with a measured value. The calculated value (80.2 ft^3/s) underestimated the measured streamflow (87.4 ft^3/s) by 8.2 percent. This value is considered reasonable based on the possible totals error resulting from calculated and measured streamflow, which often exceed 10 percent.

Discharge Hydrograph Extension and Base-Flow Separation

Stage measurements were made at the beginning of each storm and during the rising limb of the discharge hydrograph, but for most storms few measurements were made during the falling limb of the hydrograph. In order to quantify the total discharge from each storm at each monitoring site, it was necessary to extend the hydrographs in time and calculate discharge volumes for the falling limbs. This extension was accomplished by estimating the time at which runoff ended and the discharge value at that time, and applying an exponential function that describes discharge as a function of time to the flow during the falling limb of the discharge hydrograph.

The number of days between the storm peak and the end of runoff can be estimated using equation (9) (Linsley and others., 1975).

$$N = A^{0.2}, \qquad (9)$$

where,

N = number of days between the storm peak and the end of runoff,

and

A = drainage basin area (mi^2).

Thus, for monitoring sites LSC2 , WB1, and DB the value of N is 1.46, 1.81, and 1.49 days, respectively. If the end-of-storm base-flow-discharge value was not available, the pre-storm value was used.

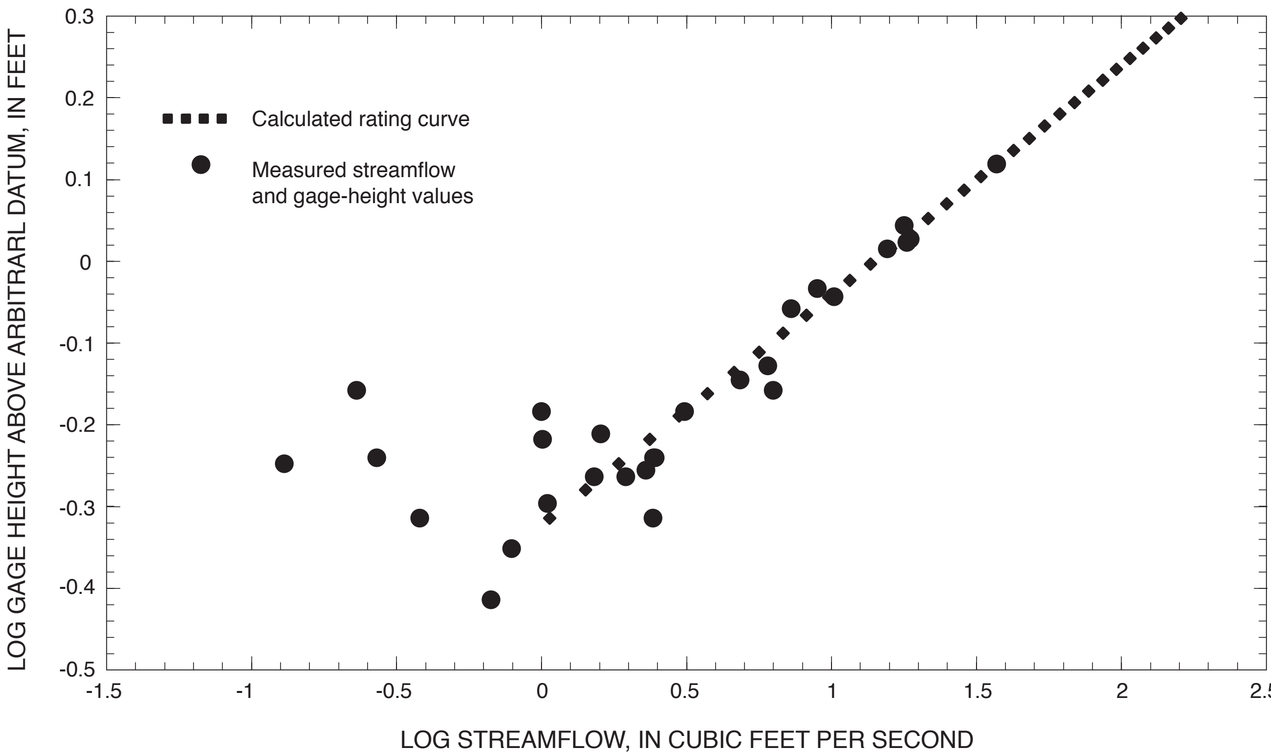


Figure 4. Rating curve for Long Swamp Creek at Toms River, N.J. (Site LSC2, see figure 1.)

Discharge during the falling limb of a discharge hydrograph decreases exponentially over time (Gray, 1970) and can be expressed as

$$Q2 = Q1K^{-t}, \qquad (10)$$

where,

Q_1 and Q_2 = discharge rates at two times during the falling limb,

K = constant,

and

t = time elapsed between measurements.

The equation is modified slightly to describe exponential decline in discharge from the last stage measurement (Q_1) to the end of runoff (Q_2) and given as

$$Q_2 = Q_1 e^{-b\,t}. \qquad (11)$$

The constant b is determined by setting Q_2 to the base-flow discharge value, defining t as the elapsed time difference between the last stage measurement and the end of runoff, and solving for b.

Total volume of water discharged in the time increment between the two stage measurements is calculated as the product of the time between measurements and the average of the two instantaneous discharge values. This calculation also can be visualized as the area of the trapezoid defined by the two time periods and the two discharge rates. To determine the discharge volume of the unmonitored falling limb of the storm, equation (11) is integrated from t_1 (last stage measurement) to t_2 (time transpired between last stage measurement and the end of runoff) and given as

$${}_{t1}\int^{t2} Q_2\,dt = {}_{t1}\int^{t2} Q_1 e^{-b\,t}\,dt = Q_1/b(e^{b\,t}-1). \qquad (12)$$

This gives the total volume discharged between the last stage measurement and the end of runoff.

Base-flow separation was approximated by drawing a line from the base-flow discharge value immediately before the storm to the end-of-storm discharge value corresponding to the end of runoff. Therefore, the base-flow discharge volume during a storm is the represented by the area of the quadrilateral defined by the beginning and ending times of the storm and their discharge values. The base-flow separation of a storm hydrograph at monitoring site LSC2 for which the end-of-storm discharge value was available and of a storm at monitoring site WB1 where the final discharge value was assumed to be equal to the initial discharge value are shown in figure 7.

Water-Quality Data

Water samples were analyzed for total nitrogen, ammonia, nitrate plus nitrite, nitrite, total phosphorus, hydrolyzable phosphorus plus orthophosphorus, orthophosphorus, total sus-

Table 4. Base-flow values for Long Swamp Creek at Toms River, N.J. (Site LSC2, fig. 1)

Event	Date of sampling	Type of measurement	Stream stage[1], in feet	Estimated streamflow[2], in cubic feet per second	Quality of estimate[3]	Date of measurement	Type of measurement	Stream stage[4], in feet above arbitrary datum	Measured streamflow[4], in cubic feet per second
18	03/28/96	Base flow	4.04	2.2	Good	03/20/96	Stormflow	4.07	2.29
21	06/28/96	Base flow	4.09	2.3	Poor	07/13/96	Stormflow	4.60	15.20
24	04/11/97	Base flow	4.14	1	Good	04/22/97	Base flow	4.17	1.00
25	08/05/97	Base flow	4.10	1	Fair	06/03/97	Stormflow	4.39	7.26
29	11/21/97	Base flow	4.04	1-2	Fair	11/10/97	Base flow	4.09	2.47
32	03/31/98	Base flow	4.21	6.31	Excellent	03/31/98	Base flow	4.21	6.31
33	06/22/98	Base flow	4.14	3	Poor	05/28/98	Stormflow	4.26	6.02
34	09/30/98	Base flow	4.05	4	Fair	08/25/98	Base flow	4.09	2.44
35	11/05/98	Base flow	4.00	1	Fair	12/08/98	Base flow	4.02	1.05
37	03/31/99	Base flow	4.05	1.5	Fair	03/17/99	Base flow	4.06	1.52
39	06/03/99	Base flow	4.04	1.9	Fair	06/22/99	Base flow	4.06	1.99
42	09/28/99	Base flow	3.98	0.8	Good	10/08/99	Base flow	3.96	0.79
43	03/08/00	Base flow	3.90	0.67	Excellent	03/08/00	Base flow	3.90	0.67

[1] Measured at time of sample collection for water-quality analysis by New Jersey Department of Environmental Protection personnel.

[2] Estimated from streamflow rating curve.

[3] Quality of estimate is subjectively determined by U.S. Geological Survey personnel during stream gaging.

[4] Measured by U.S. Geological Survey personnel.

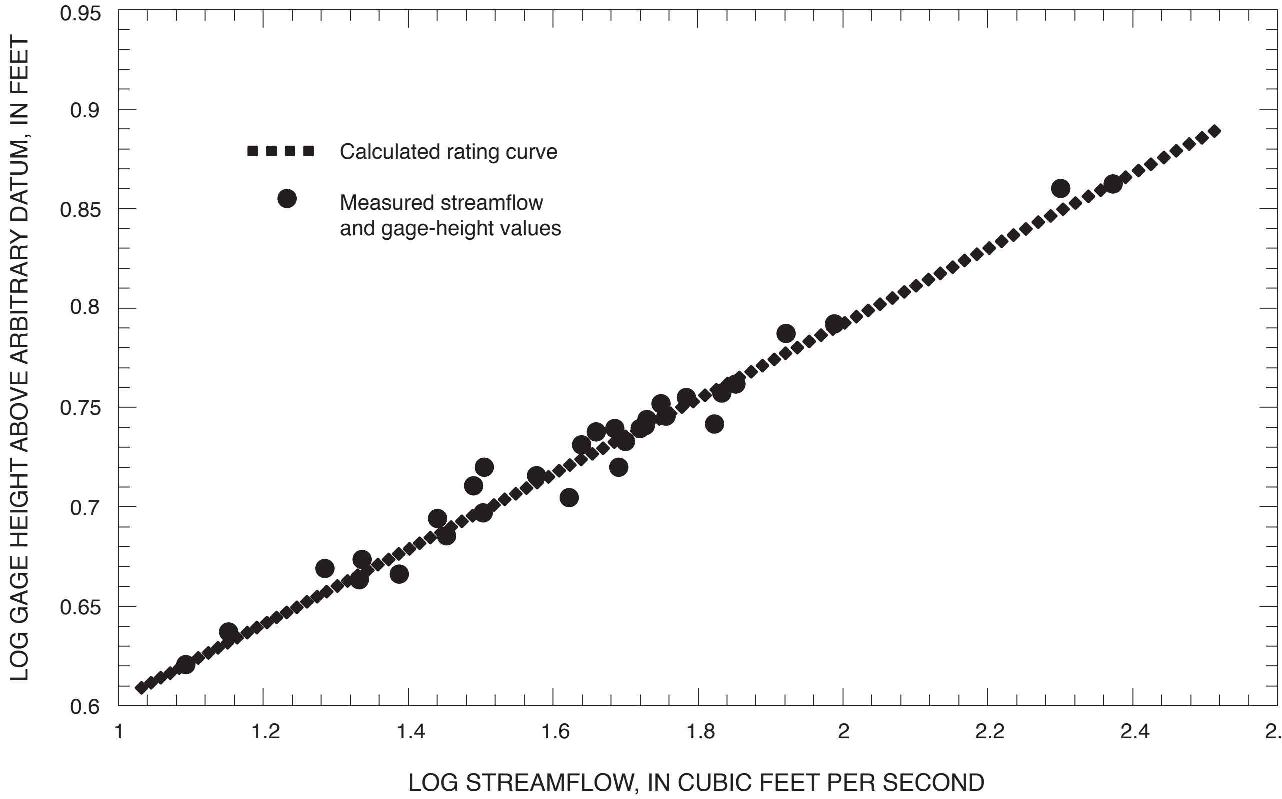


Figure 5. Rating curve for Wrangle Brook near Toms River, N.J. (Site WB1, see figure 1.)

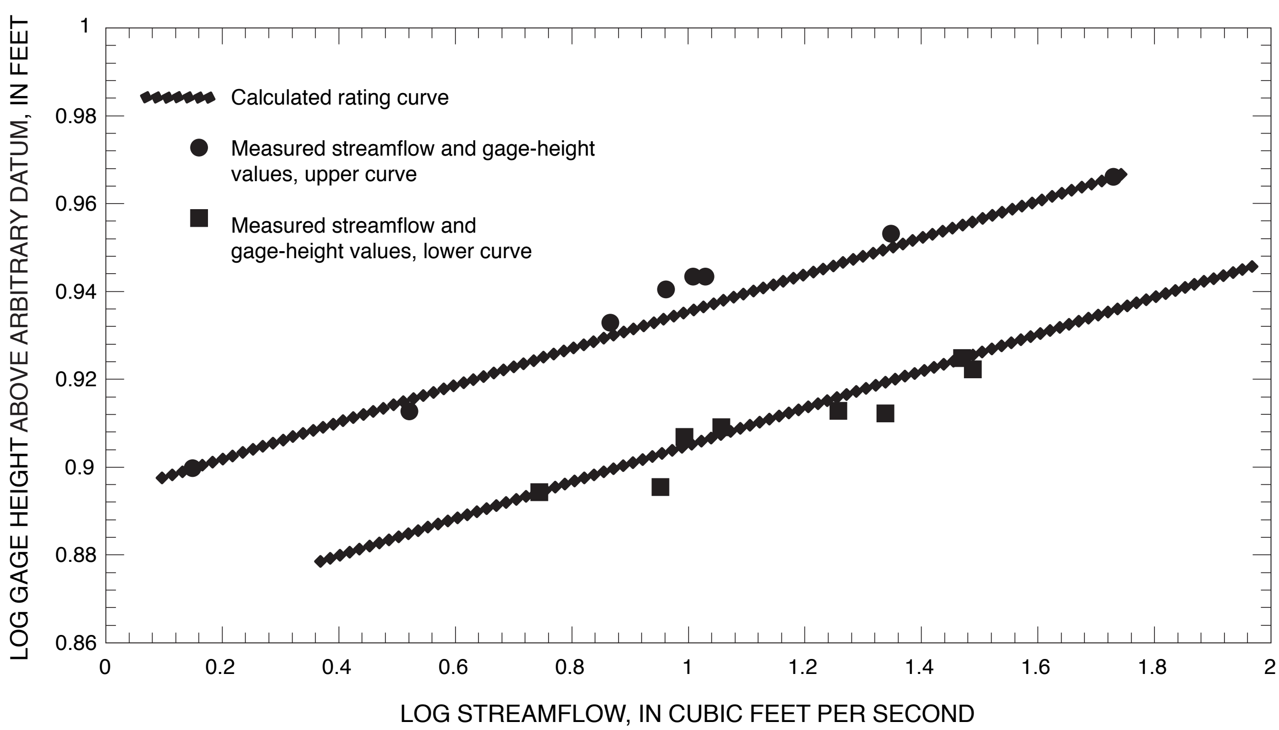


Figure 6. Rating curves for Davenport Branch near Dover, N.J. (Site DB, see figure 1.)

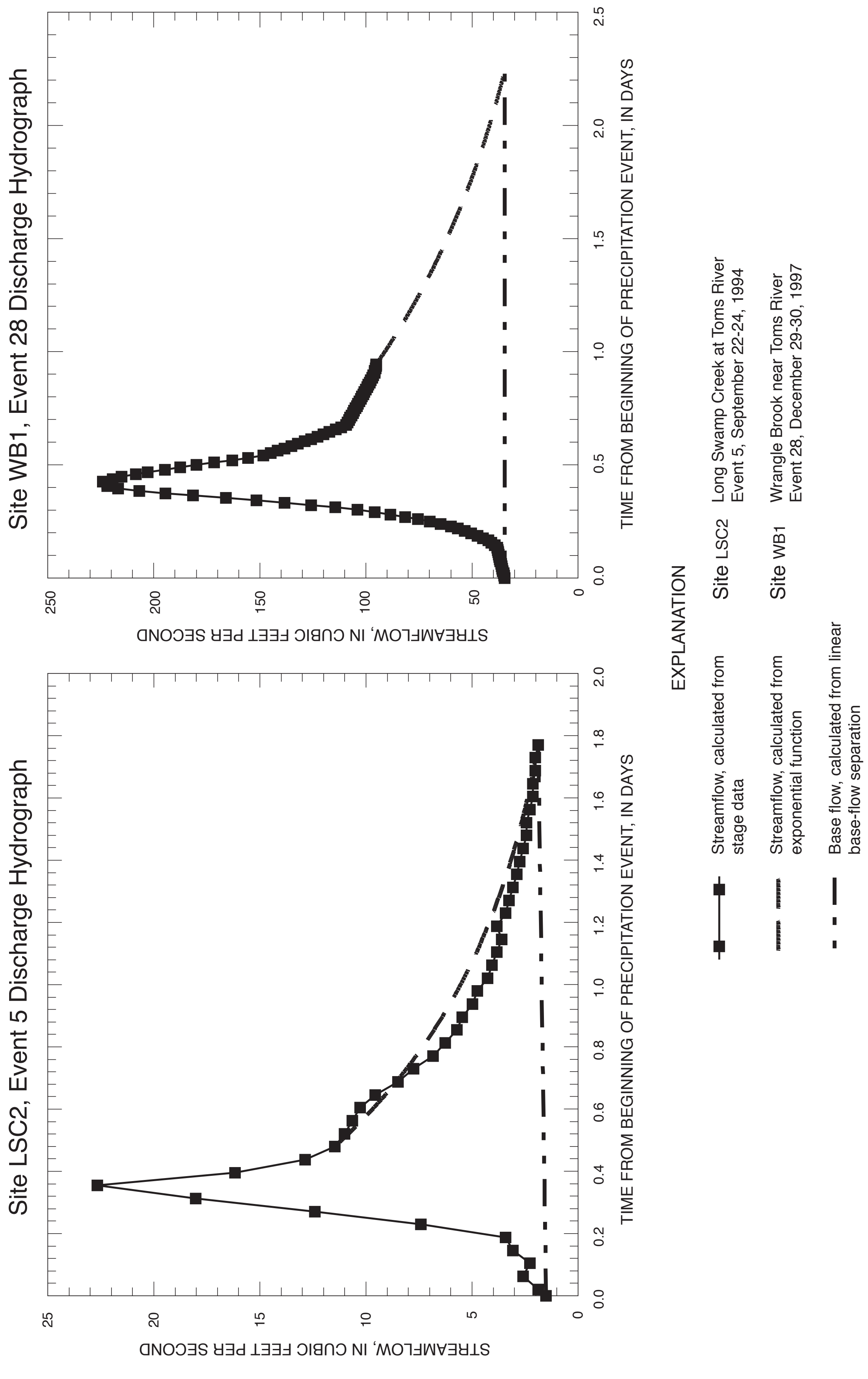


Figure 7. Examples of hydrograph extension using the exponential function method, for the Toms River drainage basin, N.J. (Sites, see figure 1.)

Table 5. Analytical methods used to quantify water-quality constituents in streamflow in the Toms River drainage basin, N.J.

[μg/L, micrograms per liter; NJDEP; New Jersey Department of Environmental Protection; APHA, American Public Health Association; mg/L, milligrams per liter; μmho/cm, micromhos per centimeter; N, nitrogen; P, phosphorus; <, less than]

Constituent	APHA analytical method	Reference	Method detection limit	Units
Total nitrogen	352	NJDEP 1989	3.8	μg/L as N
Nitrate-N	353.2	NJDEP 1989	0.7	μg/L as N
Organic nitrogen	Calculated[1]	NJDEP 1989	4.5	μg/L as N
Ortho phosphorus	300	NJDEP 1989	12.5	μg/L as P
Hydrolyzable phosphorus	365.1	NJDEP 1989	1.5	μg/L as P
Total suspended solids	160.2	USEPA 1979	1.0	mg/L
Ammonia	101	NJDEP 1989	4.5	μg/L as N
Fecal coliform bacteria	31615	NJDEP 1989	1	colonies per 100 mL
Specific conductance	2510	APHA 1985	0.1	μmho/cm
Dissolved oxygen	421B	APHA 1985	<1	mg/L

[1] Organic nitrogen concentration is calculated as the difference between total nitrogen concentration and the sum of nitrite, nitrate, and ammonia concentrations.

pended solids, and bacteria (Escherichia coliform (E. coli) and fecal coliform). All analyses were conducted by the NJDEP Leeds Point Laboratory. Analytical methods and references are listed in table 5

Some constituent concentrations were calculated. Nitrate was calculated as the difference between nitrate plus nitrite and nitrite. Concentrations of organic nitrogen were calculated as the difference between total nitrogen and the sum of ammonia and nitrate plus nitrite.

In this report, concentrations of all nitrogen species are expressed as nitrogen in micrograms per liter (μg/L as N). During the study, the method-detection limit (MDL) was evaluated periodically and changed for some constituents according to laboratory procedures. Concentrations of total suspended solids are expressed as milligrams per liter, and the MDL was 1.00 μg/L. Concentrations of bacteria are expressed as the most probable number of bacteria per 100 milliliters of sample (MPN/100 mL).

The long (more than 5 years) time frame and 37 sampling events of this project allow for the evaluation of a wide array of variables that affect the physical and water-quality characteristics of the water. These variables include the effects of base flow and stormflow, percent of land development, variability of water quality during storms, effects of growing season and nongrowing season on water quality, and interactions among the variables. Because an instantaneous stream-discharge value is calculable for most sampling times, the yields of the selected water-quality characteristics were determined. Therefore, the variability of these constituents can be viewed in terms of concentration, which is relevant to the water quality of the reach being sampled, or yield, which is relevant to the receiving water (that is, the Toms River and ultimately the Barnegat Bay) and the loading of nutrients to that water body.

Determination of Yield Values

Yields for total nitrogen, dissolved ammonia, dissolved nitrate, organic nitrogen, filtered orthophosphate, total suspended solids, and fecal coliform bacteria for monitoring sites LSC2, WB1, WB2, and DB were computed by using the equation

$$Y = (C \ x \ Q \ x \ f)/A, \quad (13)$$

where,

Y = yield in pounds per day per square mile ((lbd)/mi^2) or most probable number per day per square mile ((MPN/d)/ mi^2),

C = measured concentration in micrograms per liter or most probable number per 100 microliters,

Q = instantaneous streamflow in cubic feet per second,

f = conversion factor equal to 0.0035936 pounds per microgram, seconds per day, liters per cubic feet ((lb/mg)(s/d)(L/ft^3)) if the concentration is in micrograms per liter or 2.45 x 107 seconds per day, milliliters per cubic feet ((s/d)(mL/ft^3)) if the concentration is in most probable number per 100 milliliters,

and

A = drainage area in square miles.

Yields are weighted toward values calculated for samples collected during those storms in which a large number of samples were analyzed. Only one set of samples was collected at most monitoring sites during each base-flow sampling.

Estimation of Annual Yields

Because the monitoring sites differ in the percentage of development, a simple model was constructed to describe the relation between percentage of land development and annual yields of various constituents. The comparisons made were

total yield and percent development,
base-flow yield and percent development, and
stormflow yield and percent development.

To accomplish this it was necessary to calculate the yield under base-flow and stormflow conditions for each constituent. Annual yields are expressed in units of kilograms per year per square kilometer (kg/y/km^2) for all constituents except fecal coliform bacteria, which were given units of colony forming units per year per square kilometer (cfu/y/km^2). Yields during base flow were calculated as the product of median base-flow concentration and median base-flow discharge, divided by the drainage basin area. Yields during stormflow were calculated for each storm for which a sufficiently complete record of discharge and analytical results were available. Total discharge volume was determined for each storm by integrating the discharge hydrograph (equation 12). Base-flow separation then was used to quantify the base-flow and runoff components for each storm. Because not all storms were sampled during the period of record, the total stormflow volume and its base-flow and runoff components for the period of record were estimated by dividing the appropriate volume by the fraction of total precipitation represented by the sampled storms. These volumes were annualized by dividing by the number of years in the period of record. Precipitation data from the Toms River meteorological station were obtained from the National Climactic Data Center. Yields during runoff were calculated as the product of volume-averaged mean stormflow concentration and annual runoff volume, and divided by the drainage basin area.

Statistical methods

A statistical package (S-Plus, MathSoft, Inc.) was used to determine the relations presented in this report. Nonparametric statistical tests (Kruskal-Wallis nonparametric test, Tukey multiple comparison test, and Wilcoxon rank-sum test) were used to analyze the data from May 1994 through October 1995 presented by Hunchak-Kariouk (1999). The Kruskal-Wallis nonparametric test was used to identify differences in concentrations and yields of selected water-quality characteristics among the monitoring sites at the 0.05 significance level. The Tukey multiple comparison test was used to rank monitoring sites by concentration and yield values. The Wilcoxon rank-sum test was used to test for differences in water quality attributable to stream discharge (base flow or stormflow) and season (growing or nongrowing seasons).

The complete data set (1994-99) is large enough to allow for the use of parametric statistical methods for most water-quality characteristics. Such methods (t-tests, analysis of variance (ANOVA), and multiple comparisons) are designed for use with normally distributed data. A graphical evaluation of normality (quantile-quantile (QQ) plot) was used as an alternative to the Kolmogron-Smirnov test to determine the deviation from normality of the pooled data for each water-quality characteristic for each event type. A QQ plot should be approximately linear if the specified distribution (in this case Gaussian) is the correct model. Interpretation of the plot is subjective; however, nearly all constituents deviated widely from a normal distribution. Log-transformed data were much closer to a normal distribution in most cases, and the effectiveness of the log transformation in normalizing the data led to its use in all data subjected to parametric statistical methods.

A statistical analysis hierarchy was developed for analyzing the complete data set (fig.8). Each water-quality characteristic was considered separately, as was each event type (base flow and stormflow). Concentration and yield values were analyzed independently. The effect of filtration was evaluated with a paired-t test for chemical species that were quantified in filtered and unfiltered samples. A two-factor analysis of variance (ANOVA) was applied to each event type (base flow and stormflow event) to investigate the effects of season (growing and nongrowing) and degree of land development (comparison among monitoring sites). A 95-percent confidence level was used in all statistical analyses. The Tukey multiple comparison test was used in cases where the null hypothesis H_o, no difference among monitoring sites, was not supported at the 95-percent confidence level. Additional statistical analysis was conducted in order to determine whether concentrations and yields of analytes varied as a function of time (hydrograph segment) during sampling. Stormflow samples were categorized as (1) base flow (initial sample before precipitation began), (2) rising limb of the hydrograph, (3) peak flow, or (4) falling limb of the hydrograph. Log-normalized concentration and yield values were subjected to one-way ANOVA followed by Tukey multiple-comparison testing. Results of this analysis indicated which segment(s) of the hydrograph resulted in the highest concentrations and loads of each contaminant, and how these values varied within each hydrograph segment.

Relations of Water Quality to Streamflow, Season, and Land Development

All water-quality and hydrologic data collected for this project are included in a database file, recorded on a CD-ROM, that accompanies this report. A table of summary statistics is presented for the selected water-quality characteristics (appendix 1) that is organized in the same manner as the statistical analysis hierarchy.

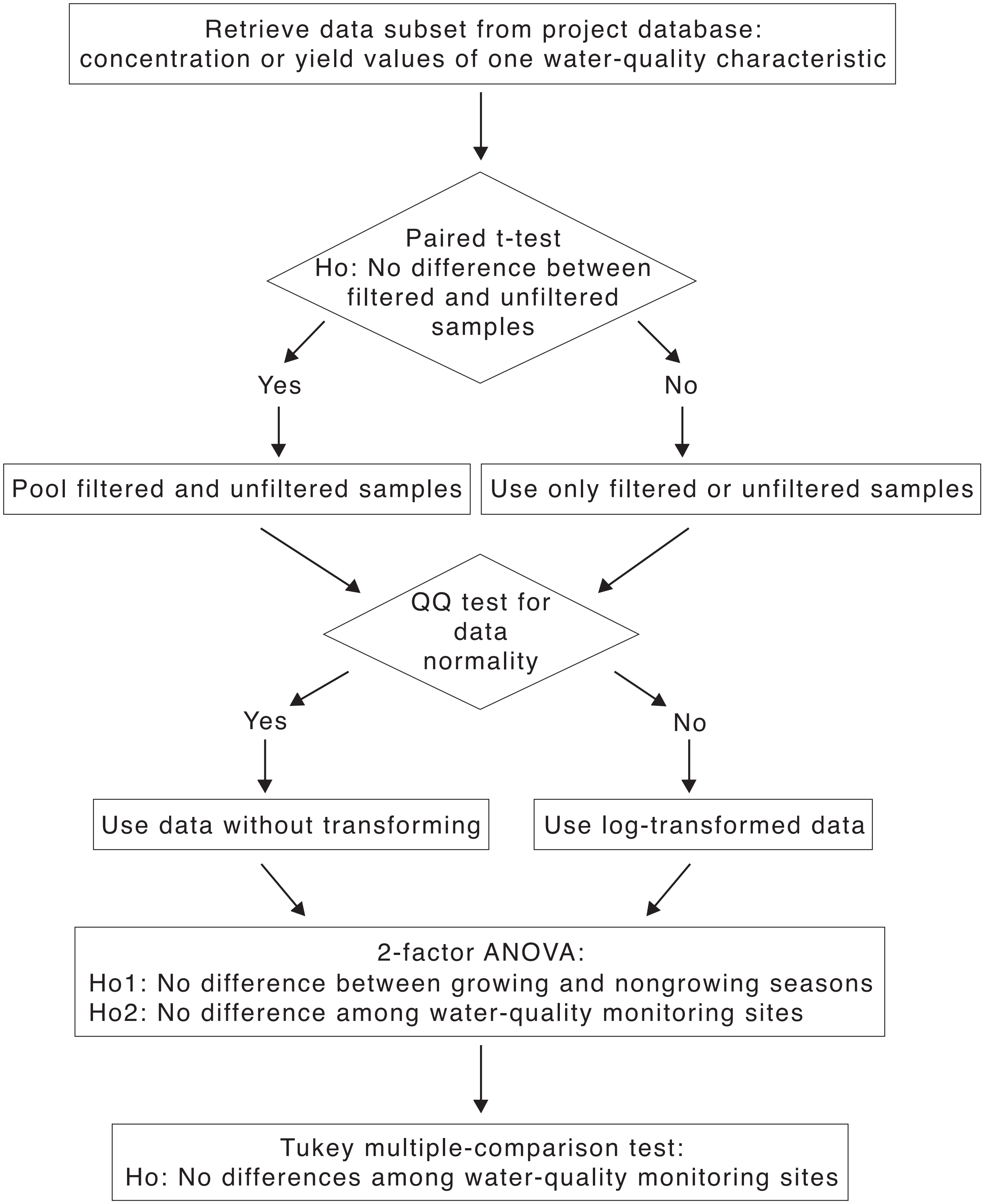


Figure 8. Flowchart showing the steps in statistical analysis for evaluating the effects of season and land development on water quality (concentrations and yields of chemical and microbiological constituents). (Ho, null hypothesis; QQ, quantile-quantile; ANOVA, analysis of variance.)

Water-Quality Data

In this section, concentrations and yields of selected water-quality characteristics in the streams studied are discussed in relation to hydrologic conditions, season, and land development. Graphical and statistical comparisons of slightly developed (Davenport Branch), moderately developed (Wrangle Brook), and highly developed (Long Swamp Creek) subbasins are presented. For each constituent, two-way analysis of variance (ANOVA) was conducted to determine whether concentration or yield varies as a function of season or land development. Three null hypotheses were tested in each ANOVA: no difference between growing and nongrowing season, no difference among sites, and no interaction between the season and site variables. For each constituent, boxplots of concentration and yield in samples collected during growing and nongrowing seasons during base flow and storms are shown. The results of Tukey multiple comparison tests also are indicated in these figures. Monitoring sites with the same letter designation showed no statistically significant difference in either concentration or yield.

Nitrogen

Nitrogen is an essential element for plant and animal growth; however, sufficiently high concentrations of certain nitrogen species can adversely affect the quality of surface water by causing excess algal growth (eutrophication) or toxicity to aquatic and terrestrial animals. Nitrogen is present in the environment in six different oxidation states, and in organic and inorganic forms. Important forms of nitrogen in surface water are, in decreasing order of oxidation state, nitrate, nitrite, organic nitrogen, and ammonia. Biological processes primarily control nitrogen cycling. Total nitrogen represents the sum of nitrate, nitrite, ammonia, and organic nitrogen. Nitrogen in all these forms can find its way into algal production pathways; the inorganic forms can be utilized directly, and organic nitrogen can be converted to ammonia by bacteria. Nitrogen enters aquatic environments from fertilizers, agricultural wastes, decomposition of organic matter, atmospheric deposition, biotic fixation, and soils and rocks. Ground water and storm runoff are important sources of nitrate and ammonia in surface water. High concentrations of nitrite and nitrate can reduce the oxygen-carrying capacity of hemoglobin in warm-blooded animals. Un-ionized ammonia is toxic to aquatic organisms.

Total Nitrogen

Total nitrogen concentrations measured in filtered and unfiltered samples were statistically compared by using a paired t-test. The null hypothesis of no difference was rejected with a probability greater than 99 percent. The mean difference between concentrations of total nitrogen in filtered and unfiltered samples was 36.7 μg/L, about 5 percent, with the unfiltered samples systematically containing higher concentrations than filtered samples. All further statistical analyses of total nitrogen data were conducted by using concentration values measured in unfiltered samples.

Results of a two-way ANOVA showed significant differences in yields, but not in concentrations, between base-flow samples in the growing season and those in the nongrowing season. Boxplots of total nitrogen concentration and yield in samples collected during growing and nongrowing seasons during base flow and storms are shown in figures 9 and 10. Total nitrogen concentrations in base flow at monitoring sites LSC2, WB1, and WB2 were similar during growing and nongrowing seasons, and the null hypothesis of no difference in concentration was supported at the 95-percent confidence level. Concentrations in samples from monitoring site DB were systematically lower than those from the other monitoring sites by about half. Monitoring sites JB and WB3 were sampled during only one and two events, respectively, and samples had low concentrations of total nitrogen compared with concentrations at the other monitoring sites.

Concentrations of total nitrogen in unfiltered stormflow samples showed the same patterns as in base-flow samples (fig. 9). Concentrations of total nitrate in samples from monitoring sites LSC2, WB2, and WB1 were not significantly different during growing and nongrowing seasons. Concentrations of total nitrate at monitoring site DB were considerably lower than at the other sites. Concentrations of total nitrogen in stormflow and base-flow samples were not significantly different. Total nitrogen concentrations for monitoring site WB3, sampled only in the growing season, were not significantly different from those for monitoring sites LSC2, WB2, WB1, or DB.

The lower total nitrogen concentrations observed at monitoring site DB (slightly developed) than at monitoring sites in moderately and highly developed subbasins (fig. 9) indicate a relation between total nitrogen concentrations and land development. Residential development in the Davenport Branch subbasin (monitoring site DB) is about 50 percent less extensive than in the Wrangle Brook subbasin (monitoring sites WB2, WB1, and WB3), and there is a greater percentage of miscellaneous land use (forest, agricultural, and water bodies) in the Wrangle Brook subbasin than in the Davenport Branch subbasin. Inspection of the miscellaneous use areas could indicate the reasons for the high total nitrogen concentrations in Wrangle Brook, which are similar to those in Long Swamp Creek.

During base flow, yields of total nitrogen at the two monitoring sites on Wrangle Brook (WB1 and WB2) were significantly higher than those at Long Swamp Creek (LSC2) and Davenport Branch (DB) during growing and nongrowing seasons (fig. 10). Yields from monitoring sites LSC2 and DB were not significantly different. Yields did not differ between growing and nongrowing seasons at any monitoring site during base flow. Yields in stormflow during the growing season at monitoring sites LSC 2, WB 2, and WB1 were not significantly different and were significantly higher than monitoring site DB. Monitoring sites WB1 and WB2 had the highest

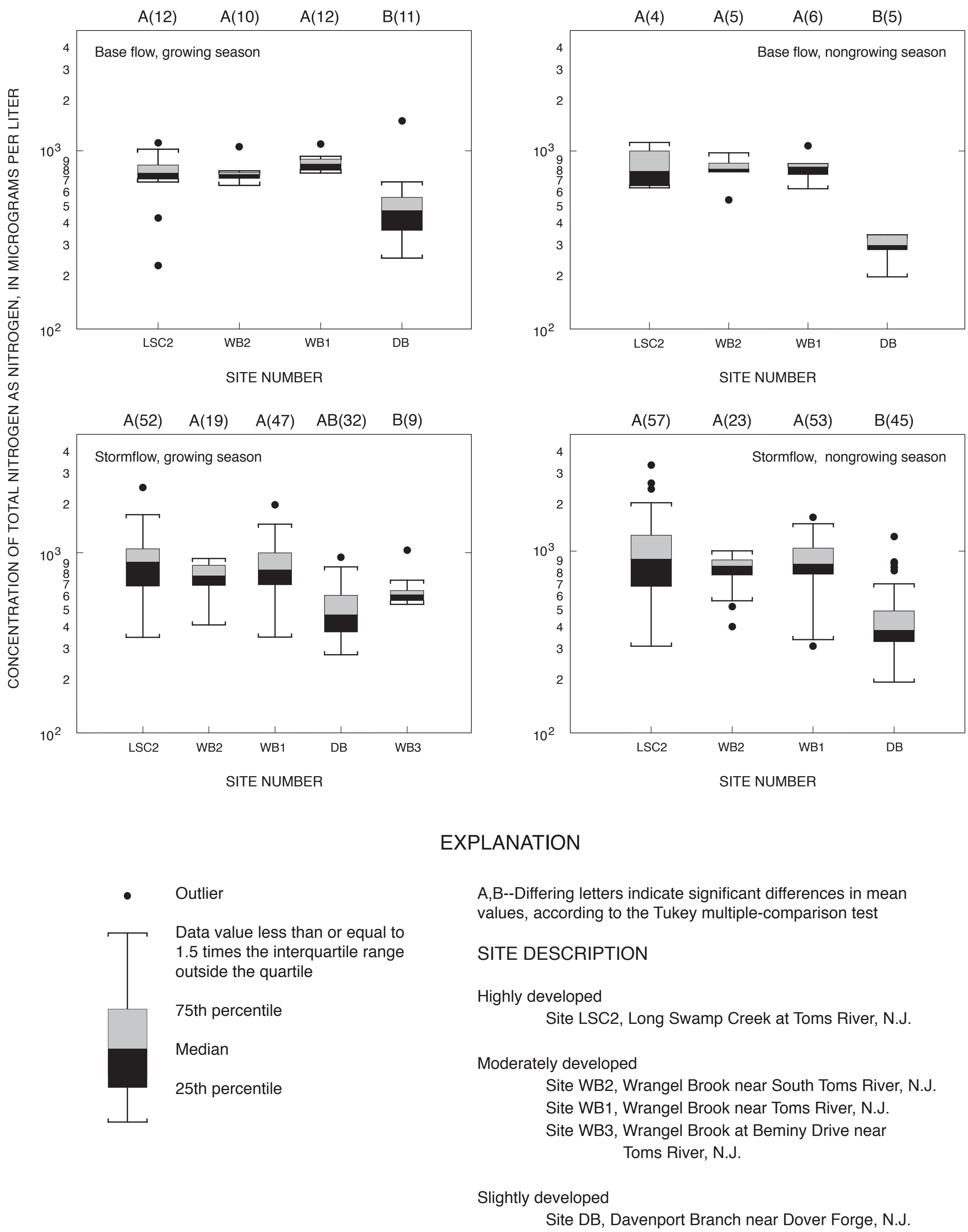


Figure 9. Distributions of total nitrogen concentrations in unfiltered water samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

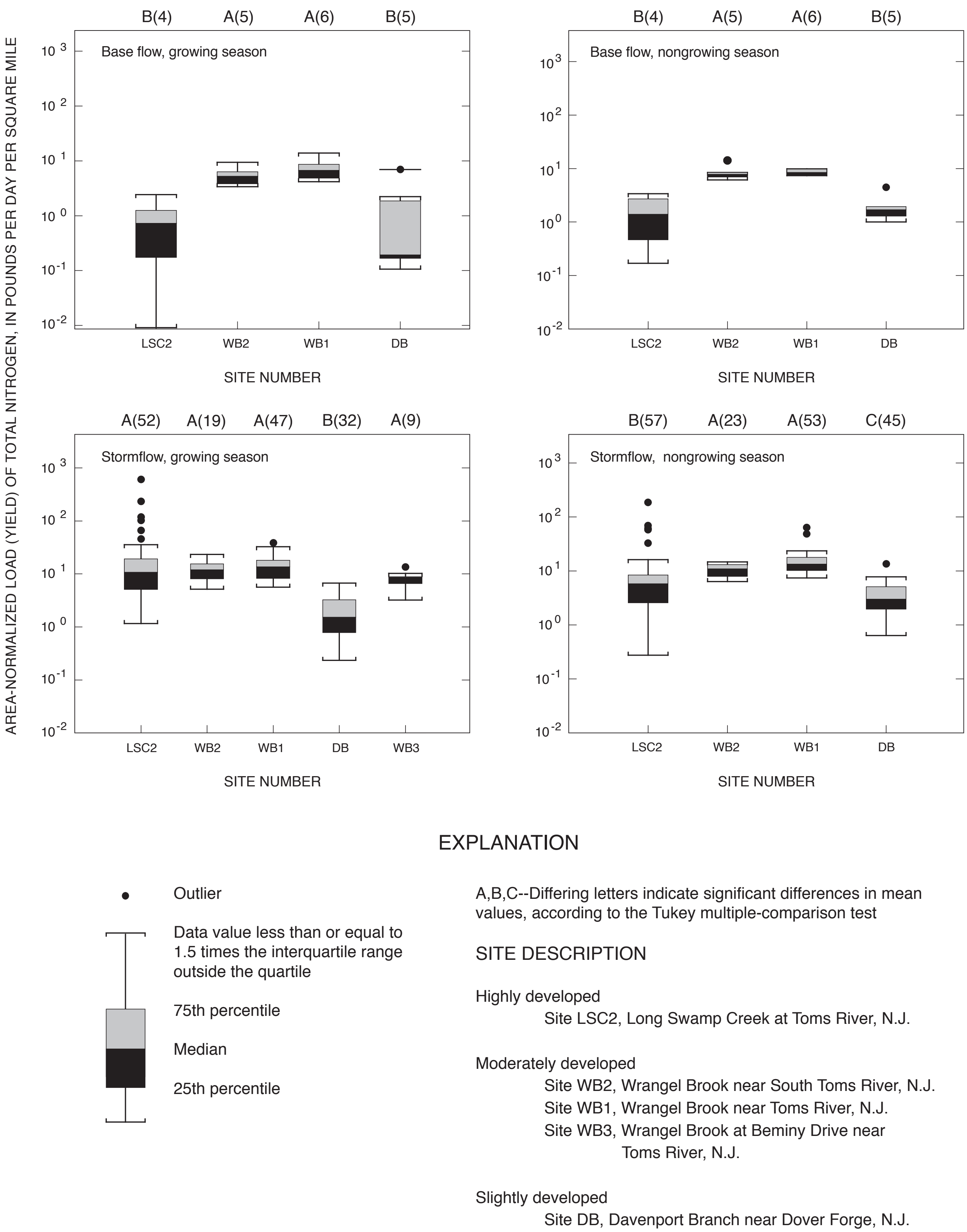


Figure 10. Distributions of area-normalized loads (yields) of total nitrogen calculated for unfiltered water samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

total nitrogen yields in the nongrowing season (median value of 13.4 and 11.0 pounds per day per square mile ((lb/d)/mi^2), with lower yields observed at monitoring site LSC2 (median value of 5.8 (lb/d)/mi^2), and the lowest yields at monitoring site DB (median value of 3.0 (lb/d)/mi^2). Agriculture upstream from the Wrangle Brook monitoring sites could contribute to the high concentrations and yields of total nitrogen in base flow in this subbasin. An experimental secondary-effluent recharge operation (spray field) was conducted in the 1980s near Wrangle Brook (R.A. Zampella, New Jersey Department of Environmental Protection, oral commun., 2000 and 2004), and some nitrogen from this activity may still be discharging into the surface water.

Boxplots of total nitrogen concentrations and yields as a function of hydrograph segment are shown in figure 11. Single-factor ANOVA was used to test for heterogeneity among the hydrograph segments (base flow, rising limb, peak flow, and falling limb) with respect to concentration and yield of total nitrogen. Although the concentrations in base-flow samples, in general, appear to be higher than concentrations in samples collected during the other hydrograph segments at all three sites, the differences were not significant at the 95-percent confidence level. In contrast, yields were significantly lower during base flow, highest during peak flow, and decreased during the falling limb at Long Swamp Creek and Wrangle Brook. For these sites, the total nitrogen yield is related to the volumetric flow rate. No relation between yield and hydrograph segment is evident for Davenport Branch (DB). The streamflow in Davenport Branch is much less responsive to precipitation than streamflow in Long Swamp Creek and Wrangle Brook, probably because there is less urban development in the Davenport Branch drainage area with less impervious surface.

Nitrate

The USEPA maximum contaminant level (MCL) for nitrate (NO_3^-) of 10 mg/L as N is the National primary drinking water standard (U.S. Environmental Protection Agency, 1999a), which is equal to the New Jersey Drinking Water MCL. When ingested, up to 10 percent of nitrate is converted to nitrite, which interferes with the oxygen carrying capacity of the blood, particularly in infants (blue baby syndrome, methemoglobinemia). About 59 million pounds of nitrate is released to water bodies annually in the U.S., of which 41 million pounds originates from nitrogenous fertilizer**.** The nitrate-N surface-water criteria are 10 mg/L for FW2 streams and 2 mg/L for PL streams (New Jersey Department of Environmental Protection, 2003).

Results of the paired t-test indicate that there is no significant difference between NO_3-N concentrations in filtered and unfiltered samples. Only filtered samples were used in the statistical analyses that follow.

Results of a two-way ANOVA indicated heterogeneity among the monitoring sites with respect to nitrate concentration and yield in the growing and nongrowing seasons. At monitoring site DB, nitrate concentrations were consistently lower than at other monitoring sites (fig. 12). This result is confirmed by Tukey test comparisons of means. Results of the Tukey test indicate that for monitoring sites LSC2, WB1 and WB2, nitrogen concentrations in filtered samples were not significantly different, and for monitoring site DB concentrations were significantly lower during base flow and storms than for sites LSC2, WB1 and WB2 (fig. 12; table 6). Mean concentrations in base-flow and storm samples collected in the nongrowing season were slightly higher than those collected in the growing season at all monitoring sites. This result would not be expected if agricultural lawn-care fertilizer were responsible for a substantial part of the nitrate.

Mean concentrations of nitrate in base-flow and stormflow samples were similar at each monitoring site for both seasons. Rapid discharge of recently recharged water into the streams in these relatively small subbasins could account for the similarity in nitrate concentration between base flow and stormflow. Age-dating the base-flow water could be used to determine whether this is the case.

Yields of nitrate in filtered samples from the Wrangle Brook monitoring sites (fig. 13) follow a pattern similar to that of concentrations--the highest yields under all conditions were present in samples from Wrangle Brook. Results of Tukey tests indicate that mean yields at monitoring sites LSC2 and DB were not significantly different and were lower than mean yields at monitoring sites WB2 and WB1 during base flow in the growing and nongrowing seasons (fig. 13; table 6). The mean yields at monitoring site LSC2 were significantly higher during stormflow than during base flow in the growing seasons (4.6 (lb/d)/mi^2 and 0.3 (lb/d)/mi^2, respectively), and nongrowing seasons (2.3(lb/d)/mi^2 and 0.7 (lb/d)/mi^2, respectively). Monitoring DB had a higher mean yield of nitrate in the growing season during stormflow (0.25 (lb/d)/mi^2) than during base flow (0.017 (lb/d)/mi^2). Mean yields were similar for base flow and stormflow for all other monitoring sites.

The high concentrations and yields of nitrate for Wrangle Brook in this study compared with the other studies could result from the use of an experimental secondary domestic wastewater disposal facility 5 to 10 years before this study began (R.A. Zampella, New Jersey Department of Environmental Protections, oral commun., 2000 and 2004). The high concentrations of nitrate, organic nitrogen, and total nitrogen observed under base-flow conditions at the Wrangle Brook sites are consistent with concentrations when such an installation is present.

Nitrate concentrations in filtered samples increased during the rising limb and peak flow at Long Swamp Creek (fig. 14); the nitrate concentration apparently was higher in runoff water than in base-flow water. This result was not the case in Wrangle Brook and Davenport Branch, where lower levels of urbanization likely contributed less nitrate to runoff. Yields of nitrate followed similar patterns—they increased during the rising limb and at peak flow in Long Swamp Creek, but not in Wrangle Brook or Davenport Branch. Thus, the boxplots illustrate that concentrations and loads of nitrate are

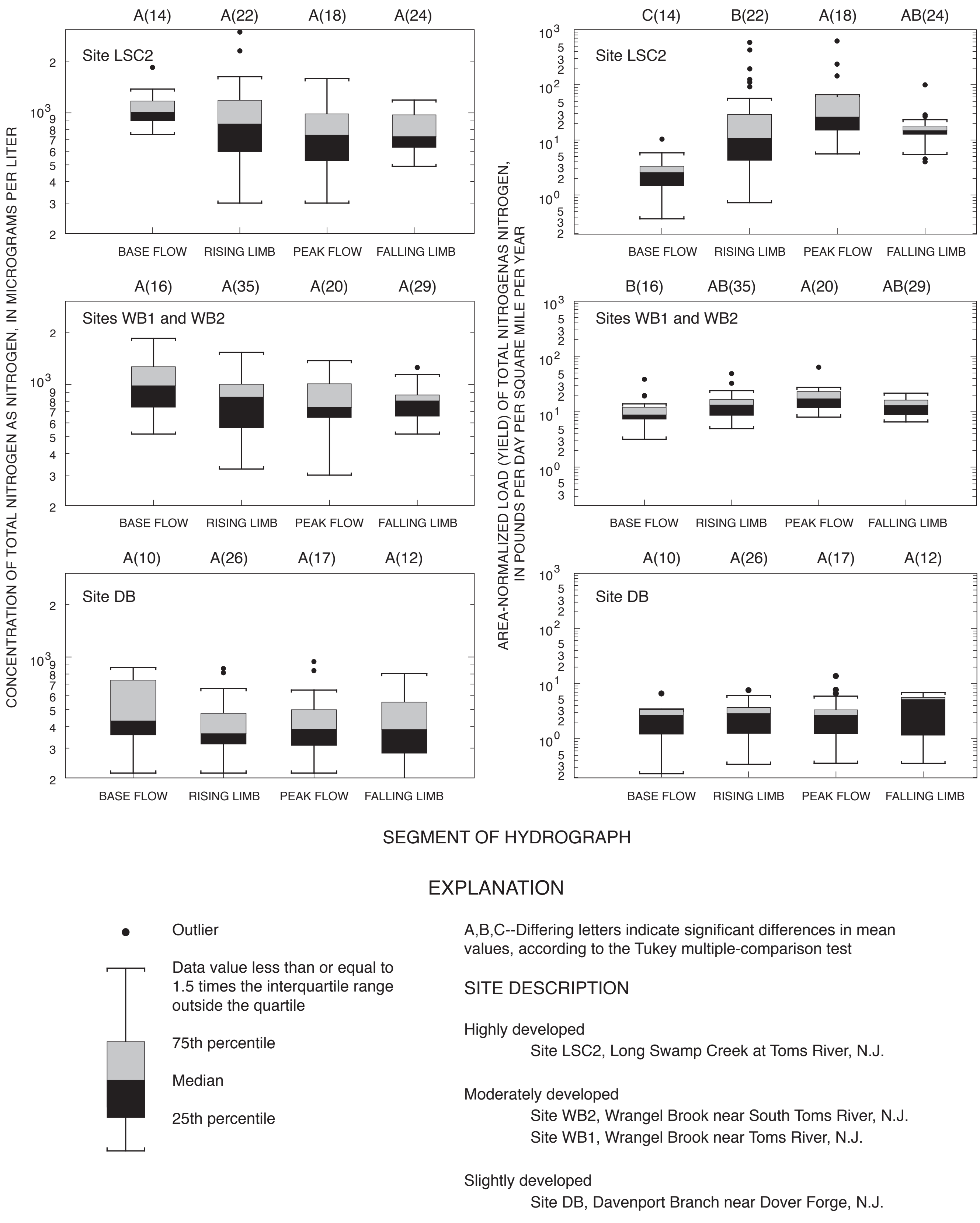


Figure 11. Distributions of total nitrogen concentrations and area-normalized loads (yields) in unfiltered water samples collected during stormflow, grouped by hydrograph segments at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

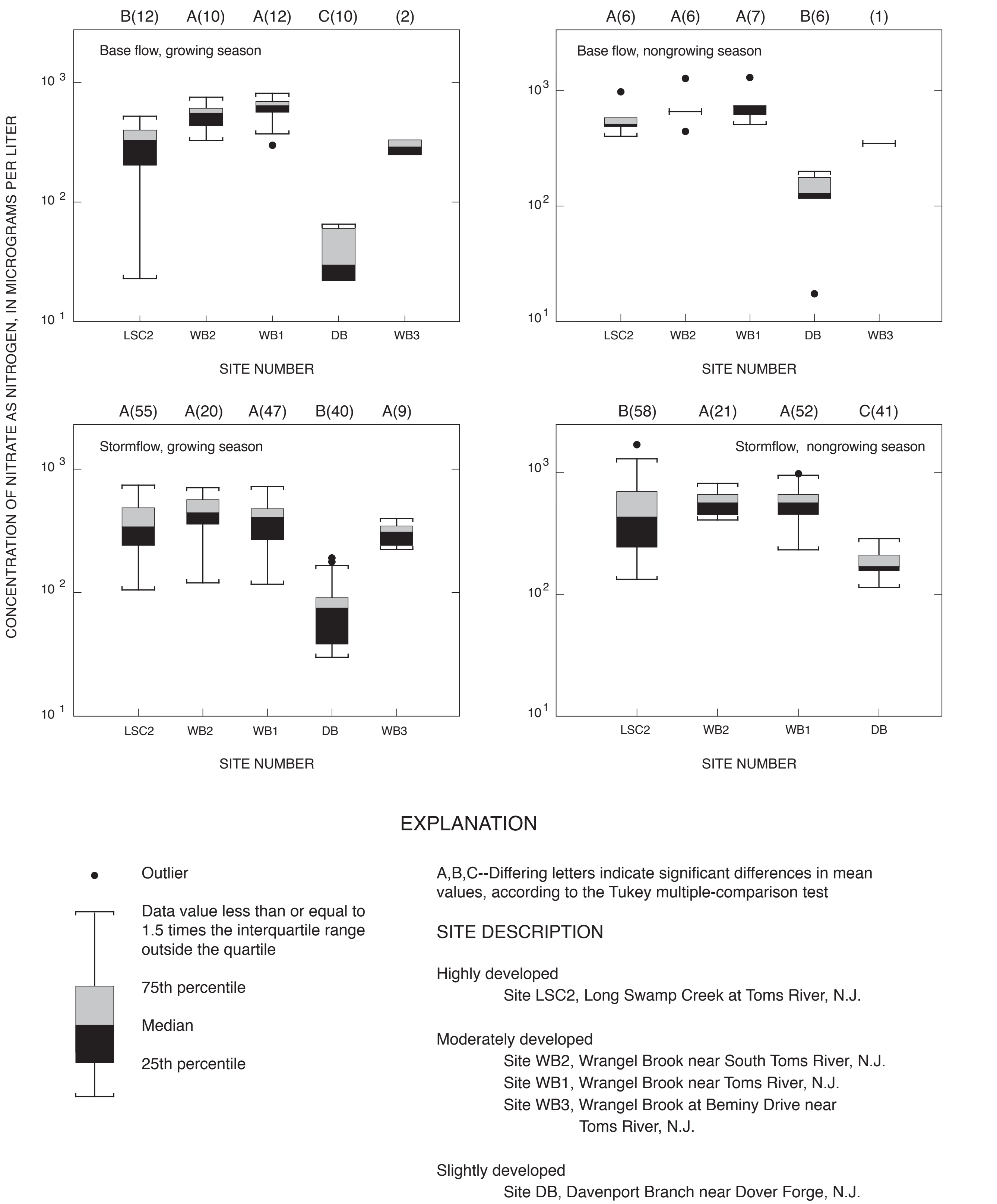


Figure 12. Distributions of nitrate concentrations in filtered water samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

Table 6. Results of statistical tests to determine whether constituent concentrations and yields differ among sites during growing and nongrowing seasons, Toms River drainage basin, N.J.

[A,B,C, differing letters indicate significant differences in mean values, according to the Tukey multiple-comparison test; --, no data are available; 0-phosphate, ortho phosphate; TSS, total suspended solids; site locations are shown on Fig. 1]

[1]Constituent	Analysis of variance results				[2]Tukey Test, growing season					Tukey Test, nongrowing season				
	Condition	[3]Ho_1	[4]Ho_2	[5]HO_3	[6]LSC2	[7]WB2	[8]WB1	[9]DB	[10]WB3	LSC2	WB2	WB1	DB	WB3
Total nitrogen concentration	Base flow	Accept	Reject	Reject	A	A	A	B	--	A	A	A	B	--
Total nitrogen concentration	Stormflow	Accept	Reject	Reject	A	A	A	B	AB	A	A	A	B	--
Total nitrogen yield	Base flow	Reject	Reject	Reject	B	A	A	B	--	B	A	A	B	--
Total nitrogen yield	Stormflow	Accept	Reject	Accept	A	A	A	B	A	B	A	A	C	--
Nitrate-N concentration	Base flow	Reject	Reject	Accept	B	A	A	C	--	A	A	A	B	--
Nitrate-N concentration	Stormflow	Reject	Reject	Reject	A	A	A	B	A	B	A	A	C	--
Nitrate-N yield	Base flow	Reject	Reject	Reject	B	A	A	B	--	B	A	A	B	--
Nitrate-N yield	Stormflow	Reject	Reject	Accept	A	A	A	B	A	B	A	A	C	--
Organic nitrogen concentration	Base flow	Reject	Reject	Reject	AB	B	B	A	--	A	AB	AB	B	--
Organic nitrogen concentration	Stormflow	Reject	Reject	Accept	A	B	A	A	AB	A	A	A	A	--
Organic nitrogen yield	Base flow	Reject	Reject	Accept	B	A	A	AB	--	A	A	A	A	--
Organic nitrogen yield	Stormflow	Reject	Reject	Reject	A	A	A	B	AB	A	A	A	B	AB
o-Phosphate concentration	Base flow	Reject	Accept	Accept	A	A	A	A	--	A	A	A	A	--
o-Phosphate concentration	Stormflow	Accept	Reject	Accept	A	BC	B	C	AB	A	BC	B	C	--
o-Phosphate yield	Base flow	Accept	Reject	Accept	B	AB	A	B	--	B	A	A	A	--
o-Phosphate yield	Stormflow	Accept	Reject	Reject	A	B	B	C	AB	A	AB	A	B	--
TSS concentration	Base flow	Reject	Accept	Accept	A	A	A	A	--	A	A	A	A	--
TSS concentration	Stormflow	Accept	Reject	Accept	AB	B	A	B	AB	A	AB	A	B	--
TSS yield	Base flow	Accept	Reject	Accept	B	A	A	B	--	B	A	A	B	--
TSS yield	Stormflow	Accept	Reject	Accept	B	B	A	C	AB	B	AB	A	B	--
Ammonia concentration	Base flow	Reject	Reject	Accept	A	B	B	AB	--	A	C	BC	B	--
Ammonia concentration	Stormflow	Reject	Reject	Reject	A	B	B	B	B	A	BC	B	C	--
Ammonia yield	Base flow	Accept	Accept	Accept	A	A	A	A	--	A	A	A	A	--
Ammonia yield	Stormflow	Reject	Reject	Accept	A	B	AB	C	AB	A	BC	AB	C	--
Coliform bacteria concentration	Base flow	Reject	Reject	Accept	A	B	B	B	--	A	A		A	--
Coliform bacteria concentration	Stormflow	Reject	Reject	Accept	A	B	AB	C	AB	A	A	A	B	--
Coliform bacteria yield	Base flow	Reject	Reject	Accept	A	A	A	A	--	A	A	A	A	--
Coliform bacteria yield	Stormflow	Reject	Reject	Accept	A	A	A	B	A	A	A	A	B	--

[1]All concentration and yield data were log-transformed before statistical analyses were performed

[3]Ho_1: Null hypothesis, no difference between growing and nongrowing seasons.

[4]Ho_2: Null hypothesis, no difference among sites.

[5]Ho_3: Null hypothesis, no interaction between explanatory variables (seasons and sites).

[6]LSC2: Monitoring site on Long Swamp Creek at Toms River, N.J.

[7]WB2: Monitoring site on Wrangle Brook near South Toms River, N.J.

[8]WB1: Monitoring site on Wrangle Brook near Toms River, N.J.

[9]DB: Monitoring site on Davenport Branch near Dover Forge, N.J.

[10]WB3: Monitoring site on Wrangle Brook near South Toms River, N.J.

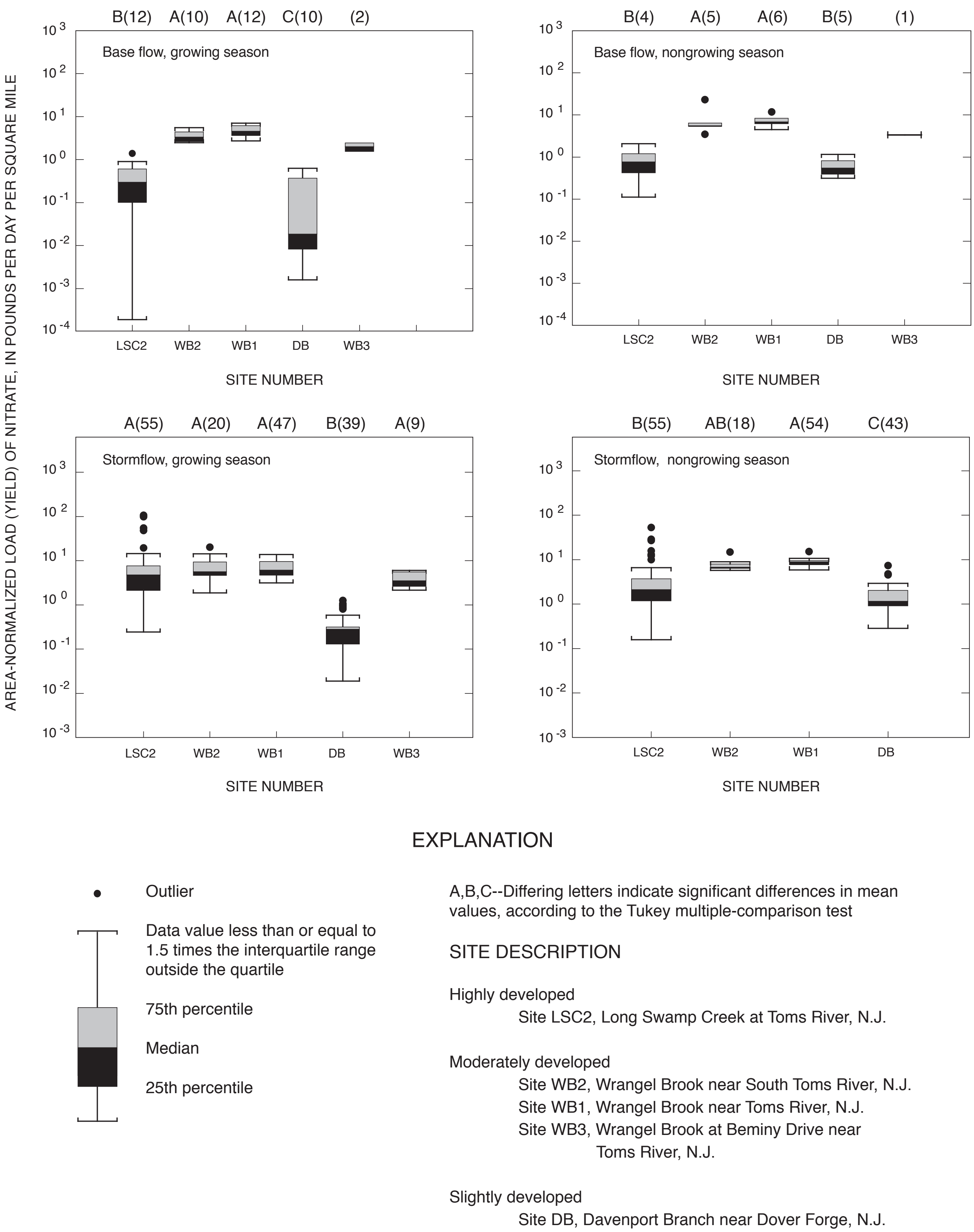


Figure 13. Distributions of area-normalized loads (yields) of nitrate calculated for filtered water samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

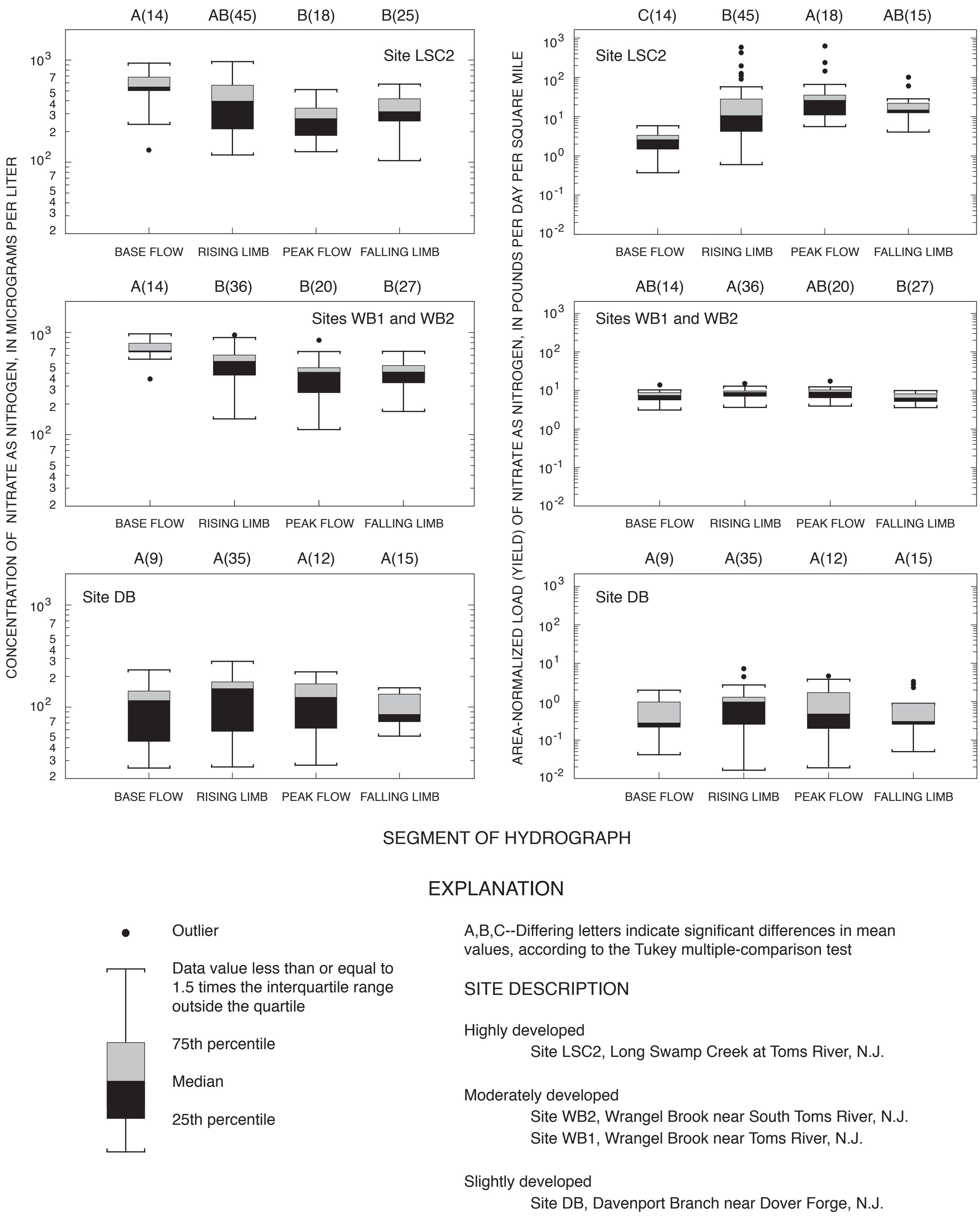


Figure 14. Distributions of nitrate concentrations and area-normalized load (yields) in unfiltered water samples collected during stormflow, grouped by hydrograph segments at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

a function of land use (urbanization). Impervious surface and urban sources of nitrate (primarily application of commercial fertilizers) are likely explanations for these levels of nitrate concentration and load.

Organic Nitrogen

In surface water, organic nitrogen is present in amino acids, proteins, nucleic acids, and other biological macromolecules. The nitrogen content of organic matter can be approximated by Redfield stoichiometry, which is an expression representing the molecular formula of algal protoplasm (Redfield, 1958) given as

$$106\ CO_2 + 16\ NO_3^- + HPO_4^{2-} + 122\ H_2O + 18\ H^+ <=> C_{106}H_{263}O_{110}N_{16}P_1 + 138\ O_2\ . \quad (14)$$

Using this formula to represent the composition of dissolved organic carbon (DOC), nitrogen represents slightly less than 10 percent of the total DOC. Concentrations of organic nitrate are determined in this work by subtracting the concentrations of inorganic species (nitrate, nitrite, and ammonia) from that of total nitrogen.

Results of a two-way ANOVA indicate that there are significant differences in concentrations and yields of organic nitrogen at the 95-percent confidence level (1) between growing and nongrowing seasons in base-flow and stormflow samples and (2) among the monitoring sites in base-flow and stormflow samples.

Boxplots of organic nitrogen-N concentrations and yields are shown in figures 15 and 16, respectively. The null hypothesis of no difference among the monitoring sites for concentration of organic nitrogen was rejected for all four sampling conditions (base flow during growing and nongrowing seasons, and stormflow during growing and nongrowing seasons). Results of the Tukey test showed that during base flow in the growing season for monitoring site DB concentrations were significantly higher than those for the Wrangle Brook monitoring sites, which were indistinguishable from those for monitoring site LSC2 (fig. 14; table 6). Although the Tukey test distinguished between some pairs of monitoring sites, the median and mean differences in concentrations were not great, as shown in appendix 1. Median concentrations ranged from 263 to 357 μg/L in the growing season and from 183 to 334 μg/L in the nongrowing season.

Yields of organic nitrogen did not differ significantly among the sites under all conditions with the exception of lower yields during base flow in the growing season at LSC2 and during stormflow in the growing season at DB. Monitoring site LSC2 had a much greater range of yields during base flow than did the other monitoring sites.

The relations between organic nitrogen concentrations and loads and hydrograph segments at the three sites (fig. 17) are similar to those for total nitrogen. Concentrations did not change substantially during precipitation events, but yields increased with increases in discharge at Long Swamp Creek and Wrangle Brook and were homogeneous in Davenport Branch. Therefore, loads of organic nitrogen in these subbasins appear to be related to urbanization and its effect on stream flashiness, which is the time for a rainfall event to be observed in the stream hydrograph.

Ammonia

Ammonia (NH_3) is the most reduced form of nitrogen in surface water. It is present in untreated domestic wastewater at approximately 12 to 50 mg/L as N (Metcalf and Eddy Inc., 1979). Additional sources of ammonia to surface water are commercial fertilizer and bacterial decomposition of organic matter under reducing (anaerobic) conditions. If ammonia is introduced into a pristine water system (neutral pH or slightly less), it is readily converted to nitrate by nitrification (National Research Council, 1979).

Ammonia toxicity to aquatic organisms is well documented. Ammonia toxicity levels are affected by dissolved oxygen concentrations, temperature, pH, previous acclimation to ammonia, carbon dioxide concentrations, and the presence of other toxic compounds (U.S. Environmental Protection Agency, 1991). A National Criterion for Ammonia in Fresh Water was established by the U.S. Environmental Protection Agency (USEPA) in 1984 (U.S. Environmental Protection Agency, 1985) and amended in 1999 (U.S. Environmental Protection Agency, 1999b). This criterion was based on research showing that uncharged ammonia, which predominates at higher pH values and lower temperatures, is more toxic to invertebrates and fishes than the charged ammonium species, which predominates at lower pH levels and higher temperatures. The unionized ammonia (NH_3) can cross cell membranes more readily at higher pH values. The increased concentration that can enter the aquatic organism heightens the toxic effect (National Research Council, 1979).

The pH dependence of the ammonia/ammonium ratio in water can be expressed as

$$NH_4^+ = NH_3 + H^+ \quad (15)$$

$$K = [NH_3][H^+]/[NH_4^+]. \quad (16)$$

The equilibrium constant K is a function of temperature; this relation has been described by Emerson and others (1975) with the equation

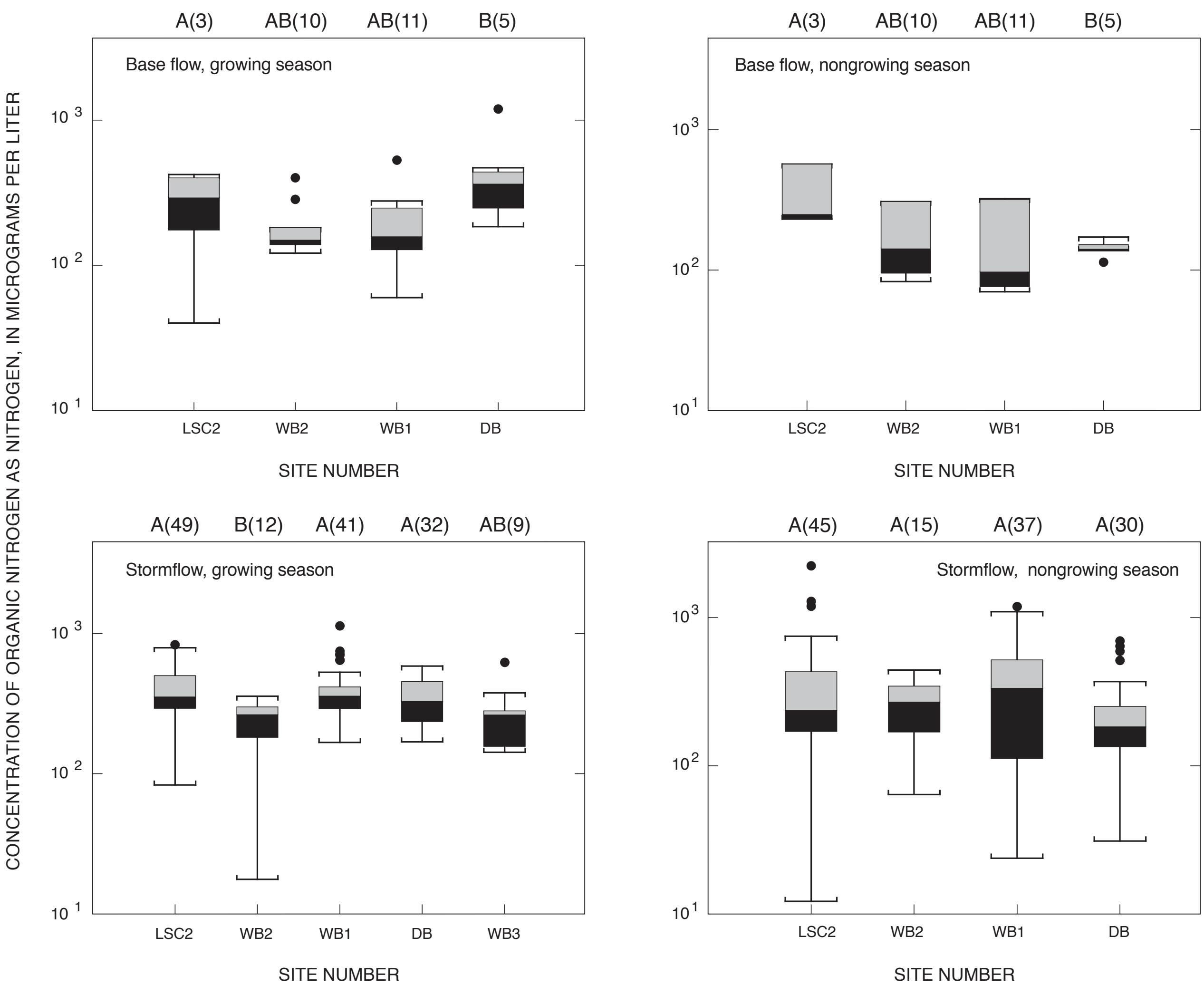
$$pK = 0.09018 + (2729.92)/(273.2 + T) \quad (17)$$

where,

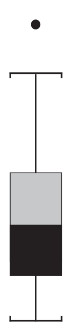
pK = -log10 K

and

T = temperature in degrees Celsius.



EXPLANATION



Outlier

Data value less than or equal to 1.5 times the interquartile range outside the quartile

75th percentile

Median

25th percentile

A,B,--Differing letters indicate significant differences in mean values, according to the Tukey multiple-comparison test

SITE DESCRIPTION

Highly developed
Site LSC2, Long Swamp Creek at Toms River, N.J.

Moderately developed
Site WB2, Wrangel Brook near South Toms River, N.J.
Site WB1, Wrangel Brook near Toms River, N.J.
Site WB3, Wrangel Brook at Beminy Drive near Toms River, N.J.

Slightly developed
Site DB, Davenport Branch near Dover Forge, N.J.

Figure 15. Distributions of organic nitrogen concentrations in water samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

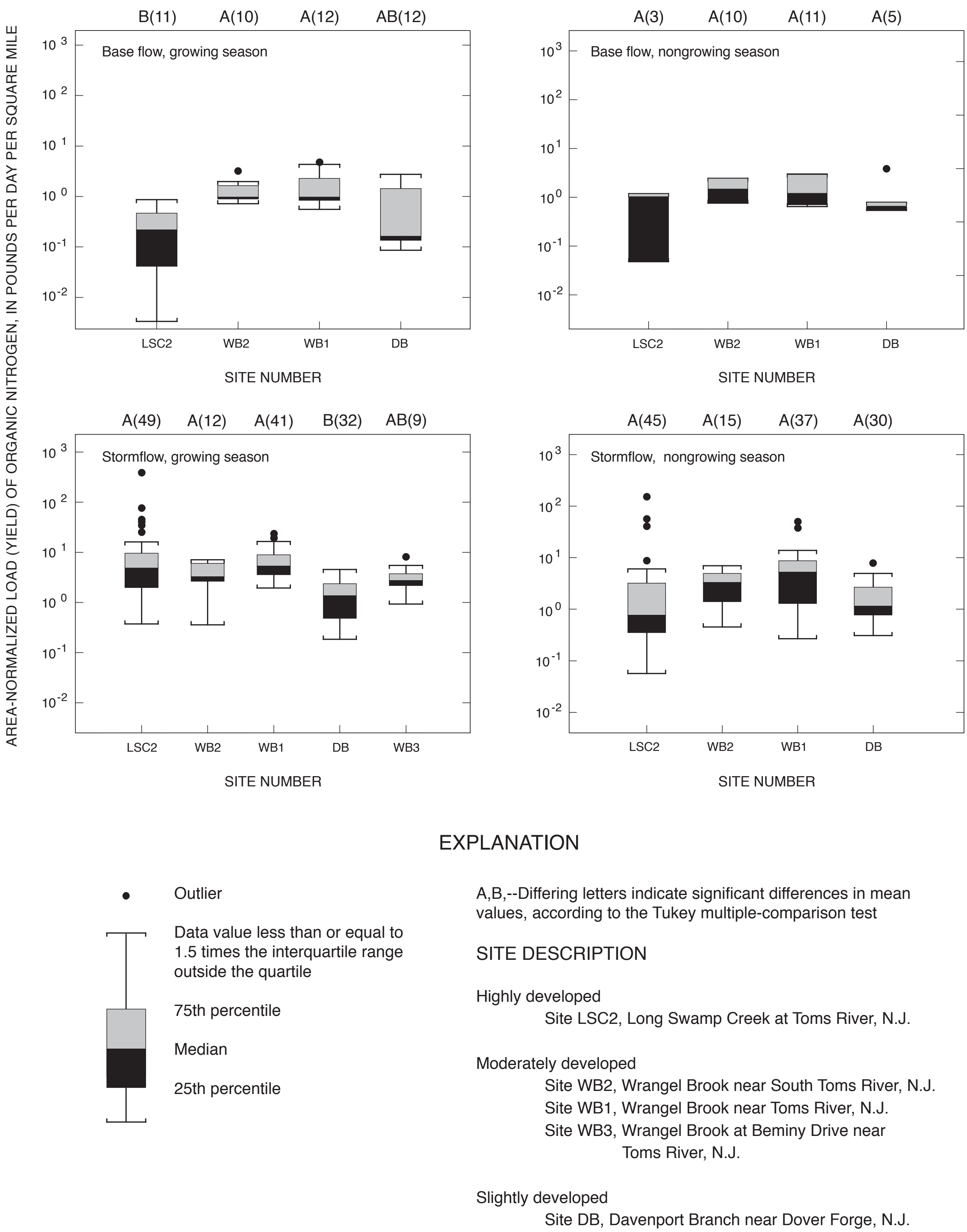


Figure 16. Distributions of area-normalized loads (yields) of organic nitrogen calculated for filtered water samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

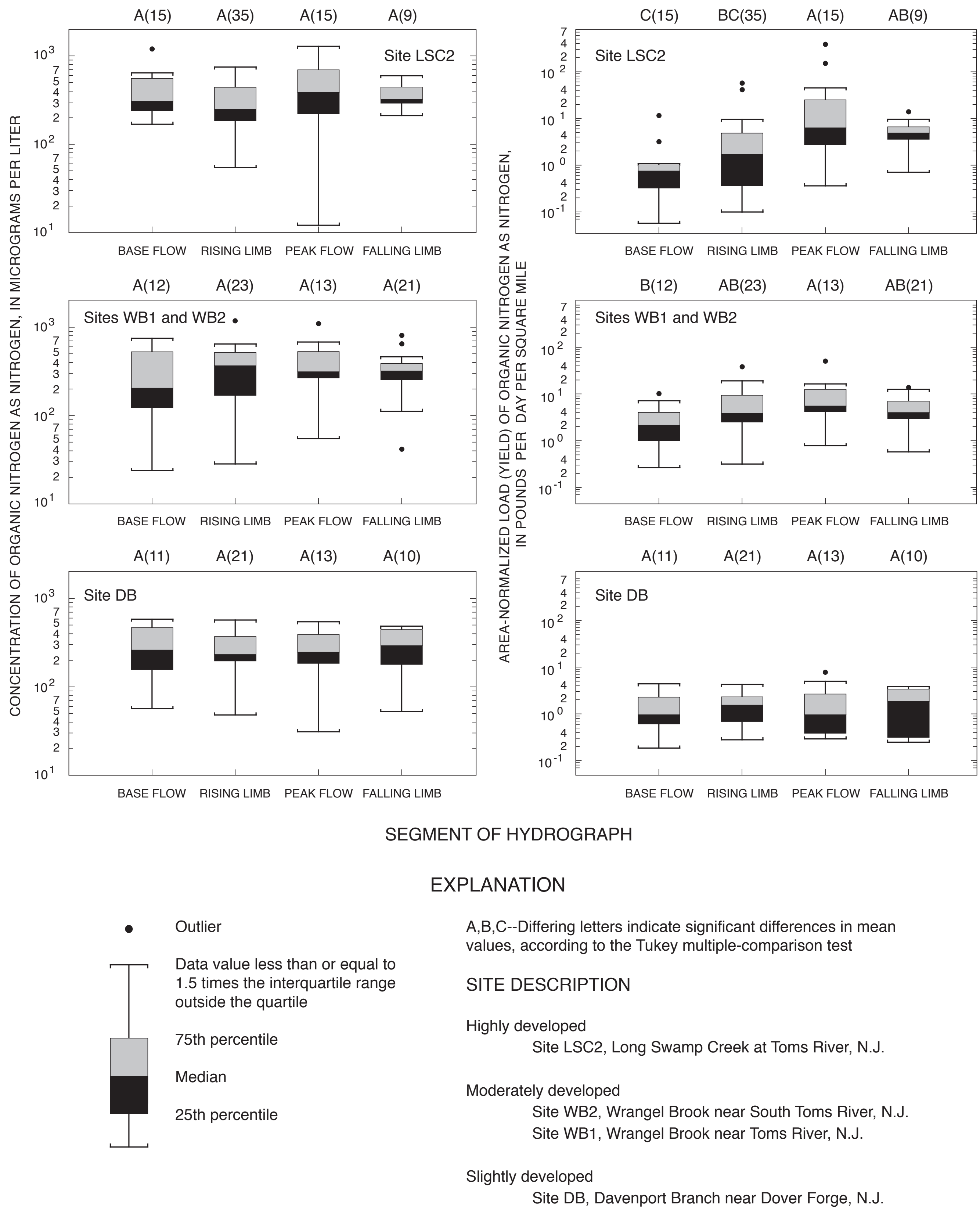


Figure 17. Distributions of organic nitrogen concentrations and area-normalized loads (yields) in unfiltered water samples collected during stormflow, grouped by hydrograph segments at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

Federal and State standards for acute (1-hour, USEPA, or 3-hour, NJDEP) and chronic (30-day) exposure to ammonia in mg/L as N consider the ammonia/ammonium equilibrium condition, water temperature, designated uses, and whether or not salmonid fish and early life-stage fish are present (U.S. Environmental Protection Agency, 1999b; New Jersey Department of Environmental Protection, 2003).

Filtered-water, unfiltered-water, and particulate samples were analyzed for ammonia. The median loss from filtration (difference between filtered and unfiltered samples) was 4.2 μg/L or 9.0 percent. Losses as high as 82.1 percent were observed for some samples. A paired t-test determined that differences between filtered and unfiltered samples were significant at the 95-percent confidence level. Therefore, filtered and unfiltered ammonia concentrations are considered separately. Only results for filtered ammonia are discussed in this report. Summary statistics for filtered ammonia are shown in appendix 1. Concentrations ranged from 2.07 μg/L (base flow, nongrowing season at monitoring site WB2) to 682 μg/L (base flow, growing season at monitoring site LSC2). Yields ranged from 0.0055 (lb/d)/mi^2 (base flow, growing season at monitoring site LSC2) to 113.9 (lb/d)/mi^2 (stormflow, growing season at monitoring site LSC2).

Boxplots of ammonia concentrations at the monitoring sites are shown in figure 18. Median concentrations for samples from monitoring site LSC2 are significantly higher than for samples from other monitoring sites during base flow and stormflow, and during growing and nongrowing seasons. Concentrations in stormflow samples generally are higher than those in base-flow samples. Concentrations in samples from monitoring sites WB2, WB1, and WB3 (all on Wrangle Brook) are similar under all conditions; however, concentrations for monitoring site WB2 (closest to Toms River) tend to be slightly lower. Concentrations of ammonia for monitoring site DB appear to be slightly higher (as high as 346 μg/L) than those for the Wrangle Brook monitoring sites during base flow, but not during stormflow. Two-way ANOVA results indicated that the null hypothesis of no difference in concentrations between growing and nongrowing seasons and among the monitoring sites was rejected for base-flow and stormflow sample sets. Concentrations in the growing season were significantly higher than in the nongrowing season. Ammonia concentrations in filtered base-flow samples collected in the growing season at monitoring site LSC2 in a highly developed subbasin were significantly higher than those at monitoring sites WB2 and WB1; however, the difference in concentrations between monitoring sites LSC2 and DB was within the 95-percent confidence interval as determined by the Tukey multiple comparison test (fig 18; table 6). Ammonia concentrations in filtered samples collected during base flow at monitoring sites WB2, WB1, and WB3 appeared to be equal, although the two samples collected at monitoring site WB3 were not sufficient to apply the Tukey test to this monitoring site. The trend of slightly higher ammonia concentrations at monitoring site DB in a slightly developed subbasin than those at monitoring sites WB2 and WB1 in moderately developed subbasins and at monitoring site JB in an undeveloped subbasin was apparent when the complete (1994-99) data set was tested. This trend also was apparent for the year 1 ammonia concentration data presented by Hunchak-Kariouk (1999). The single base-flow sample from monitoring site JB had a lower ammonia concentration than the mean and median ammonia values for all other monitoring sites. During the nongrowing season, ammonia concentrations at monitoring site LSC2 were significantly higher than those at all other monitoring sites. The median concentration in base-flow samples at this site during the nongrowing season was 49.6 μg/L and during the growing season, 108.2 μg/L. The trend of higher ammonia concentrations in base-flow samples collected during the growing season than in those collected during the nongrowing season indicates rapid solute transport from the point of fertilizer application to shallow ground-water discharge. An alternative explanation could be the more rapid biologically mediated oxidation of ammonia to nitrate in the warmer waters of the growing season. The median concentration in stormflow for monitoring site LSC2, 120 μg/L, was slightly higher than the concentration in base flow and much greater than that at all other monitoring sites during stormflow.

Yields of NH_3-N during stormflow were significantly higher than those during base flow. Yields during base flow at all monitoring sites were not significantly different, but were higher at monitoring site LSC2 than at the other monitoring sites during stormflow (fig. 19). Results of ANOVA for ammonia yields during base flow showed no difference between growing and nongrowing seasons or among monitoring sites, but there were significant differences for yields during stormflow in both categories. The differences between the ammonia yields during base flow at all monitoring sites were not statistically significant at the 95-percent confidence level. The median yield was higher during the growing season (0.09 (lb/d)/mi^2) than during the nongrowing season (0.06 (lb/d)/mi^2). Mean concentrations and yields for monitoring sites WB1, WB2, and DB were lower than those in the growing season, except for the yields at monitoring site WB1, which was similar to that in the growing season. The median yield of ammonia at this monitoring site (1.5 (lb/d)/mi^2) was higher than the yields at all other monitoring sites, and the yield at monitoring site DB (0.18 (lb/d)/mi^2) was much lower than at all other monitoring sites.

Boxplots of ammonia concentrations and yields grouped by progressive hydrograph segments (fig. 20) show that only Long Swamp Creek demonstrates heterogeneity in concentration (highest during the rising limb), but Long Swamp Creek and Wrangle Brook have higher loads of ammonia during stormflow than in the preceding base-flow periods. As with other nitrogen compounds, variability in concentration and loading of ammonia is increased by increased levels of urbanization, mediated primarily by the more rapid response of discharge to precipitation.

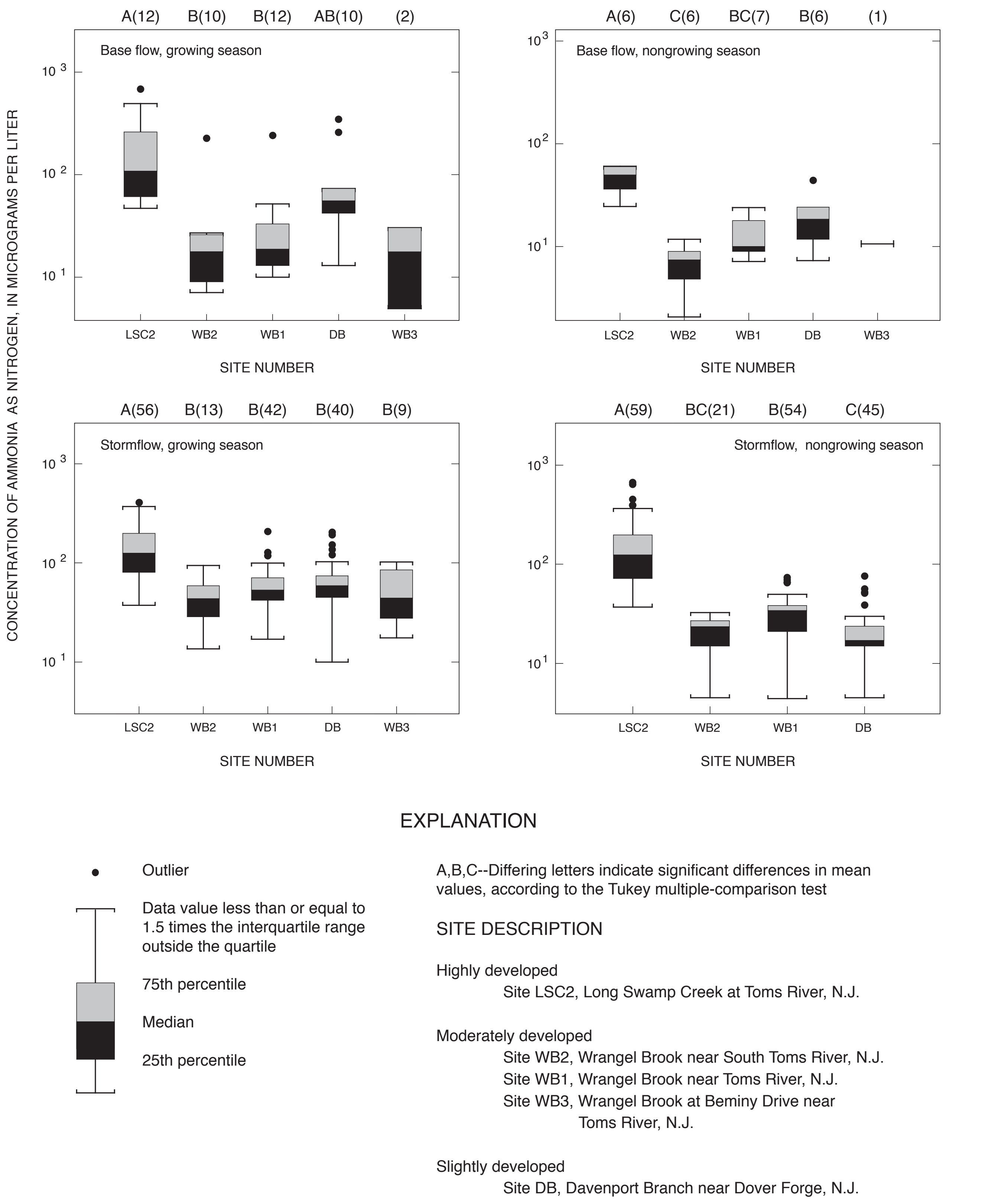


Figure 18. Distributions of ammonia concentrations in filtered water samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

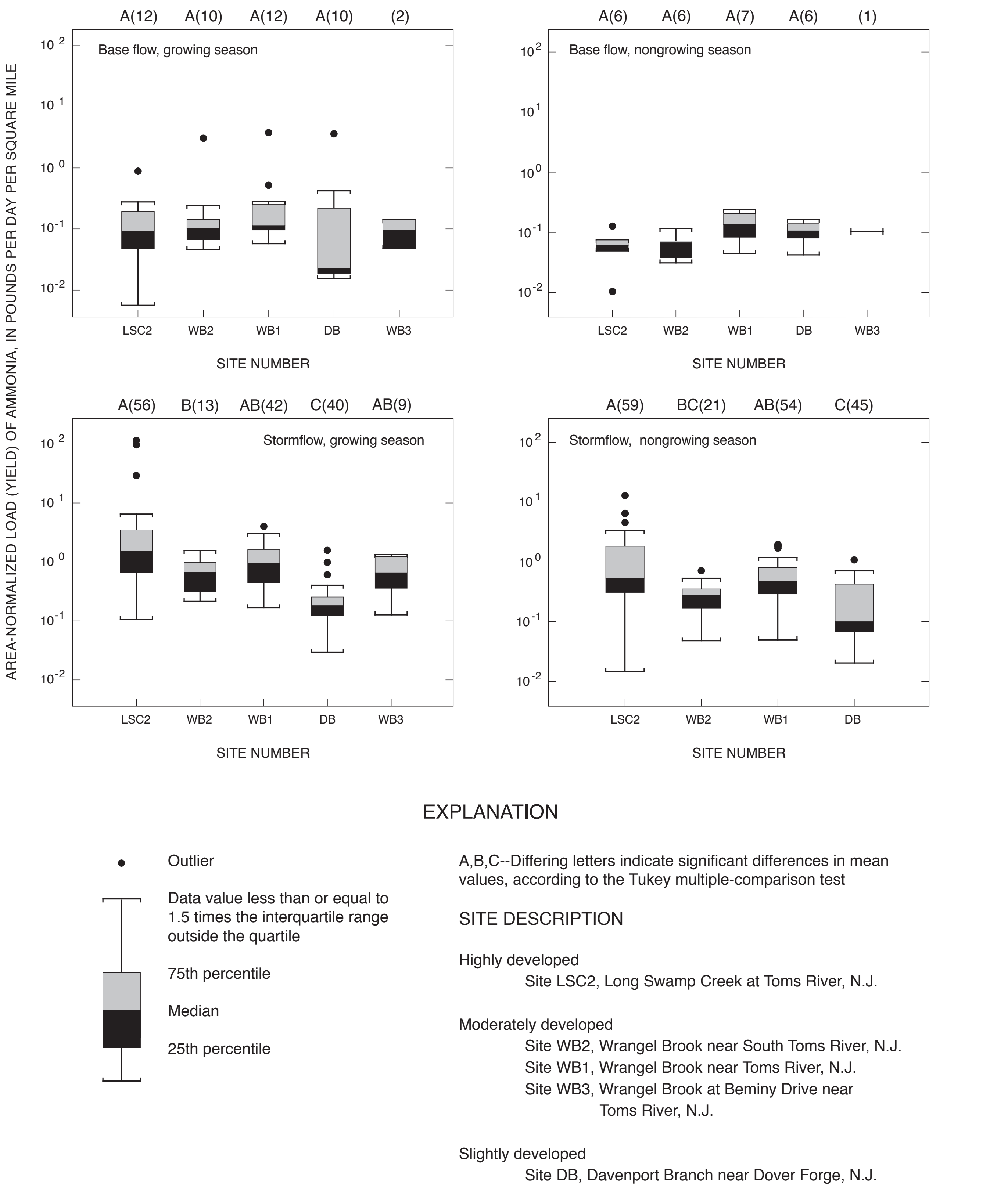


Figure 19. Distributions of area-normalized loads (yields) of ammonia calculated for filtered water samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

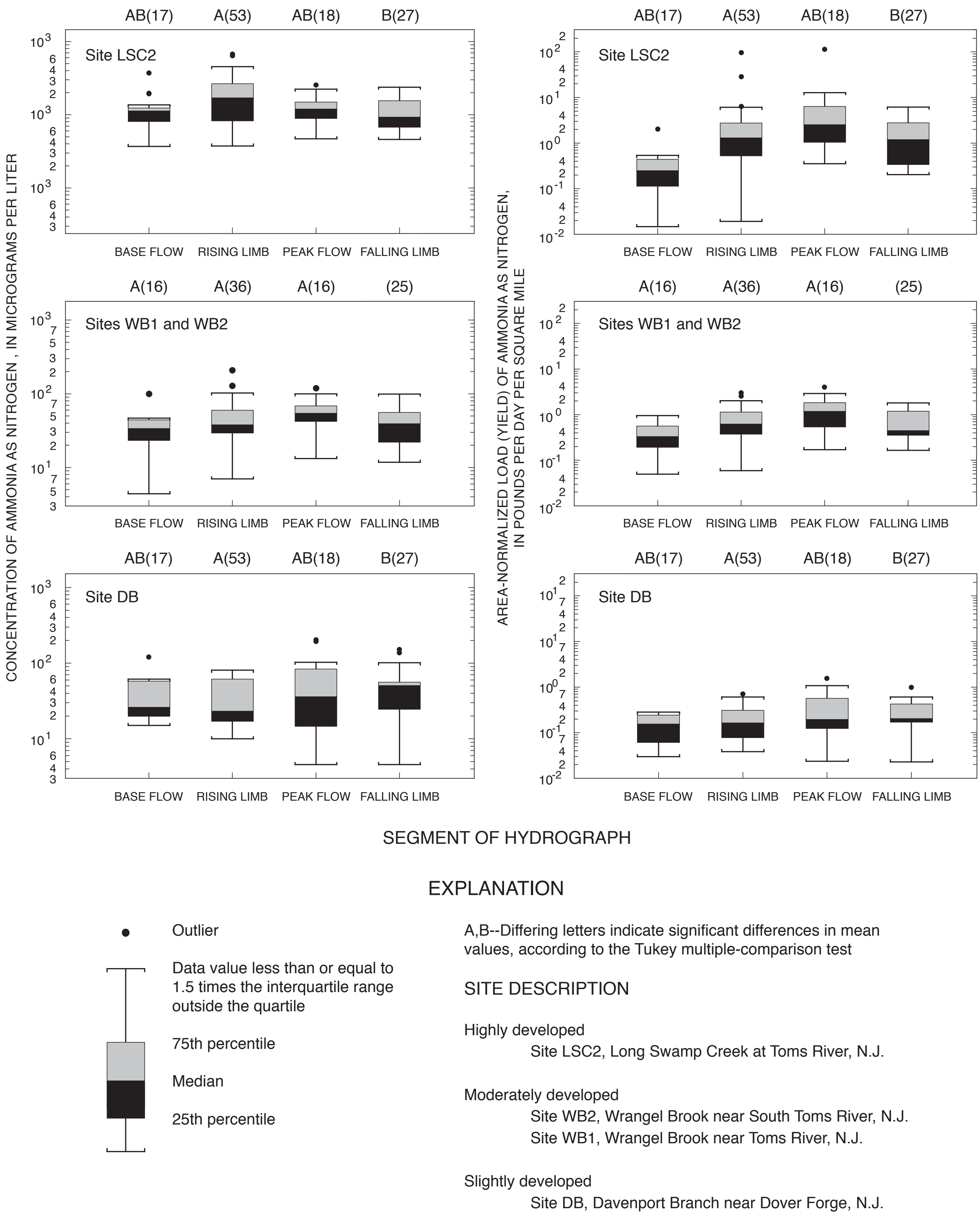


Figure 20. Distributions of ammonia concentrations and area-normalized loads (yields) in unfiltered water samples collected during stormflow, grouped by hydrograph segments at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

Fecal Coliform Bacteria

Densities of fecal coliform bacteria can be used as an indicator of contamination from fecal material, which may contain organisms that are harmful to human health. Coliform bacteria reside in the intestinal tracts of mammals and birds where they symbiotically assist in the digestion process. Quantitative coliform data are reported as the most probable number (MPN) of fecal coliform bacteria in 100 milliliters (mL) of water (American Public Health Association and others, 1999). The numerical criteria for FW2 streams, the classification of Wrangle Brook, are "fecal coliform levels shall not exceed a geometric average of 200 MPN/100 mL nor should more than 10 percent of the samples collected during any 30-day period exceed 400 MPN/100 mL" (New Jersey Department of Environmental Protection, 1998). All of Jakes Branch and the reaches of Davenport Branch upstream from monitoring site DB are designated as PL streams and must be maintained at the quality of their present state or that quality necessary to attain or protect the designated uses, whichever is most stringent.

The MPN is obtained by serially diluting a sample, usually in order-of-magnitude steps with five to ten replicates at each dilution level, then counting the number of replicates at each level that contain a viable population of the organism of interest. A "positive" replicate is indicated by color change, gas evolution, cloudiness of the sample, or some other chemical or physical change that indicates the presence of a viable microbial population. The assumption is made that a detectable population can arise from one viable individual. The numbers of positive replicates at the lowest three dilutions are used with a probability function to determine the MPN of viable organisms in the original sample. The MPN is itself an approximation and carries its own sources of error, which increase as the number of culture tubes decreases. The upper and lower bounds of the 95-percent confidence interval can differ by as much as a factor of 10 (American Public Health Association and others, 1999). Large differences in MPN among samples, therefore, must be present before heterogeneity among samples can be demonstrated to be significant with respect to viable microbial agents such as fecal coliform bacteria. An additional limitation of the data in this study is the uncertainty associated with 14 of the 220 samples tested that had counts greater than a maximum quantifiable value (usually 16,000 cfu (colony-forming units)/100 mL). This limitation occurs when all replicates are positive in all dilutions. Although this result represents only 6 percent of the samples, the "greater than" values are clustered at the beginning of storm events at monitoring sites LSC2, WB2, and WB3. The highest densities of fecal coliform bacteria that occur at these monitoring sites cannot be determined from this data set.

Boxplots of MPN values and yields for fecal coliforms are shown in figures 21 and 22, and summary statistics are shown in appendix 1. Results of the two-way ANOVA indicate that during base flow in the growing season counts of coliform bacteria are higher than in the nongrowing season, and differences among counts at the different monitoring sites are statistically significant at the 95-percent confidence level. This result was true for density (MPN/100 mL) and yield (MPN/d/mi^2). Migratory birds could be responsible for additional fecal coliform bacteria loading during the growing season. During the growing season, fecal coliform bacteria densities in base flow were higher at monitoring site LSC2 than at the other monitoring sites. The median value at monitoring site LSC2 was 1,250 cfu/100 mL; at Site WB2, 170 cfu/100 mL; at Site WB1, 200 cfu/100 mL; and at Site DB, 130 cfu/100 mL. During the nongrowing season, all densities of coliform bacteria in base flow were lower than during growing seasons, and monitoring sites LSC2 and WB2 had the highest fecal coliform bacteria densities (both 23 cfu/100 mL) of the four sites. Because these streams have no permitted sewage discharges, a part of the high fecal coliform bacteria density in base-flow samples during the growing (warm) season probably is attributable to wild mammals and birds.

For monitoring site LSC2, coliform bacteria in base-flow samples during the nongrowing season had a geometric average MPN of 1,005 cfu/100 mL, considerably greater than the 200 cfu/100 mL limit for an FW2 stream. The geometric means for monitoring site LSC2 in the nongrowing season and of all other monitoring sites at all times were less than 200 cfu/100 mL.

Yields of fecal coliforms in base-flow samples from monitoring site DB have a slightly lower distribution than those from the other monitoring sites, but the difference is not statistically significant when tested with the Tukey multiple comparison test. Yields of fecal coliforms were about an order of magnitude greater in the growing season than in the nongrowing season.

The one sample collected at monitoring site JB (undeveloped control site, Jakes Branch) during stormflow conditions had an MPN value of <2 cfu/100 mL. This value is not consistent with the supposition that much of the fecal coliform bacteria come from wildlife. More fecal coliform sampling at that monitoring site under different conditions would provide information about the percentage of contamination at the other monitoring sites that is not anthropogenic. Geometric means of MPN at all monitoring sites in stormflow samples during the growing season were at or greater than 200 cfu/100 mL. Only monitoring site DB had a geometric mean that was less than this limit during nongrowing seasons. It is likely that fecal coliform bacteria are introduced to streams almost entirely by runoff. This result is expected because the transport of microbes through ground water is slow, and survival of the short-lived fecal coliform bacteria during transport through the subsurface for more than a 5 to10 feet is not likely.

Densities and yields of fecal coliforms increased with increasing streamflow at Long Swamp Creek and Wrangle Brook (fig. 23). This result is expected, as this constituent is primarily a surface-water phenomenon, and water discharging into streams as base flow would be expected to have little or no viable population of fecal coliform bacteria. Data for Davenport Branch were insufficient to test for heterogeneity

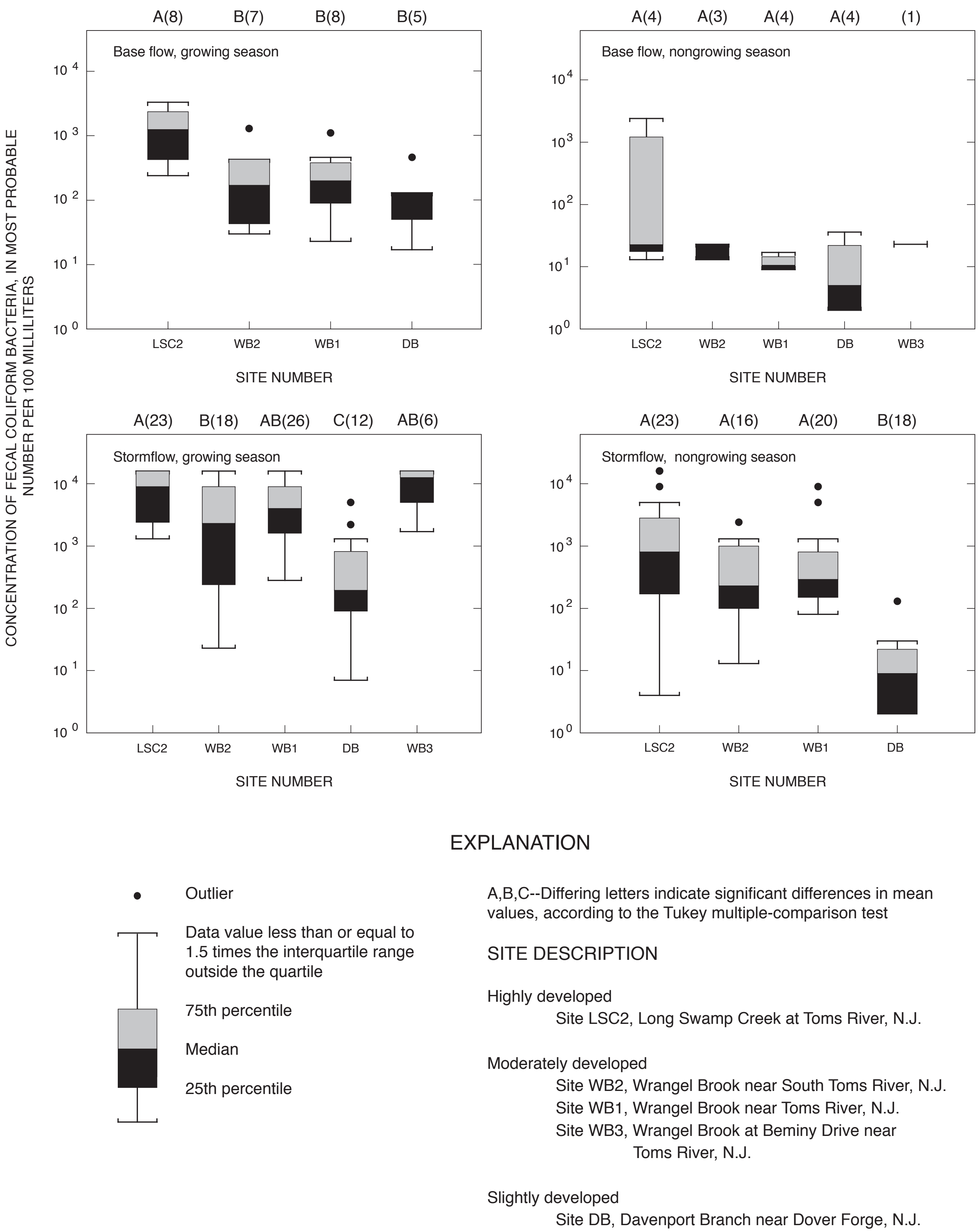


Figure 21. Distributions of fecal coliform bacteria concentrations in samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

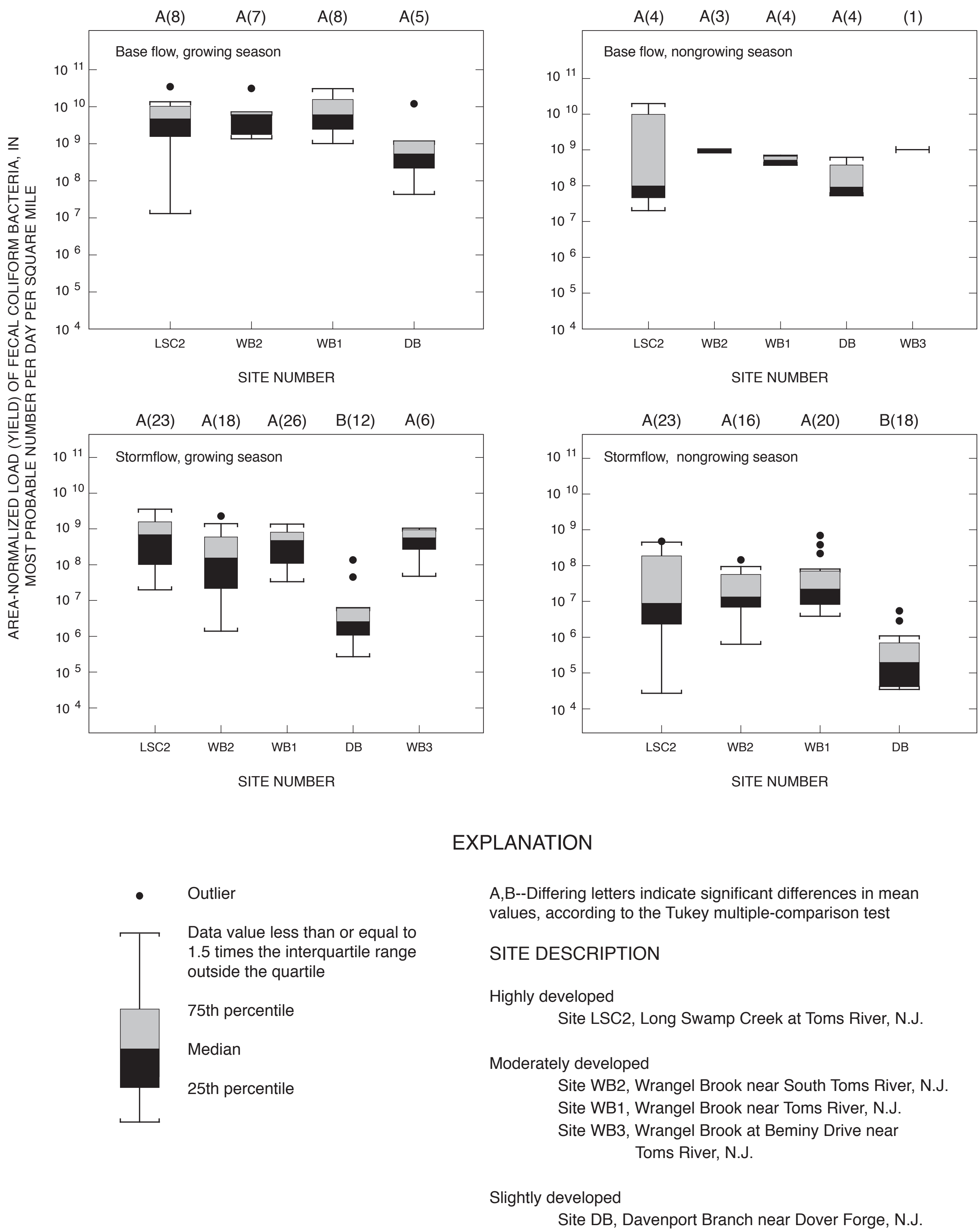


Figure 22. Distributions of area-normalized loads (yields) of fecal coliform bacteria calculated for samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

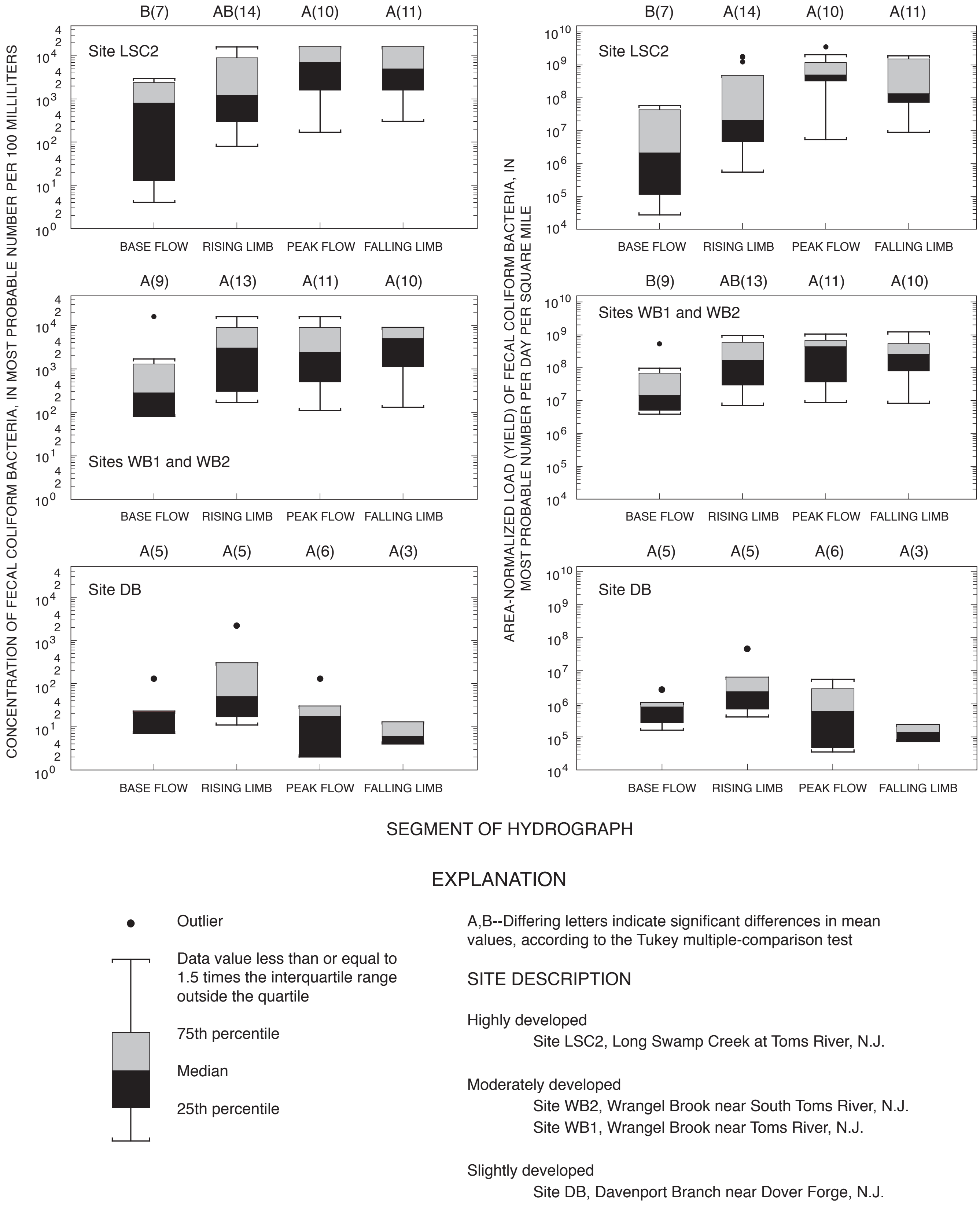


Figure 23. Distributions of fecal coliform concentrations and area-normalized loads (yields) in unfiltered water samples collected during stormflow, grouped by hydrograph segments at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

among the hydrograph segments using ANOVA and Tukey test; however, as shown in figure 23, streamflow during the rising limb of the hydrograph contains a substantial portion of the fecal coliform bacteria. Data from all three sites indicate that vulnerability to unhealthful levels of coliform bacteria in streams is directly related to streamflow and increases in streamflow during storms, and that this effect is increased by urbanization.

Overall, there is a clear pattern of increasing fecal coliform bacteria yields with increasing development. The problem is more severe during the growing season and is associated only with runoff; essentially no fecal coliform bacteria contamination is attributable to ground-water discharge.

Total Suspended Solids

The term “total solids” refers to matter suspended or dissolved in water or wastewater and is related to both specific conductance and turbidity. Total solids (also referred to as total residue) is the term used for material left in a container after evaporation and drying of a water sample. Total solids includes both total suspended solids (TSS), the part of total solids retained in a filter with a specified pore size, and total dissolved solids, the part that passes through the filter (American Public Health Association and others, 1999).

Method 2540D of American Public Health Association and others (1999) specifies the use of glass-fiber filter disks with a pore size of about 1.5 microns for separating suspended solids from the water sample. The water sample passes through the filter under negative pressure; then the filter is rinsed to remove dissolved solids and dried at 103° to105°C for at least 1 hour. The increase in filter mass (mg) divided by the sample volume (L) is the TSS in milligrams per liter. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause problems for stream health and aquatic life. Light penetration of water is reduced as TSS increases. This light reduction can reduce photosynthesis in algae and other aquatic plants, in turn reducing the production of oxygen in the water. Decreased water clarity from suspended solids also interferes with the capacity of fish to catch prey. Additionally, suspended solids can clog the gills of fish, which leads to poor health or even death. Trace elements and organic compounds can be adsorbed onto suspended particles, which may be ingested by aquatic organisms, leading to toxicity or bioaccumulation. The U.S. Environmental Protection Agency (USEPA) does not provide a standard for TSS in drinking water, but does specify that turbidity (largely resulting from suspended solids) may not exceed 5 nephelometric units (NTU) or 1 NTU for water systems using filtration. The New Jersey criteria for TSS is 40 mg/L for FW2-NT streams (New Jersey Department of Environmental Protection, 1998).

Summary statistics for TSS are shown in appendix 1. Results of two-way ANOVA indicate that at base flow there is a significant difference in concentrations of TSS between the growing and nongrowing seasons. From the boxplots of base-flow concentrations (fig. 24), it can be seen that TSS concentrations tend to be slightly higher in the growing season. In any case, concentrations in all seasons in these streams during base flow are too low to be problematic. The two-way ANOVA also determined that there are no significant differences at base flow among the monitoring sites in concentrations of TSS for each of the seasons.

No significant differences in concentrations of TSS between the growing and nongrowing seasons were determined by the two-way ANOVA for stormflow samples. Boxplots of TSS in stormflow samples collected during the growing and nongrowing seasons (fig. 24; table 6) show similar patterns; however, monitoring site DB had slightly lower distributions than the other monitoring sites. The two-way ANOVA showed that the apparent differences among the means of stormwater samples are statistically significant. Monitoring site DB (slightly developed) had the lowest TSS distributions in both seasons.

Yields of TSS in stormflow during the growing and nongrowing seasons are not significantly different among the monitoring sites, according to the two-way ANOVA. Boxplots of the yields of TSS during storms (fig. 25; table 6) show similar patterns for the seasons; however, the yield of TSS at monitoring site DB is clearly lower than at the other monitoring sites during the growing and nongrowing seasons. Monitoring site WB1 had the highest median TSS yield (393 mg/L), higher even than the median yield at monitoring site LSC2 (177 mg/L). A source of suspended solids may be present near monitoring site WB1 that is downstream from WB2 and the confluence of Davenport Branch and Wrangle Brook.

Concentrations and yields of TSS, differentiated by hydrograph segment, are shown for the three subbasins in figure 26. Concentrations increased slightly during the rising limb in Long Swamp Creek but not in the other streams, and decreased during the falling limb at Long Swamp Creek and in Wrangle Brook. This result could be considered an unexpected finding, because stormwater generally is associated with high turbidity and high concentrations of dissolved solids. Sediment filtration during subsurface discharge, which probably represents a substantial part of the discharge in these streams, located in relatively flat topographies, would decrease the sediment yield during storms. These subbasins also lack appreciable areas of agricultural land use, which is known to contribute high loads of sediment during precipitation.

Orthophosphate

Phosphorus is an essential element for all organisms, but excessive loads of phosphorus in surface water contributes to eutrophication. Phosphorus can be present in organic forms; however, in general the highest concentrations are present in inorganic forms (orthophosphate and polyphosphates). Application of inorganic fertilizers is an important source of phosphorus in runoff and in surface waters. Concentrations of orthophosphate were not quantified in most base-flow samples

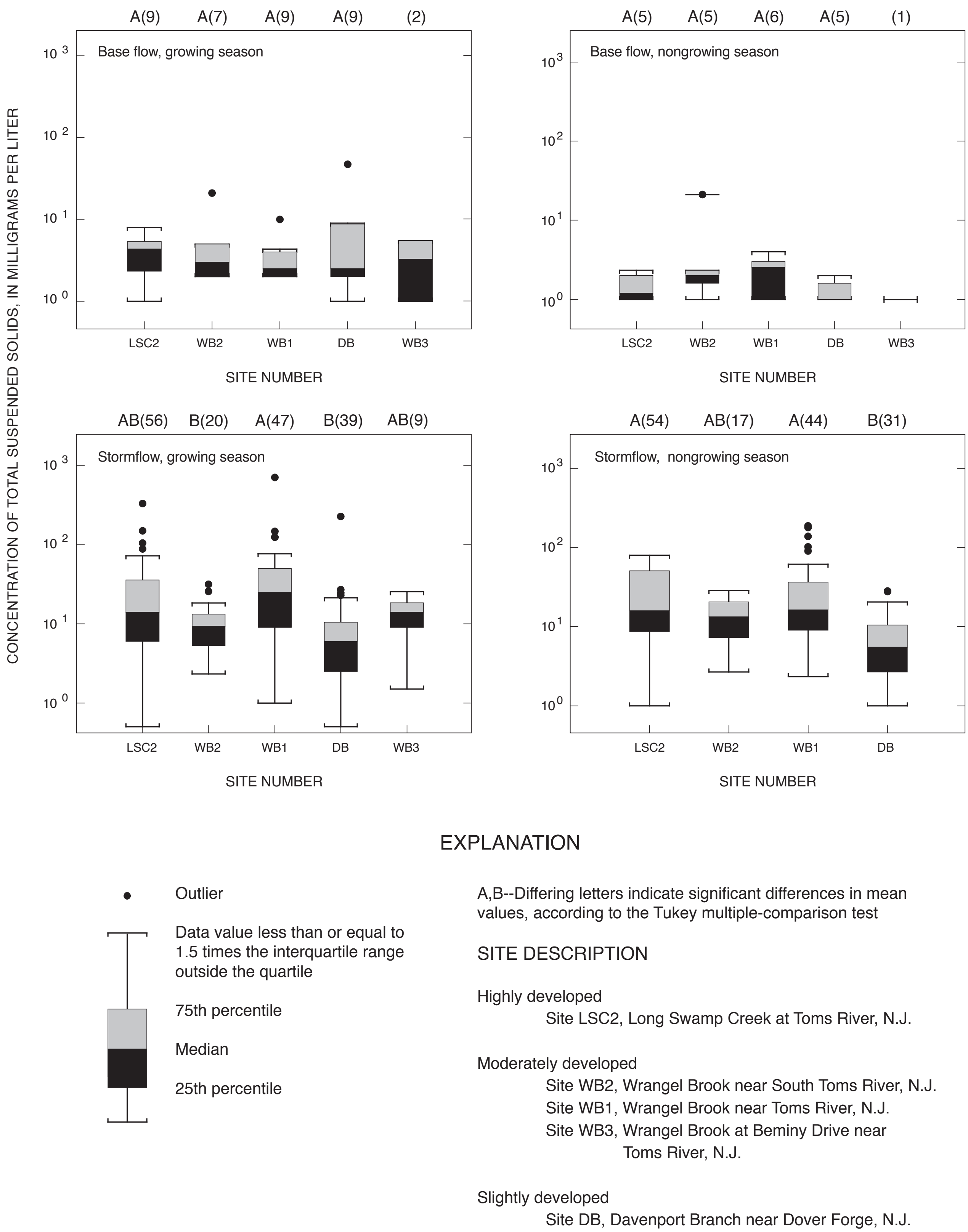


Figure 24. Distributions of total suspended solids concentrations in unfiltered water samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

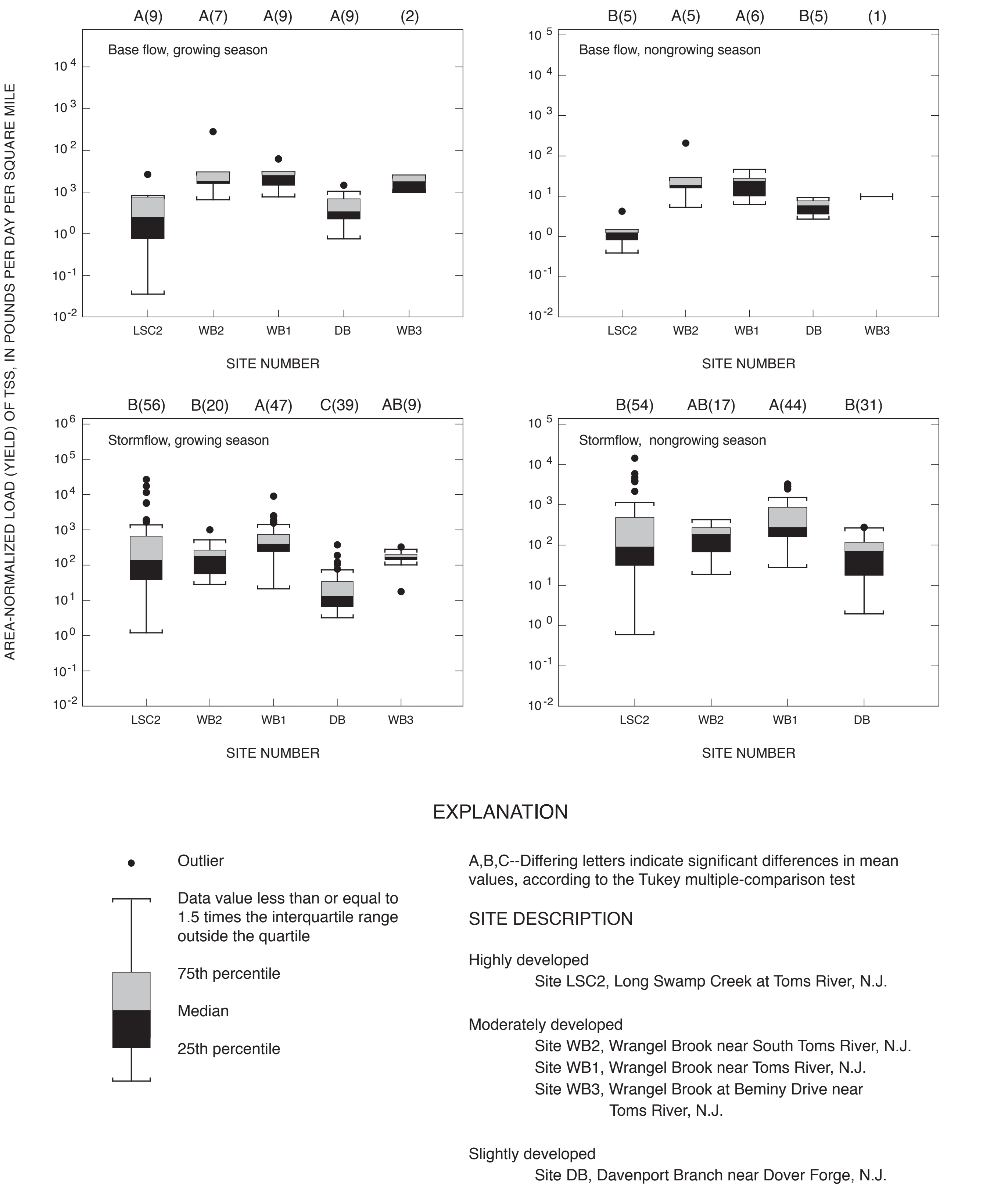


Figure 25. Distributions of area-normalized loads (yields) of total suspended solids (TSS) calculated for samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

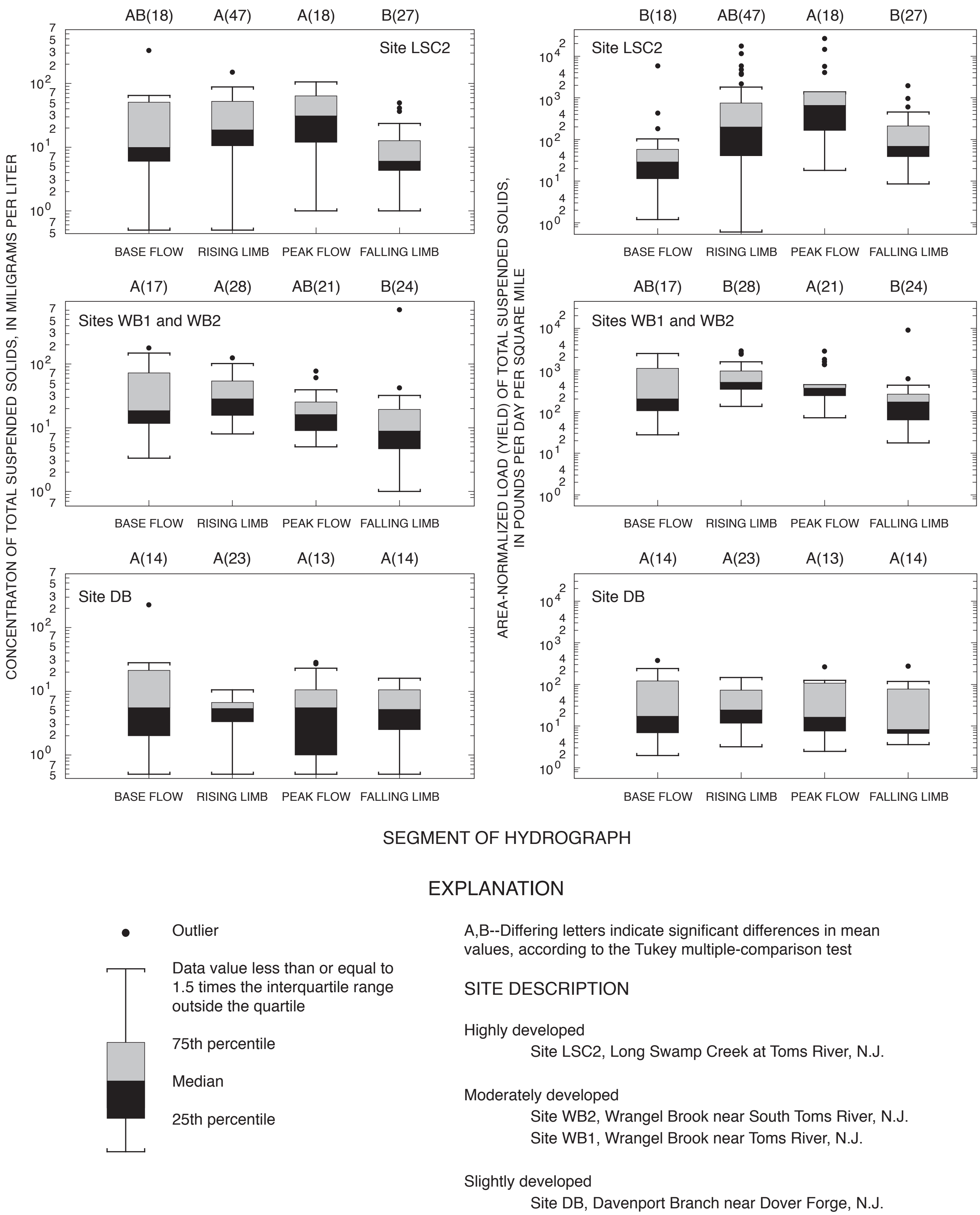


Figure 26. Distributions of total suspended solids concentrations and area-normalized loads (yields) in unfiltered water samples collected during stormflow, grouped by hydrograph segments at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

collected before March 6, 1995, because the detection limit up to that time was 13 μg/L, and most samples contained less than that concentration. Only subsequent samples, with a detection limit of 1 μg/L, were used in the statistical analysis of the orthophosphate data. Only 17 of 381 samples collected after March 6, 1995, were determined to contain concentrations less than the detection limit (usually 1 μg/L, occasionally 1.87μg/L). These samples were assigned a value of 0.5 multiplied by the detection limit.

Results of the two-way ANOVA indicated no significant difference in mean orthophosphate concentrations among the monitoring sites during base flow but a significant difference in mean concentrations between growing and nongrowing seasons. Boxplots of orthophosphate concentrations (fig. 27) show that concentrations in the growing season were higher than those in the nongrowing season (table 6). This result probably is related to fertilizer application patterns. Results of the two-way ANOVA conducted on orthophosphate yields during base flow indicate that there is no significant difference between yields in the growing and nongrowing seasons, but the differences in orthophosphate concentrations in water samples compared among the monitoring sites are significant. Monitoring site LSC2 appears to have the lowest yield during base flow (fig. 27; table 6) (though it is not significantly lower than that of monitoring site DB) during the growing season. In the nongrowing season during base flow, the monitoring site LSC2 yield distribution is significantly lower than that of the other monitoring sites.

The distributions of orthophosphate concentrations in stormflow during growing and nongrowing seasons were not significantly different, as determined by the two-way ANOVA. Boxplots of concentrations and yields in stormflow (figs. 27 and 28) show that the four monitoring sites had similar distributions in both seasons. Results of the Tukey multiple comparison tests indicate that monitoring site LSC2 had significantly higher mean concentrations than the other monitoring sites during growing and nongrowing seasons. The mean concentration of orthophosphate at monitoring site DB was consistently lower for stormflow samples in both seasons (fig. 27). This pattern is consistent with the association of high orthophosphate concentrations and high percentages of land development.

A two-way ANOVA was unable to distinguish between mean yields of orthophosphate during stormflow in the growing and nongrowing seasons. In the growing season, monitoring site LSC2 had a higher distribution of mean yields than monitoring sites WB2, WB1 and DB but not lower than monitoring site WB3. Monitoring site DB had the lowest distribution of yield values during the growing season. For the nongrowing season, results of the Tukey test indicate that mean yields of orthophosphate were higher at highly urbanized LSC2 (Long Swamp Creek) than at slightly developed Site DB (Davenport Branch). Orthophosphate yields for the two moderately developed Wrangle Brook monitoring sites (WB2 and WB1) appear to be intermediate between yields from sites LSC2 and DB, on the basis of the Tukey test results and visual examination of the boxplots (fig. 28). Thus, a direct relation between orthophosphate yield and extent of urbanization is evident.

The concentration of orthophosphate increases from the level prior to precipitation events to the levels reached during the rising limb, peak flow, and falling limb of the hydrograph for the Long Swamp Creek monitoring site (fig. 29). This result was verified by single-factor ANOVA and Tukey testing. In contrast, concentrations of orthophosphate were homogeneous in all segments of the hydrographs for the Wrangle Brook and Davenport Branch monitoring sites. The higher level of urban development in the Long Swamp Creek subbasin appears to contribute more orthophosphate than is present in the less-developed subbasins. Application of commercial fertilizers is a likely source. Yields of orthophosphate increased during precipitation events at Long Swamp Creek and at Wrangle Brook, reflecting the increases in stream stage and discharge. Yields at Davenport Branch during storms were homogeneous. Apparently, urbanization increases the loading of orthophosphate and intensifies the peak loads and concentrations by accelerating the flow-rate increase. This increase probably is due to the increased impervious surface associated with urbanization.

Discharge hydrograph extension and base-flow separation results

The discharge hydrograph extension and base-flow separation methods described previously were applied successfully at monitoring sites LSC2 and WB1. The falling limb of monitoring site DB, however, did not return predictably to base-flow levels after storms, and it was not possible to separate runoff from base flow. For this monitoring site, yield during base flow was calculated as the product of the average concentration and the average discharge during base flow. Yield in runoff was calculated as the product of the average stormflow concentration, the approximate fraction of time the stream received runoff (0.3), and the difference between average stormflow and base-flow discharge.

Estimated Annual Yields

Estimated annual yields of seven constituents are shown in figure 30. Base-flow and runoff components of yield are shown separately. Yields of fecal coliform bacteria and TSS principally came from runoff. The monitoring sites on Wrangle Brook (sites WB2 and WB1) had high yields of nitrate in base flow relative to that for other monitoring sites. The additional nitrate from stormflow is inconsequential in this subbasin. When base-flow data were evaluated, none of the constituents increased as a function of percent of land development (fig. 30). A relation is present, however, between stormflow concentration and percent of land development for various constituents. There is a linear relation between percent of land development and yields in runoff of orthophosphate,

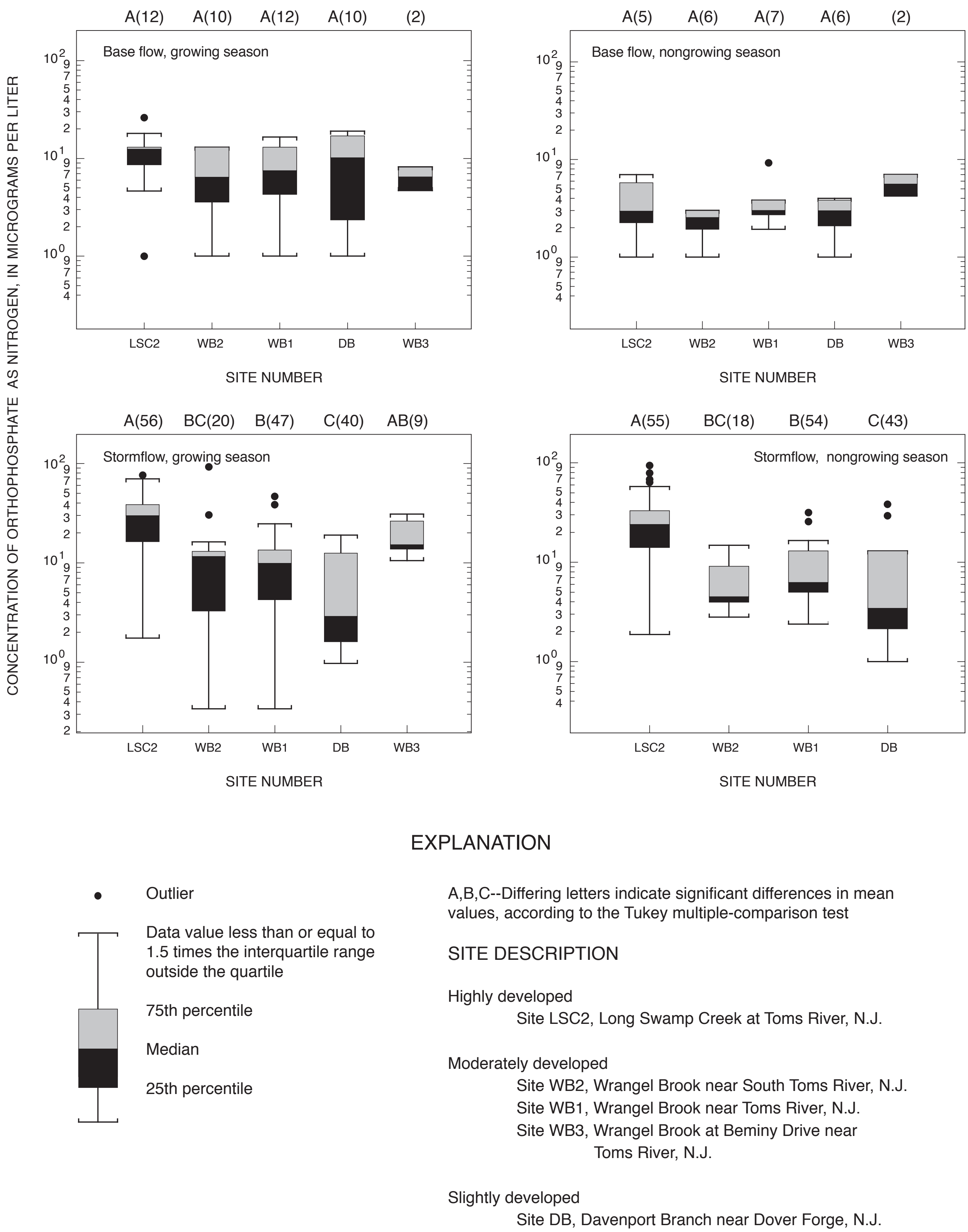
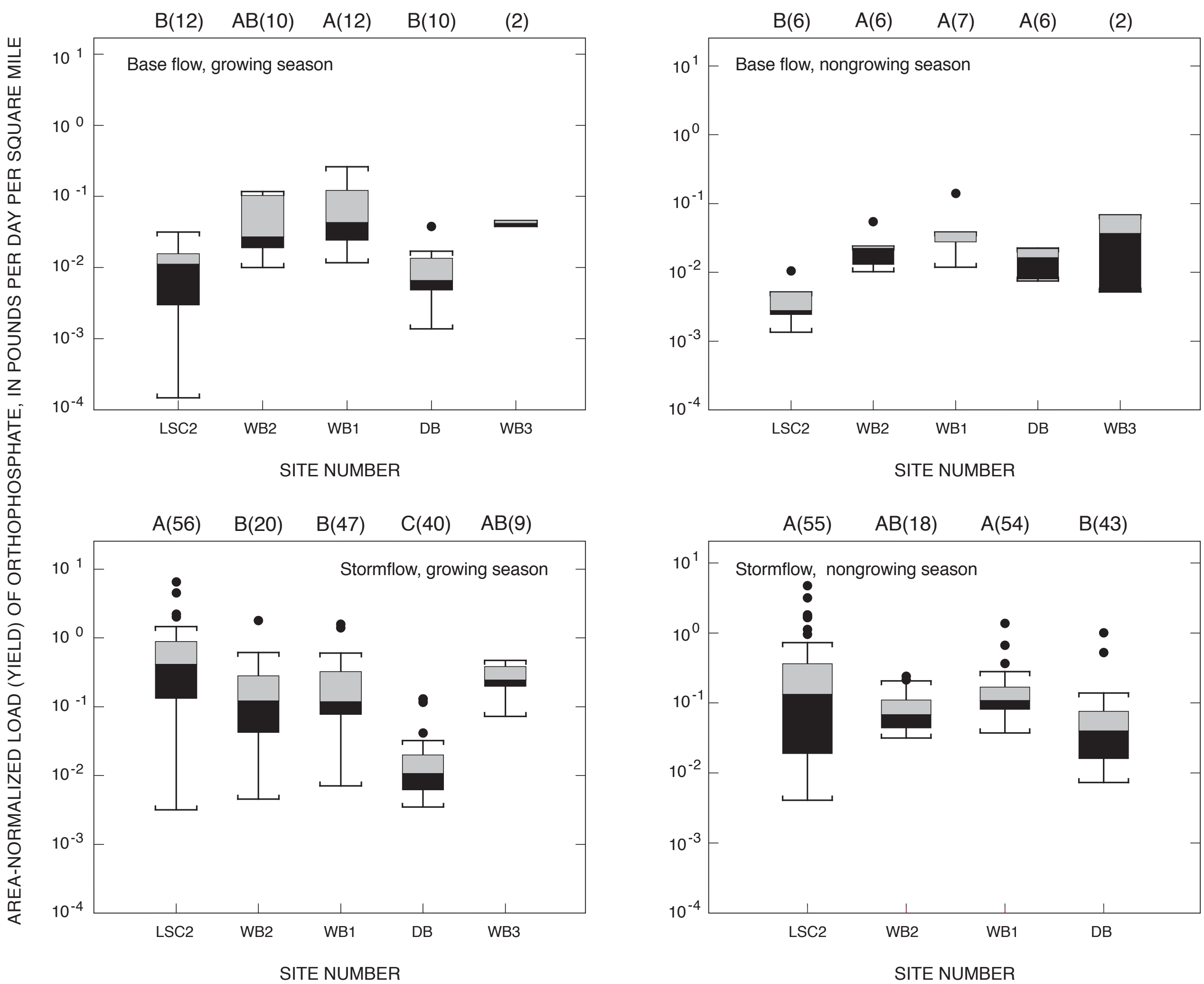
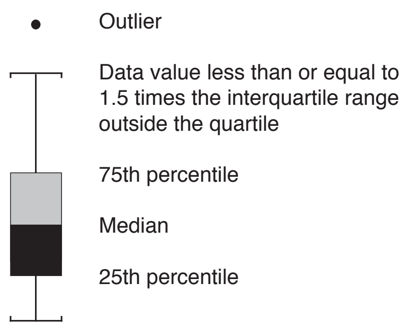


Figure 27. Distributions of orthophosphate concentrations in filtered water samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)



EXPLANATION



A,B,C--Differing letters indicate significant differences in mean values, according to the Tukey multiple-comparison test

SITE DESCRIPTION

Highly developed

Site LSC2, Long Swamp Creek at Toms River, N.J.

Moderately developed

Site WB2, Wrangel Brook near South Toms River, N.J.

Site WB1, Wrangel Brook near Toms River, N.J.

Site WB3, Wrangel Brook at Beminy Drive near Toms River, N.J.

Slightly developed

Site DB, Davenport Branch near Dover Forge, N.J.

Figure 28. Distributions of area-normalized loads (yields) of orthophosphate calculated for filtered water samples collected during base flow and stormflow in the growing and nongrowing seasons at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

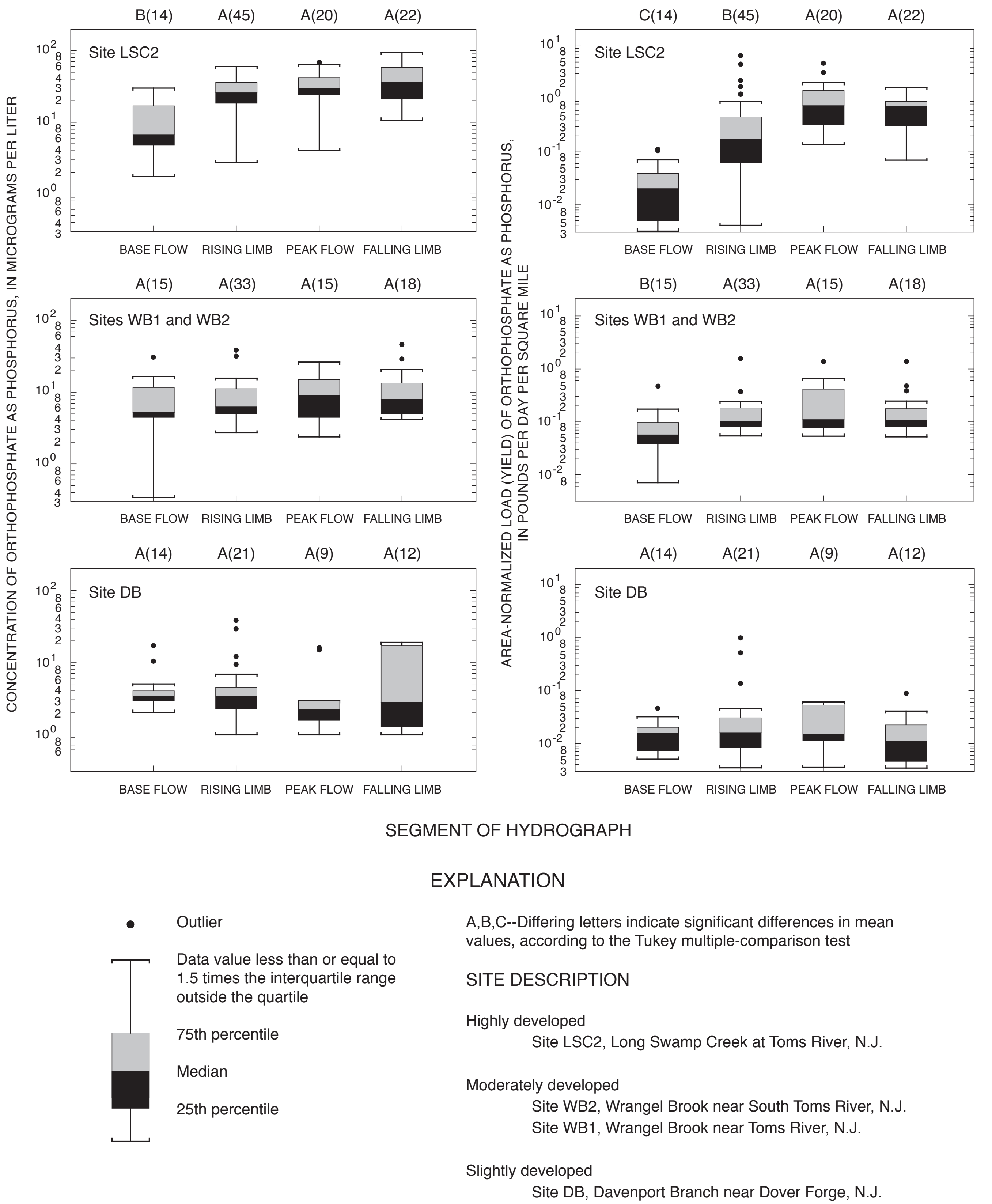


Figure 29. Distributions of orthophosphate concentrations and area-normalized loads (yields) in unfiltered water samples collected during stormflow, grouped by hydrograph segments at measurement sites in the Toms River drainage basin, N.J., 1994-99. (Sites shown in figure 1.)

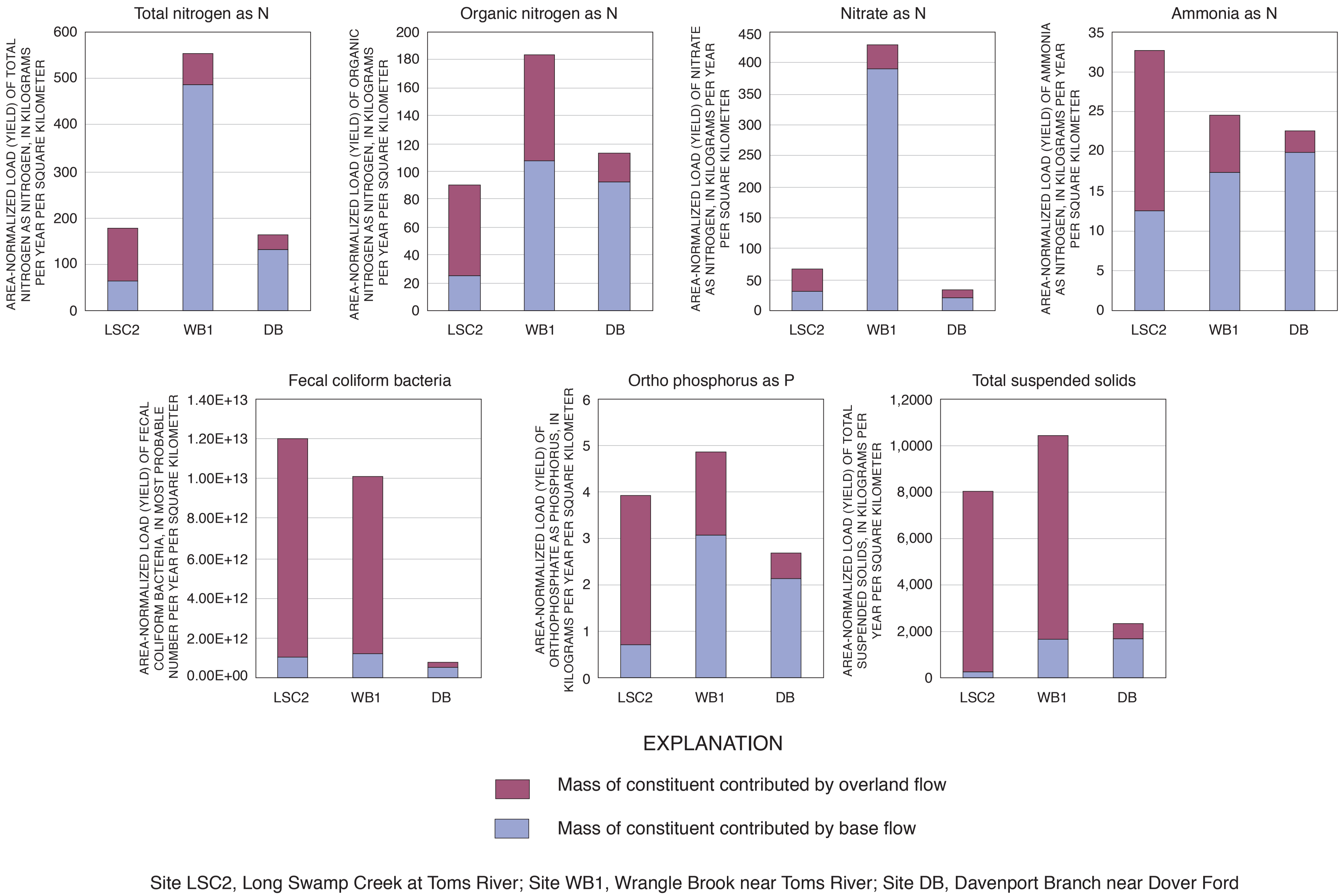


Figure 30. Base-flow and stormflow components of estimated annual area-normalized loads (yields) of selected constituents, Toms River drainage basin, N.J. (Sites shown in figure 1.)

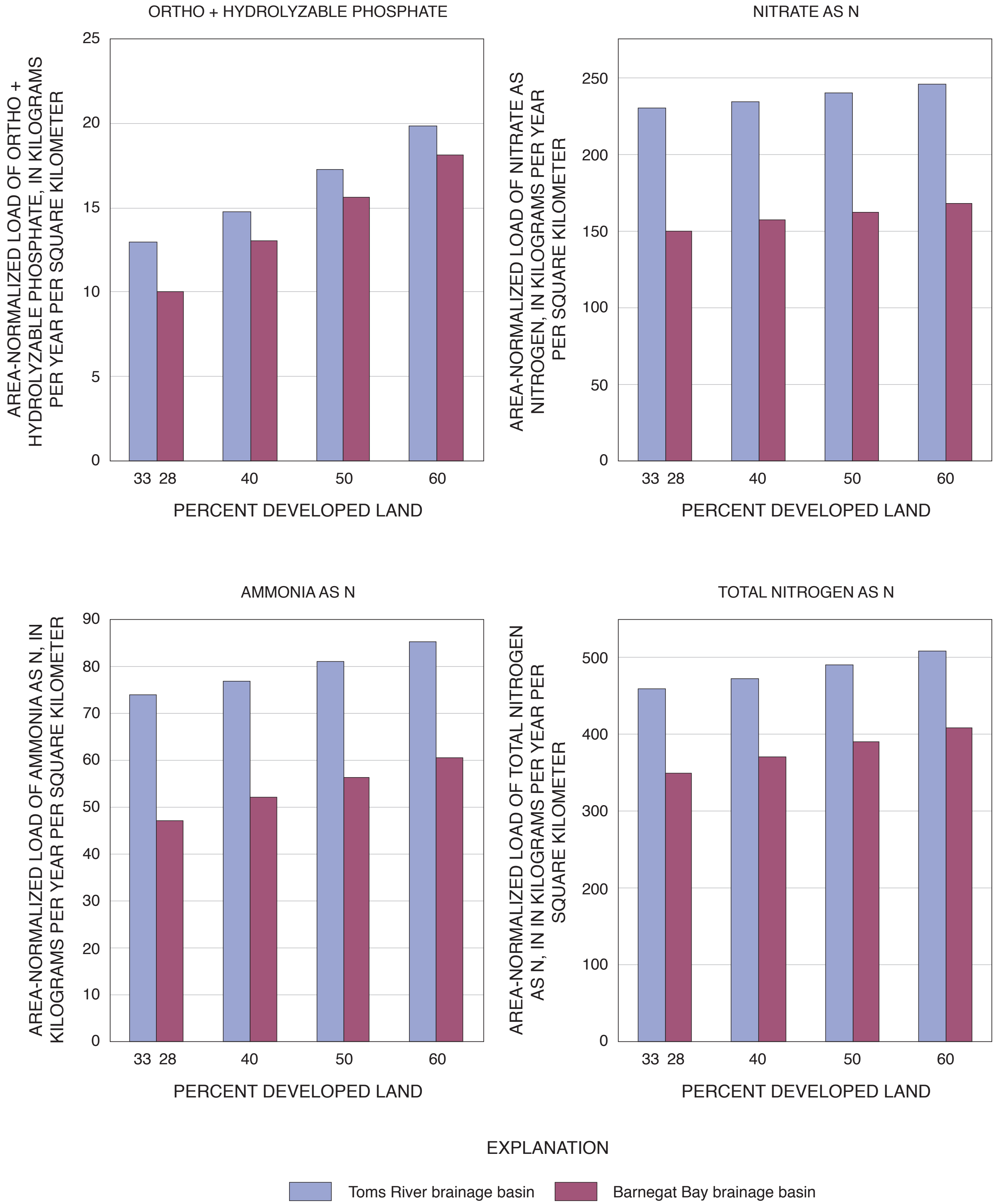


Figure 31. Estimated annual area-normalized loads (yields) of selected constituents, resulting from additional land development in the Toms River and Barnegat Bay drainage basins, N.J.

fecal coliform bacteria, ammonia, and total nitrogen. Yields of organic nitrogen, TSS, and nitrate were higher in samples from Wrangle Brook, which drains a moderately developed subbasin, than in samples from Long Swamp Creek in a highly developed subbasin, but yields for all three of these constituents were lowest in samples from Davenport Branch, a slightly developed subbasin.

In another study, annual yields of total phosphorus, total nitrogen, nitrate-N, and ammonia-N were estimated for the major river basins of the Barnegat Bay estuary using available water-quality data and two categories of discharge (high flow--75th quartile and low flow--25th quartile) (Hunchak and Nicholson, 2001). Annual yields for Wrangle Brook (WB1) and Long Swamp Creek (LSC2) estimated in this way were comparable to those determined in this study (table 7). Total phosphate was analyzed only in samples from the first two sampling events in this study; however, the mean unfiltered total phosphorus concentration was 55.4 μg/L, and the mean unfiltered hydrolyzable phosphorus plus orthophosphate was 54.1 μg/L in samples where both analyses were run. Therefore, in the streams monitored in this study, total phosphorus appears to be essentially equal to the sum of hydrolyzable phosphorus plus orthophosphate. Yields of all species calculated by Hunchak and Nicholson (2001) are similar to those calculated in this study, although the values obtained by Hunchak and Nicholson (2001) were lower. This result could be the result of the use of the 75th quartile to characterize high-flow conditions; the largest storms, which contribute to the total yields, are not included in the calculations.

Total yields of the nitrogen and phosphorus species, TSS, and fecal coliform bacteria do not appear to be related to percentage of land development in the Long Swamp, Wrangle Brook, and Davenport Branch subbasins. Base-flow yields do not appear to be related to the percent of land development (fig 30). As previously stated, an experimental secondary effluent spray field may be responsible for the high concentrations and yields of constituents in base flow associated with domestic wastewater in the Wrangle Brook subbasin. Yields in base flow of total nitrogen, organic nitrogen, ammonia, orthophosphate, and TSS also were higher in samples from Davenport Branch than from Long Swamp Creek, which has about 300 percent more developed land. Therefore, it does not appear that a reasonably accurate estimate of yields in base flow can be made for a drainage basin on the basis of the yields at a nearby basin.

Yields in overland flow, however, appear to be greater in the more-developed subbasins for most constituents than in less-developed subbasins. The estimated yield of each constituent contributed by additional future land development was added to the yields for the Toms River and Barnegat Bay drainage basins (fig. 31). Only the anticipated overland-flow contribution was added; therefore, any long-term contributions from ground-water discharge are neglected. These are, therefore, conservative estimates of the effects of increasing percent of land development on constituent yields. Also, for these projections, it is assumed that the yields in stormflow from these large drainage areas have land-development-to-yield relations similar to those of the Long Swamp Creek and Davenport Branch subbasins. Water-quality data for Wrangle Brook were not used in these projections because the high base-flow yields of various constituents (relative to stormflow yields) made accurate estimation of stormflow yields impossible.

Results of the method described earlier indicate that yields of hydrolyzable phosphorus plus orthophosphate will increase substantially in the Toms River and Barnegat Bay Basins as the percentage of land development increases from current (2005) levels from 28 percent to 33 percent. This increase in phosphorous could affect the amount of the algal mass in Barnegat Bay. The phosphorous yield increases shown in figure 31 represent only the additional contribution from runoff and do not include any increases in phosphorous from ground-water discharge that could result from further land development. The method cannot be used to predict substantial increases in nitrogen species with further development (fig. 30). This limitation is because most of the nitrogen load in Toms River drainage basin and the entire Barnegat Bay drainage basin is introduced by ground-water discharge, not by runoff. As in the case of phosphorus, increasing contributions of nitrogen species from ground-water discharge that could result from additional development are discounted in this method of estimation. If a substantial part of the nitrogen load in Barnegat Bay drainage basin is from point sources, such as domestic wastewater-treatment plant effluents, the percentage of nitrogen attributed to ground-water discharge could be underestimated. In that case, additional nitrogen and phosphorous loads resulting from increased population and the accompanying increase in wastewater volumes would have to be added to estimated yields.

The method of estimation described above can be validated by calculating base-flow and runoff contributions of nitrogen and phosphorus species, TSS, and coliform bacteria to Toms River. Additional verification could be possible using load and discharge data from other subbasins in the Barnegat Bay drainage basin.

Summary and Conclusions

Water quality of the Toms River and its tributaries in Ocean County, New Jersey, and of Barnegat Bay into which the river and tributaries drain is affected by nonpoint-source contamination. A multi-year study (1994-99) was undertaken to assess the extent to which land development is a factor in the loads of nutrients and other constituents that enter these streams from storm runoff. Chemical and physical characteristics of water quality were measured during base-flow and stormflow conditions at four streams--Long Swamp Creek, Wrangle Brook, Davenport Branch and Jakes Branch--that drain into the Toms River. The four subbasins have different degrees of total land development. Concentrations and yields (area normalized instantaneous loads) of nutrients, fecal

Table 7. Yields for selected surface-water monitoring sites, Toms River drainage basin, N.J., calculated by two methods.

[Yields are in kilograms per year per square kilometer.]

Method	[1]Total Phosphate as phosphorus		Nitrate as nitrogen		Ammonia as nitrogen		Total nitrogen as nitrogen	
	Site LSC2	Site WB1	Site LSC2	Site WB1	Site LSC2	Site WB1	Site LSC2	Site WB1
[2]Hunchak and Nicholson, 2001	7.5	12	53	340	16	14	110	470
This study	15	15	68	430	33	24	177	556

[1]Ortho plus hydrolyzable phosphate in this study.

[2]Yield calculated by using water-quality and streamflow data at high flow (75th quartile of flow rates) and low flow (25th quartile of flow rates) (Hunchak and Nicholson, 2001).

coliform bacteria, and total suspended solids were compared among the streams.

Nitrogen species were found to be largely attributable to base-flow discharge, especially in the moderately developed Wrangle Brook subbasin. Yields of ammonia in base flow were roughly equivalent among the streams, but yields in stormflow were higher in the more highly developed subbasins.

Fecal coliform bacteria and total suspended solids are attributable almost entirely to stormflow. Concentrations and yields are much higher in the more-developed Long Swamp Creek and Wrangle Brook subbasins than in Davenport Branch. Concentrations and yields of phosphate species were higher during stormflow in samples from Long Swamp Creek than in those from the other streams.

Total discharge was calculated for each monitoring site for the entirety of each storm during which water-quality samples were collected. Base-flow separation was used to calculate the total volume of runoff for these storms. By determining the fraction of annual precipitation that occurred during these storms, the total annual volume of runoff that reached each stream could be calculated. Total annualized yields in base flow and runoff were determined from annual volumes of base flow and runoff and volume-averaged mean concentrations during stormflow and base-flow conditions. Therefore, the annualized yield of each constituent was separated into base-flow and runoff components.

No apparent relation was found between percent of land development and yields in base flow for the constituents studied. Nutrients, especially nitrate, were present in much higher concentrations in samples collected from Wrangle Brook during base flow than those from the other streams. Yields of fecal coliform bacteria and total suspended solids were insignificant in base-flow samples at all monitoring sites.

Strong correlations were found between percentage of land development and yields in stormwater of ammonia, total nitrogen, the phosphate species, and to a lesser extent fecal coliform bacteria. Although only three streams, one each in slightly, moderately, and highly developed subbasins are used in this analysis, the large amount of data collected and strong correlations indicate that the observed relations between percentage of land development and yield reflect the actual increase in nonpoint-source contaminant loads with increased land development.

A model was developed that predicts the yields of phosphorous and nitrogen species for the Toms River and entire Barnegat Bay drainage basins as a function of percentage of land development. This model incorporates additional runoff contributions and neglects possible increased contaminant loads from ground-water discharge. It is clear that increasing land development will substantially increase phosphorus loading from runoff. Yields of nitrogen species also will increase, but the proportional increases in these will not be as substantial as for phosphorous because the highest concentrations and yields of nitrogen species are contributed by ground-water discharge, not by runoff during precipitation events.

References Cited

American Public Health Association, American Water Works Association, and Water Environment Federation, 1999, Standard methods for the examination of water and wastewater (29th ed.): Washington, D.C., American Public Health Association, variously paged.

Connell, Robert, Jr., and Schuster, Robert, 1996, Toms River nonpoint source pollution study, water quality monitoring: Trenton, N.J., New Jersey Department of Environmental Protection, 8 p., 4 app.

Buchanan, T.J., and Somers, W.P., 1969, U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter A8, Discharge measurements at gaging stations.

Deluca, M.J., Oden, J.H., Romanok, K.M., and Riskin, M.L., 1999, Water Resource Data, New Jersey, Water Year 1998, Volume 3. Water-Quality Data: U.S. Geological Survey Water-Data Report NJ-98-3, 450 p.

Deluca, M.J., Romanok, K.M., Riskin, M.L., Mattes, G.L., Thomas, A.M., and Gray, B.J., 2000, Water resource data for New Jersey - water year 1999, volume 3. Water-quality data: U.S. Geological Survey Water-Data Report NJ-99-3, 517 p.

Emerson, K., Ruso, C.R., Lund, R.E., and Thurston, R.V., 1975, Aqueous ammonia equilibrations; effect of pH and temperature: Journal of the Fisheries Research Board of Canada, no. 32, p. 2379-2383.

Fusillo, T.V., 1981, Impact of suburban residential development on water resources in the area of Winslow Township, Camden County, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 81-27, 38 p.

Fusillo, T.V., Schornick, J.C., Jr., Koester, H.E., and Harriman, D.A., 1980, Investigation of acidity and other water-quality characteristics of Upper Oyster Creek, Ocean County, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 80-10, 30 p.

Gray, D.M., 1970, Handbook on the principles of hydrology: Huntington, N.Y., Water Information Center, Inc., p. 7.

Hirsch, R.M., 1982, A comparison of four streamflow record extension techniques: Water Resources Research, v.18, no.4, p. 1081-1088.

Hunchak-Kariouk, Kathryn., 1999, Relations of water quality to land use in the drainage basins of four tributaries to the Toms River, New Jersey, 1994-95: U.S. Geological Survey Water-Resources Investigations Report 99-4001, 120 p.

Hunchak-Kariouk, Kathryn., and Nicholson, R.S., 2001, Watershed contributions of nutrients and other nonpoint source contaminants to the Barnegat Bay-Little Egg Harbor Estuary: Journal of Coastal Research, no. 32, p. 28-81.

Johnsson, P.A., and Barringer, J.L., 1993, Water quality and hydrogeochemical processes in McDonalds Branch Basin, New Jersey Pinelands, 1984-88: U.S. Geological Survey Water-Resources Investigations Report 91-4081, 111 p.

Kennedy, E.J., 1984, Discharge ratings at gaging stations: Techniques of water-resource investigations of the U.S. Geological Survey, book 3, chap., A10, 58 p.

Kennish, M.J., 1997, The Barnegat Bay National Estuary Program: an overview of anthropogenic impacts, *in* Flimlin, G.E., and Kennish, M.J., eds., Proceedings of the Barnegat Bay Ecosystem Workshop, Rutgers Cooperative Extension of Ocean County, Toms River, N.J., p. 351-360.

Lathrop, R.G., 2000, New Jersey Land Cover Change Analysis Project, 1972-1984-1995: New Brunswick, N.J., Center for Remote Sensing and Spatial Analysis, Cook College, 38 p.

Lathrop, R.G., and Bognar, J.A, 2001, Habitat loss and alteration in the Barnegat Bay region: Journal of Coastal Research, no. 32, p. 212-228.

Linsley, R.K., Kohler, M.A., and Paulhus, J.L.H., 1958, Hydrology for Engineers: New York, McGraw-Hill Book Co., Inc., p. 156.

Lord, D.G., Barringer, J.L., Johnsson, P.A., Schuster, P.F., Walker, R.L., Fairchild, J.E., Sroka, B.N., and Jacobsen, Eric, 1990, Hydrogeochemical data from an acidic deposition study at McDonalds Branch basin in the New Jersey Pinelands, 1983-86: U.S. Geological Survey Open-File Report 88-500, 132 p.

Lynch, J.A, and Corbett, E.S., 1990, Evaluation of best management practices for controlling nonpoint pollution from silvicultural operations: Water Resources Bulletin, v. 26, no. 1, p. 41-52.

Metcalf and Eddy, Inc., 1979, Wastewater Engineering: Treatment, Disposal, Reuse. McGraw Hill, 1979, 920 p.

National Oceanic and Atmospheric Administration, 1991, Climatological data annual summary, New Jersey 1991: National Oceanic and Atmospheric Administration, v. 96, no. 13, p. 2-3.

National Oceanic and Atmospheric Administration, 1992, Climatological data annual summary, New Jersey 1992: National Oceanic and Atmospheric Administration, v. 97, no. 13, p. 2-3.

National Research Council (NRC), Committee on Medical and Biological Effects of Environmental Pollutants, Subcommittee on Ammonia, 1979, Ammonia: Baltimore, Md., University Park Press, 384 p.

New Jersey Department of Environmental Protection, 1998, New Jersey 1998 State water quality inventory report: Trenton, N.J., New Jersey Department of Environmental Protection, sections separately paginated, accessed August 6, 2001, at URL http://www.state.nj.us/dep/dsr/watershed/305-main.htm

New Jersey Department of Environmental Protection, 1999, Initial Surface Water Quality Characterization and Assessment Report (Based on DEP Data) For Watershed Management Area 12, July 16, 1999: Trenton, N.J., New Jersey Department of Environmental Protection, 29 p.

New Jersey Department of Environmental Protection, 2003, N.J.A.C 7, Chapter 9 B, Surface Water Quality Standards: Trenton, N.J., New Jersey Department of Environmental Protection, 127 p.

New Jersey Department of Environmental Protection and Energy, 1993a, A watershed management plan for Barnegat Bay: Trenton, N.J., New Jersey Department of Environmental Protection and Energy, 257 p.

New Jersey Department of Environmental Protection and Energy, 1993b, New Jersey 1992 State water quality inventory report: Trenton, N.J., New Jersey Department of Environmental Protection, 188 p.

Price, C.V., and Schaefer, F.L., 1995, Estimated loads of selected constituents from permitted and nonpermitted sources at selected surface-water-quality stations in the Musconetcong, Rockaway, and Whippany River Basins, New Jersey, 1985-90: U.S. Geological Survey Water-Resources Investigations Report 95-4040, 28 p.

Redfield, A.C., 1958, The biological control of chemical factors in the environment: American Scientist, no. 46, p. 205-221.

Reed, T.J., Centinaro, G.L., DeLuca, M.J., and Oden, J.H., 1998, Water Resource Data, New Jersey, Water Year 1997, Volume 1. Surface-Water Data: U.S. Geological Survey Water-Data Report NJ-97-1, 608 p.

Reiser, R.G., and O'Brien, A.K., 1999, Pesticides in streams in New Jersey and Long Island, New York, and relation to land use: U.S. Geological Survey Water-Resources Investigations Report 98-4261, 12 p.

Rogers, Golden, and Halpern, Inc., 1990, Profile of the Barnegat Bay: Philadelphia, Pa., Report prepared for the Barnegat Bay Study Group by Rogers, Golden, and Halpern, Inc., in association with Expert Information Systems, Inc., 6 chaps., 2 app.

Ruffner, J.A., and Bair, F.E., eds, 1977, The weather almanac (2d ed.): New York, Avon Books, p. 35.

Schornick, J.C., Jr., and Fishel, D.K., 1980, Effects of storm runoff on water quality in the Mill Creek drainage basin, Willingboro, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 80-98, 111 p.

Seitzinger, S.P., and Pilling, I.E., 1992, Eutrophication and nutrient loading in Barnegat Bay: initial studies of the importance of sediment-water nutrient interactions: Philadelphia, Pa., The Academy of Natural Sciences, Report No. 92-24F.

U.S. Environmental Protection Agency, 1985, Ambient water quality criteria for ammonia – 1984: Washington, D.C., EPA-440/5-85-001, 272 p.

U.S. Environmental Protection Agency, 1987, Quality criteria for water: Washington, D.C., EPA-440/5-86- 001, 477 p.

U.S. Environmental Protection Agency, 1991, Technical support document for water quality-based toxics control: Washington, D.C., EPA/505/2-90-001, 335 p.

U.S. Environmental Protection Agency, 1999a, National Primary Drinking Water Standards: Washington, D.C., EPA 810-F-88-008, 6 p.

U.S. Environmental Protection Agency, 1999b, Update of ambient water quality criteria for ammonia: Washington, D.C., EPA-822-R-99-014, 151 p.

U.S. Geological Survey, 1986, Land use and land cover digital data from 1:250,000- and 1:100,000-scale maps: National Mapping Program Technical Instructions: Data users guide 4: U.S. Geological Survey, 36 p.

Zampella, R.A., 1994, Characterization of surface water quality along a watershed disturbance gradient: Water Resources Bulletin, v. 30, p. 605-611.

Appendix

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Total nitrogen concentration as nitrogen in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	227.3	640.8	752.4	250.0	238.0	195.9
1st quartile	706.2	701.8	782.7	372.1	238.0	271.0
Mean	736.1	749.4	852.8	532.6	238.0	346.1
Median	750.0	737.0	841.0	462.0	238.0	346.1
3rd quartile	815.8	754.6	893.6	533.5	238.0	421.2
Highest value	1,111	1,054	1,092	1,471	238.0	496.2
Number of observations	12	10	12	11	1	2
Standard deviation	235.0	116.2	94.6	333.9	na	212.4

Total nitrogen yield as nitrogen in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	3.4	4.2	0.1	na	1.9
1st quartile	0.2	3.9	4.9	0.2	na	2.0
Mean	0.8	5.4	7.1	1.3	na	2.1
Median	0.7	5.2	6.7	0.2	na	2.1
3rd quartile	1.2	6.2	8.5	1.9	na	2.2
Highest value	2.4	9.4	14.0	7.0	na	2.3
Number of observations	12	10	12	11	1	2
Standard deviation	0.8	1.9	2.8	2.1	na	0.3

Total nitrogen concentration as nitrogen in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	621.7	530.6	614.2	196.3	na	432.9
1st quartile	647.4	765.0	756.1	279.4	na	432.9
Mean	819.6	784.2	817.3	289.3	na	432.9
Median	769.5	792.2	814.4	295.1	na	432.9
3rd quartile	941.7	856.0	843.3	337.5	na	432.9
Highest value	1,118	977.0	1,071	338.0	na	432.9
Number of observations	4	5	6	5	0	1
Standard deviation	230.2	163.6	150.2	58.0	na	na

Total nitrogen yield as nitrogen in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.2	6.1	7.4	1.0	na	4.2
1st quartile	0.6	6.9	7.5	1.3	na	4.2
Mean	1.6	8.7	8.6	2.1	na	4.2
Median	1.4	7.8	8.5	1.7	na	4.2
3rd quartile	2.4	8.4	9.7	1.9	na	4.2
Highest value	3.4	14.3	9.9	4.4	na	4.2
Number of observations	4	5	6	5	0	1
Standard deviation	1.4	3.2	1.2	1.4	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Total nitrogen concentration as nitrogen in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	338.4	397.0	340.0	271.0	na	517.0
1st quartile	658.5	660.5	671.0	364.6	na	543.0
Mean	908.9	722.2	844.1	487.7	na	632.7
Median	884.3	743.0	801.2	450.5	na	583.5
3rd quartile	1,046	835.1	989.9	573.6	na	615.7
Highest value	2,296	928.0	1,844	941.0	na	1,033.0
Number of observations	52	19	47	32	0	9
Standard deviation	348.4	152.5	278.3	172.0	na	160.7

Total nitrogen yield as nitrogen in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	1.2	5.2	5.6	0.2	na	3.2
1st quartile	5.3	8.3	8.5	0.8	na	6.6
Mean	32.6	12.1	14.8	2.2	na	8.1
Median	10.8	12.0	13.6	1.5	na	8.6
3rd quartile	18.8	15.3	17.9	3.2	na	8.9
Highest value	608.0	23.3	38.4	6.7	na	13.5
Number of observations	52	19	47	32	0	9
Standard deviation	89.6	4.9	7.1	1.7	na	3.0

Total nitrogen concentration as nitrogen in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	300.0	384.1	300.0	190.1	na	na
1st quartile	639.0	740.5	747.2	317.4	na	na
Mean	993.0	789.2	874.1	432.2	na	na
Median	900.3	825.1	847.0	366.5	na	na
3rd quartile	1221.7	888.2	1,036	468.0	na	na
Highest value	2,957	1,001	1,529	1,200	na	na
Number of observations	57	23	53	45	0	0
Standard deviation	528.1	160.4	266.4	220.8	na	na

Total nitrogen yield as nitrogen in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.3	6.4	7.4	0.6	na	na
1st quartile	2.6	8.0	10.2	2.0	na	na
Mean	12.3	10.4	15.5	3.7	na	na
Median	5.8	11.0	13.4	3.0	na	na
3rd quartile	8.4	12.4	17.9	5.1	na	na
Highest value	186.8	14.7	63.4	13.6	na	na
Number of observations	57	23	53	45	0	0
Standard deviation	27.3	2.5	9.3	2.4	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Nitrate concentration as nitrogen in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	18.0	325.8	299.0	12.0	19.0	328.3
1st quartile	211.6	446.8	579.0	18.8	19.0	na
Mean	285.0	523.1	610.1	34.1	19.0	328.3
Median	316.2	555.0	641.1	25.2	19.0	328.3
3rd quartile	388.5	596.1	693.3	53.4	19.0	na
Highest value	511.0	751.0	811.0	64.9	19.0	328.3
Number of observations	12	10	12	10	1	1
Standard deviation	154.0	132.9	149.6	20.5	na	na

Nitrate yield as nitrogen in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	2.5	2.7	0.0	na	1.5
1st quartile	0.1	2.7	3.6	0.0	na	na
Mean	0.4	3.6	4.8	0.2	na	1.5
Median	0.3	3.3	4.5	0.0	na	1.5
3rd quartile	0.6	4.3	5.9	0.3	na	na
Highest value	1.3	5.5	7.0	0.6	na	1.5
Number of observations	12	10	12	10	0	1
Standard deviation	0.4	1.1	1.5	0.2	na	na

Nitrate concentration as nitrogen in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	480.7	652.6	616.7	111.6	na	345.8
1st quartile	498.9	653.0	722.3	112.6	na	345.8
Mean	632.4	778.1	804.7	146.1	na	345.8
Median	540.5	661.0	730.8	139.1	na	345.8
3rd quartile	674.0	661.0	742.5	176.0	na	345.8
Highest value	967.9	1,263	1,284	191.2	na	345.8
Number of observations	4	5	6	5	0	1
Standard deviation	227.3	271.0	239.4	36.4	na	na

Nitrate yield as nitrogen in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.1	3.5	4.5	0.3	na	3.4
1st quartile	0.5	5.3	6.3	0.4	na	3.4
Mean	0.7	8.7	7.4	0.7	na	3.4
Median	0.8	5.3	6.8	0.7	na	3.4
3rd quartile	1.0	6.4	7.9	0.8	na	3.4
Highest value	1.2	22.9	11.7	1.1	na	3.4
Number of observations	4.0	5.0	6.0	5.0	0.0	1.0
Standard deviation	0.5	8.0	2.5	0.3	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Nitrate concentration as nitrogen in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	103.7	117.0	112.0	25.4	na	221.5
1st quartile	241.0	365.1	271.5	35.6	na	240.1
Mean	362.0	439.8	389.6	70.4	na	305.8
Median	339.3	441.6	407.4	70.9	na	308.3
3rd quartile	461.2	557.4	474.0	86.1	na	345.5
Highest value	714.3	704.9	723.5	182.0	na	396.8
Number of observations	55	20	47	39	0	9
Standard deviation	159.5	154.4	152.1	40.0	na	61.5

Nitrate yield as nitrogen in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.2	1.8	3.1	0.0	na	2.1
1st quartile	2.1	4.8	4.6	0.1	na	2.6
Mean	9.8	7.4	6.7	0.3	na	3.9
Median	4.6	5.5	6.0	0.3	na	3.5
3rd quartile	7.4	9.2	8.6	0.3	na	5.5
Highest value	103.0	20.1	13.7	1.2	na	6.0
Number of observations	55	20	47	39	0	9
Standard deviation	19.7	4.2	2.7	0.3	na	1.5

Nitrate concentration as nitrogen in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	127.0	403.0	228.6	109.5	94.4	na
1st quartile	243.9	489.1	441.5	151.8	94.4	na
Mean	510.1	576.8	561.5	176.8	94.4	na
Median	426.6	577.1	550.7	165.0	94.4	na
3rd quartile	722.8	667.1	654.5	197.5	94.4	na
Highest value	1,649	810.9	973.0	280.5	94.4	na
Number of observations	55	18	54	43	1	0
Standard deviation	342.8	123.4	175.3	42.2	na	na

Nitrate yield as nitrogen in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.2	5.7	5.8	0.3	na	na
1st quartile	1.2	6.4	7.6	0.9	na	na
Mean	4.7	7.5	8.8	1.7	na	na
Median	2.3	7.0	8.9	1.1	na	na
3rd quartile	3.7	7.9	9.4	2.2	na	na
Highest value	52.2	14.8	17.4	7.3	na	na
Number of observations	55	18	54	43	0	0
Standard deviation	8.5	2.1	1.9	1.4	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Ammonia concentration as nitrogen in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	47.0	7.1	10.0	13.0	9.0	5.0
1st quartile	63.1	10.3	14.0	44.1	9.0	11.3
Mean	195.9	37.4	40.0	98.4	9.0	17.7
Median	108.2	17.8	18.8	55.5	9.0	17.7
3rd quartile	212.5	24.6	27.1	71.4	9.0	24.0
Highest value	682.0	226.4	240.7	346.1	9.0	30.4
Number of observations	12	10	12	10	1	2
StdDev.	205.4	66.8	64.6	110.8	na	18.0

Ammonia yield as nitrogen in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	0.0	0.1	0.0	na	0.0
1st quartile	0.0	0.1	0.1	0.0	na	0.1
Mean	0.2	0.4	0.5	0.4	na	0.1
Median	0.1	0.1	0.1	0.0	na	0.1
3rd quartile	0.2	0.1	0.2	0.2	na	0.1
Highest value	0.9	3.0	3.8	3.6	na	0.1
Number of observations	12	10	12	10	1	2
Standard deviation	0.2	0.9	1.0	1.1	na	0.1

Ammonia concentration as nitrogen in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	24.6	2.1	7.2	7.3	na	10.6
1st quartile	38.5	5.1	9.4	12.8	na	10.6
Mean	46.7	7.1	13.2	20.7	na	10.6
Median	49.6	7.4	10.0	18.5	na	10.6
3rd quartile	58.3	9.0	16.3	23.4	na	10.6
Highest value	60.5	11.8	24.0	44.0	na	10.6
Number of observations	6	6	7	6	0	1
Standard deviation	14.3	3.5	6.0	12.9	na	na

Ammonia yield as nitrogen in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	0.0	0.0	0.0	na	0.1
1st quartile	0.1	0.0	0.1	0.1	na	0.1
Mean	0.1	0.1	0.1	0.1	na	0.1
Median	0.1	0.1	0.1	0.1	na	0.1
3rd quartile	0.1	0.1	0.2	0.1	na	0.1
Highest value	0.1	0.1	0.2	0.2	na	0.1
Number of observations	6	6	7	6	0	1
Standard deviation	0.0	0.0	0.1	0.0	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Ammonia concentration as nitrogen in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	37.4	13.6	17.0	10.0	16.6	17.5
1st quartile	80.7	25.2	42.0	46.3	16.6	27.7
Mean	147.7	41.9	59.9	65.8	16.6	55.6
Median	119.6	38.1	52.0	60.0	16.6	44.3
3rd quartile	195.2	56.8	69.9	76.0	16.6	85.2
Highest value	405.9	94.0	207.8	204.0	16.6	102.2
Number of observations	57	14	43	41	1	9
Standard deviation	85.3	22.9	34.1	44.4	na	33.0

Ammonia yield as nitrogen in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.1	0.1	0.2	0.0	na	0.1
1st quartile	0.6	0.3	0.4	0.1	na	0.4
Mean	6.2	0.7	1.2	0.2	na	0.7
Median	1.5	0.6	1.0	0.2	na	0.7
3rd quartile	3.4	1.0	1.6	0.3	na	1.2
Highest value	113.9	1.6	4.0	1.6	na	1.3
Number of observations	57	14	43	41	1	9
Standard deviation	19.6	0.5	0.9	0.3	na	0.5

Ammonia concentration as nitrogen in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	37.0	4.5	4.4	4.5	na	na
1st quartile	72.7	15.0	21.0	15.0	na	na
Mean	166.6	21.0	32.3	21.4	na	na
Median	123.9	23.5	34.1	17.0	na	na
3rd quartile	192.1	26.9	38.3	23.7	na	na
Highest value	670.6	32.5	73.2	76.1	na	na
Number of observations	59	21	54	45	0	0
Standard deviation	137.5	8.3	15.6	14.1	na	na

Ammonia yield as nitrogen in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	0.0	0.0	0.0	na	na
1st quartile	0.3	0.2	0.3	0.1	na	na
Mean	1.4	0.3	0.6	0.2	na	na
Median	0.5	0.3	0.5	0.1	na	na
3rd quartile	1.8	0.4	0.8	0.4	na	na
Highest value	12.8	0.7	2.0	1.1	na	na
Number of observations	59	21	54	45	0	0
Standard deviation	2.1	0.2	0.5	0.2	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Organic nitrogen concentration as nitrogen in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	40.0	121.0	59.8	184.0	207.0	134.0
1st quartile	204.8	140.5	128.5	256.3	207.0	134.0
Mean	267.0	187.4	201.2	389.3	207.0	134.0
Median	291.0	149.0	157.1	324.9	207.0	134.0
3rd quartile	359.9	177.8	240.5	402.0	207.0	134.0
Highest value	422.0	401.0	530.0	1,191.0	207.0	134.0
Number of observations	11	10	12	12	1	1
Standard deviation	127.7	88.0	121.9	268.9	na	na

Organic nitrogen yield as nitrogen in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	0.7	0.6	-0.2	na	0.6
1st quartile	0.1	0.9	0.9	0.1	na	0.6
Mean	0.3	1.3	1.8	0.6	na	0.6
Median	0.2	1.0	1.0	0.2	na	0.6
3rd quartile	0.4	1.6	2.2	1.4	na	0.6
Highest value	0.9	3.2	4.8	2.7	na	0.6
Number of observations	11	10	12	12	0	1
Standard deviation	0.3	0.8	1.4	0.9	na	

Organic nitrogen concentration as nitrogen in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	230.5	82.9	70.0	113.8	na	74.1
1st quartile	239.7	95.0	76.5	137.6	na	74.1
Mean	349.6	187.9	170.3	143.2	na	74.1
Median	249.0	141.5	96.8	141.0	na	74.1
3rd quartile	409.2	307.0	317.5	151.7	na	74.1
Highest value	569.3	307.0	324.0	171.6	na	74.1
Number of observations	3	10	11	5	0	1
Standard deviation	190.5	106.6	119.6	21.1	na	

Organic nitrogen yield as nitrogen in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	0.8	0.6	0.5	na	0.7
1st quartile	0.5	0.8	0.7	0.5	na	0.7
Mean	0.8	1.6	1.7	1.3	na	0.7
Median	1.0	1.5	1.2	0.7	na	0.7
3rd quartile	1.1	2.5	2.9	0.8	na	0.7
Highest value	1.2	2.5	3.0	3.9	na	0.7
Number of observations	3	10	11	5	0	1
Standard deviation	0.6	0.8	1.1	1.5	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Organic nitrogen concentration as nitrogen in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	83.3	17.7	167.0	168.9	na	142.2
1st quartile	292.7	190.3	290.4	236.2	na	156.4
Mean	399.6	233.4	395.4	346.3	na	269.7
Median	351.3	263.4	357.0	327.3	na	261.5
3rd quartile	500.0	298.2	416.0	449.0	na	279.9
Highest value	830.1	356.6	1,135.2	583.9	na	620.9
Number of observations	49	12	41	32	0	9
Standard deviation	169.6	103.3	187.1	121.8	na	153.5

Organic nitrogen yield as nitrogen in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.4	0.4	1.9	0.2	na	0.9
1st quartile	2.0	2.8	3.6	0.5	na	2.2
Mean	16.7	3.9	6.9	1.6	na	3.4
Median	4.8	3.2	5.3	1.4	na	2.7
3rd quartile	9.6	5.9	8.9	2.3	na	3.7
Highest value	386.5	7.1	23.7	4.6	na	8.1
Number of observations	49	12	41	32	0	9
Standard deviation	55.7	2.2	4.8	1.2	na	2.1

Organic nitrogen concentration as nitrogen in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	12.2	64.1	23.8	31.1	na	na
1st quartile	171.0	176.4	112.0	139.3	na	na
Mean	369.1	251.4	368.6	235.3	na	na
Median	237.4	269.0	333.8	183.3	na	na
3rd quartile	432.0	329.5	518.0	250.2	na	na
Highest value	2,245	444.0	1,186	696.0	na	na
Number of observations	45	15	37	30	0	0
Standard deviation	389.5	118.5	287.3	171.8	na	na

Organic nitrogen yield as nitrogen in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.1	0.5	0.3	0.3	na	na
1st quartile	0.4	1.6	1.3	0.8	na	na
Mean	7.1	3.4	7.5	1.8	na	na
Median	0.8	3.3	5.3	1.1	na	na
3rd quartile	3.2	4.9	8.8	2.6	na	na
Highest value	151.6	7.0	50.7	7.8	na	na
Number of observations	45	15	37	30	0	0
Standard deviation	24.2	2.1	9.9	1.7	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Orthophosphate concentration as phosphorus in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.5	0.5	0.5	0.5	6.0	4.7
1st quartile	8.2	2.0	3.6	3.5	6.0	5.6
Mean	11.2	4.3	6.5	10.3	6.0	6.4
Median	9.8	4.0	7.0	10.2	6.0	6.4
3rd quartile	12.9	6.4	8.0	16.8	6.0	7.3
Highest value	26.0	9.0	16.6	19.0	6.0	8.2
Number of observations	9	7	9	10	1	2
Standard deviation	7.4	3.3	4.8	7.4	na	2.5

Orthophosphate yield as phosphorus in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	0.0	0.0	0.0	na	0.0
1st quartile	0.0	0.0	0.0	0.0	na	0.0
Mean	0.0	0.0	0.1	0.0	na	0.0
Median	0.0	0.0	0.0	0.0	na	0.0
3rd quartile	0.0	0.0	0.0	0.0	na	0.0
Highest value	0.0	0.0	0.3	0.0	na	0.1
Number of observations	9	7	9	10	1	2
Standard deviation	0.0	0.0	0.1	0.0	na	0.0

Orthophosphate concentration as phosphorus in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.5	0.5	1.9	0.5	na	7.0
1st quartile	2.4	2.0	2.9	2.3	na	7.0
Mean	3.8	2.3	3.8	2.7	na	7.0
Median	3.6	2.6	3.0	3.0	na	7.0
3rd quartile	5.4	3.0	3.4	3.6	na	7.0
Highest value	7.0	3.0	9.2	4.0	na	7.0
Number of observations	6	6	7	6	0	1
Standard deviation	2.4	1.0	2.5	1.3	na	na

Orthophosphate yield as phosphorus in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	0.0	0.0	0.0	na	0.1
1st quartile	0.0	0.0	0.0	0.0	na	0.1
Mean	0.0	0.0	0.0	0.0	na	0.1
Median	0.0	0.0	0.0	0.0	na	0.1
3rd quartile	0.0	0.0	0.0	0.0	na	0.1
Highest value	0.0	0.1	0.1	0.0	na	0.1
Number of observations	6	6	7	6	0	1
Standard deviation	0.0	0.0	0.0	0.0	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Orthophosphate concentration as phosphorus in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	1.8	0.3	0.3	1.0	33.7	10.5
1st quartile	17.1	2.8	4.3	1.6	33.7	13.7
Mean	30.1	13.0	10.9	5.3	33.7	19.3
Median	30.0	3.9	9.0	2.9	33.7	15.2
3rd quartile	38.5	9.1	13.6	4.0	33.7	26.3
Highest value	76.0	92.4	46.7	19.0	33.7	31.0
Number of observations	55	14	44	38	1	9
Standard deviation	18.0	24.2	9.1	5.9	na	7.8

Orthophosphate yield as phosphorus in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	0.0	0.0	0.0	na	0.1
1st quartile	0.2	0.0	0.1	0.0	na	0.2
Mean	0.7	0.2	0.3	0.0	na	0.3
Median	0.4	0.1	0.1	0.0	na	0.2
3rd quartile	0.9	0.1	0.3	0.0	na	0.4
Highest value	6.5	1.8	1.6	0.0	na	0.5
Number of observations	55	14	44	38	1	9
Standard deviation	1.1	0.5	0.3	0.0	na	0.1

Orthophosphate concentration as phosphorus in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.9	2.8	2.4	0.5	na	na
1st quartile	15.4	4.0	4.6	1.5	na	na
Mean	26.7	5.3	7.5	5.2	na	na
Median	24.1	4.5	5.7	2.9	na	na
3rd quartile	32.5	5.1	8.5	4.3	na	na
Highest value	94.3	14.8	31.7	38.4	na	na
Number of observations	48	15	42	31	0	0
Standard deviation	19.9	3.1	5.6	8.1	na	na

Orthophosphate yield as phosphorus in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	0.0	0.0	0.0	na	na
1st quartile	0.0	0.0	0.1	0.0	na	na
Mean	0.5	0.1	0.2	0.1	na	na
Median	0.1	0.1	0.1	0.0	na	na
3rd quartile	0.5	0.1	0.1	0.0	na	na
Highest value	4.8	0.2	1.4	1.0	na	na
Number of observations	48	15	42	31	0	0
Standard deviation	0.9	0.0	0.2	0.2	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Fecal coliform bacteria concentration in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	240.0	30.0	23.0	17.0	na	na
1st quartile	463.0	77.0	110.0	50.0	na	na
Geo.mean	1,005	170.0	175.0	92.0	na	na
Median	1,250	170.0	200.0	130.0	na	na
3rd quartile	2,325	365.0	340.0	130.0	na	na
Highest value	3,300	1,300	1,100	460.0	na	na
Number of observations	8	7	8	5	0	0
Standard deviation	1,141	447.0	349.0	176.0	na	na

Fecal coliform bacteria yield in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	1.31E+04	1.37E+06	1.02E+06	4.28E+04	na	na
1st quartile	1.92E+06	2.97E+06	2.56E+06	2.21E+05	na	na
Mean	8.44E+06	8.33E+06	1.00E+07	2.80E+06	na	na
Median	4.70E+06	6.12E+06	6.00E+06	5.29E+05	na	na
3rd quartile	8.71E+06	6.80E+06	1.26E+07	1.18E+06	na	na
Highest value	3.43E+07	3.13E+07	3.08E+07	1.21E+07	na	na
Number of observations	8	7	8	5	0	0
Standard deviation	1.13E+07	1.04E+07	1.08E+07	5.19E+06	na	na

Fecal coliform bacteria concentration in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	13.0	13.0	9.0	2.0	na	23.0
1st quartile	20.0	18.0	9.0	2.0	na	23.0
Geo.mean	63.0	19.0	11.0	6.0	na	23.0
Median	23.0	23.0	11.0	5.0	na	23.0
3rd quartile	617.0	23.0	13.0	15.0	na	23.0
Highest value	2400	23.0	17.0	36.0	na	23.0
Number of observations	4	3	4	4	0	1
Standard deviation	1190.0	6.0	4.0	16.0	na	na

Fecal coliform bacteria yield in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	2.02E+04	8.39E+05	3.77E+05	5.24E+04	na	1.02E+06
1st quartile	5.96E+04	9.34E+05	4.02E+05	5.24E+04	na	1.02E+06
Mean	4.98E+06	9.79E+05	5.30E+05	2.16E+05	na	1.02E+06
Median	9.79E+04	1.03E+06	5.18E+05	9.14E+04	na	1.02E+06
3rd quartile	5.01E+06	1.05E+06	6.46E+05	2.55E+05	na	1.02E+06
Highest value	1.97E+07	1.07E+06	7.06E+05	6.27E+05	na	1.02E+06
Number of observations	4	3	4	4	0.0	1.0
Standard deviation	9.81E+06	1.23E+05	1.61E+05	2.77E+05	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Fecal coliform bacteria concentration in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	1,300	23.0	280.0	7.0	2.0	1700.0
1st quartile	2,700	380.0	1,600	110.0	2.0	6000.0
Geo.mean	6,045	1394	3,537	200.0	2.0	11301.0
Median	,9000	2,300	4,000	195.0	2.0	12500.0
3rd quartile	16,000	8,000	9,000	573.0	2.0	16000.0
Highest value	1,6000	16,000	16,000	5000	2.0	16000.0
Number of observations	23	18	26	12	1	6
Standard deviation	6,205	4,536	5,289	1470	na	6334.0

Fecal coliform bacteria yield in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	1.99E+07	1.40E+06	3.37E+07	2.71E+05	na	4.78E+07
1st quartile	1.15E+08	2.97E+07	1.21E+08	1.08E+06	na	3.38E+08
Mean	8.99E+08	3.97E+08	5.09E+08	1.73E+07	na	5.76E+08
Median	6.92E+08	1.54E+08	4.71E+08	2.58E+06	na	5.66E+08
3rd quartile	1.56E+09	5.42E+08	7.76E+08	6.06E+06	na	8.57E+08
Highest value	3.59E+09	2.30E+09	1.37E+09	1.35E+08	na	1.06E+09
Number of observations	23	18	26	12	1	6
Standard deviation	9.16E+08	6.01E+08	4.18E+08	3.92E+07	na	3.86E+08

Fecal coliform bacteria concentration in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	4.0	13.0	80.0	2.0	na	na
1st quartile	200.0	115.0	160.0	2.0	na	na
Geo.mean	648.0	228.0	396.0	8.0	na	na
Median	800.0	230.0	290.0	9.0	na	na
3rd quartile	2,600	900.0	800.0	21.0	na	na
Highest value	16,000	2,400	9,000	130.0	na	na
Number of observations	23	16	20	18	0	0
Standard deviation	4,667	677.0	2154	30.0	na	na

Fecal coliform bacteria yield in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	2.74E+04	6.32E+05	3.84E+06	3.49E+04	na	na
1st quartile	3.06E+06	8.89E+06	8.25E+06	4.27E+04	na	na
Mean	1.06E+08	3.34E+07	8.84E+07	7.21E+05	na	na
Median	8.82E+06	1.33E+07	2.21E+07	1.97E+05	na	na
3rd quartile	1.70E+08	5.63E+07	6.94E+07	6.51E+05	na	na
Highest value	4.80E+08	1.45E+08	7.05E+08	5.47E+06	na	na
Number of observations	23.0	16.0	20.0	18.0	0.0	0.0
Standard deviation	1.62E+08	4.22E+07	1.72E+08	1.37E+06	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Suspended solids concentration in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.5	1.0	1.0	0.5	1.0	0.5
1st quartile	2.3	2.0	1.0	1.3	1.0	1.8
Mean	3.9	5.4	3.4	8.7	1.0	3.0
Median	4.3	3.0	2.5	2.5	1.0	3.0
3rd quartile	5.3	4.5	4.0	8.8	1.0	4.3
Highest value	8.0	21.0	10.0	47.0	1.0	5.5
Number of observations	9	7	9	9	1	2
Standard deviation	2.5	7.0	2.8	14.7	na	3.5

Suspended solids yield in base flow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.0	6.5	7.6	0.7	na	9.8
1st quartile	0.8	15.9	14.4	2.2	na	13.7
Mean	5.8	55.8	28.6	5.1	na	17.6
Median	2.5	18.1	24.7	3.4	na	17.6
3rd quartile	7.6	25.7	30.5	6.9	na	21.5
Highest value	26.3	282.8	62.8	14.4	na	25.5
Number of observations	9	7	9	9	0	2
Standard deviation	8.3	100.3	20.5	4.6	na	11.1

Suspended solids concentration in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.5	1.0	0.5	0.5	na	na
1st quartile	1.0	1.6	1.0	0.5	na	na
Mean	1.4	5.6	2.2	0.8	na	na
Median	1.2	2.0	2.5	0.5	na	na
3rd quartile	2.0	2.3	2.9	1.0	na	na
Highest value	2.3	21.0	4.0	1.6	na	na
Number of observations	5	5	6	5	0	0
Standard deviation	0.7	8.6	1.4	0.5	na	na

Suspended solids yield in base flow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.4	5.3	6.2	2.7	na	na
1st quartile	0.8	16.1	13.0	3.6	na	na
Mean	1.6	55.1	22.7	5.8	na	na
Median	1.2	18.7	23.3	5.8	na	na
3rd quartile	1.5	29.0	26.9	7.7	na	na
Highest value	4.2	206.7	45.9	9.2	na	na
Number of observations	5	5	6	5	0	0
Standard deviation	1.5	85.1	14.1	2.7	na	na

Appendix 1. Summary statistics for selected constituent concentrations and yields, by base flow, stormflow, growing season, and nongrowing season, in samples from selected streams in Ocean County, New Jersey.—Continued

[na, not applicable; Qu, quartile; N, nitrogen; Std dev, standard deviation; concentrations are in milligrams per liter except fecal coliform bacteria, which are in most probable number per deciliter; E, estimated; yields are in pounds per day per square mile; site locations are given in fig. 1]

Suspended solids concentration in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.5	2.3	1.0	0.5	1.0	1.5
1st quartile	6.0	5.3	9.0	2.5	1.0	9.0
Mean	30.1	10.7	48.9	12.9	1.0	14.6
Median	14.0	9.3	25.0	6.0	1.0	14.0
3rd quartile	33.1	13.1	47.8	10.0	1.0	18.5
Highest value	330.7	31.7	709.5	228.0	1.0	25.5
Number of observations	56.0	20.0	47.0	39.0	1.0	9.0
Standard deviation	50.4	7.5	104.0	36.0	na	7.7

Suspended solids yield in stormflow, growing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	1.2	28.5	21.3	3.2	na	17.8
1st quartile	39.8	58.2	246.8	6.8	na	145.4
Mean	1503.1	214.1	786.1	36.8	na	177.0
Median	136.5	177.7	393.6	13.3	na	166.3
3rd quartile	632.4	263.0	720.6	30.9	na	203.7
Highest value	26,608	1,001	9,008	375.6	na	332.2
Number of observations	56.0	20.0	47.0	39.0	0.0	9.0
na’s	0	0	0	0	na	0
Standard deviation	4,473.1	229.8	1,366	67.6	na	93.1

Suspended solids concentration in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.5	2.7	2.3	0.5	na	na
1st quartile	8.7	7.3	9.5	3.2	na	na
Mean	27.4	13.5	33.1	8.1	na	na
Median	15.8	13.3	16.3	5.5	na	na
3rd quartile	50.4	20.5	34.2	10.4	na	na
Highest value	80.0	28.7	187.7	28.3	na	na
Number of observations	54	17	43	31	0	0
Standard deviation	24.6	7.4	43.7	7.4	na	na

Suspended solids yield in stormflow, nongrowing season

Site	LSC2	WB2	WB1	DB	JB	WB3
Lowest value	0.6	18.9	27.8	2.0	na	na
1st quartile	31.4	67.7	159.6	18.6	na	na
Mean	884.3	184.9	638.8	84.3	na	na
Median	89.4	183.3	273.2	69.6	na	na
3rd quartile	469.4	270.5	832.5	116.7	na	na
Highest value	14,414	424.2	3,229	276.4	na	na
Number of observations	54	17	43	31	0	
Standard deviation	2,291	119.4	819.7	82.6	na	