Prepared in cooperation with the New England Interstate Water Pollution Control Commission

Concentrations, Loads, and Yields of Total Nitrogen and Total Phosphorus in the Barnegat Bay-Little Egg Harbor Watershed, New Jersey, 1989–2011, at Multiple Spatial Scales

Scientific Investigations Report 2014–5072

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By Ronald J. Baker, Christine M. Wieben, Richard G. Lathrop, and Robert S. Nicholson

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Contents

Abstract.....	1
Introduction.....	2
Purpose and Scope	2
Description of Study Area	4
Previous Studies	4
Methods.....	8
Water Budgets	8
Acquisition, Screening, and Management of Water-Quality Data	9
Determination of Sample Flow Condition	10
Base-Flow Nutrient Load Calculation	11
Daily Precipitation	11
Base-Flow Separation	11
Determination of Base-Flow Mean Concentrations of Total Nitrogen and Total Phosphorus in Streams	14
Runoff Nutrient Load Calculation	18
Percent Imperviousness.....	18
Monthly, Seasonal, and Annual Precipitation.....	19
Determination of Event-Mean Concentrations of Total Nitrogen and Total Phosphorus in Streams	19
Calibration	24
Turf Analysis	25
Evaluation of Available Water-Quality Data	29
Estimates of Total Nutrient Loads	31
Base-Flow Loads on the Watershed Scale	31
Base-Flow Loads on a Segment Scale	33
Base-Flow Loads on a HUC-14 Scale.....	35
Base-Flow Yields on a HUC-14 Scale	35
Runoff Loads on the Watershed Scale.....	35
Runoff Loads on a Segment Scale	35
Runoff Loads on a HUC-14 Scale	35
Runoff Yields on a HUC-14 Scale.....	39
Relations among Turf Coverage, Land Use, and Nutrient Loads	42
Summary and Conclusions.....	47
References Cited.....	49

Figures

1. Map showing location of Barnegat Bay-Little Egg Harbor estuary and watershed, New Jersey.....	3
2. Map showing locations of north, central, and south segments of the Barnegat Bay-Little Egg Harbor watershed and corresponding estuary segments.....	5
3. Maps showing land use in the Barnegat Bay-Little Egg Harbor watershed, 1986, 1995, 2002, and 2007.....	6
4. Map showing locations of precipitation data-collection stations used to estimate base-flow nutrient loads, Barnegat Bay-Little Egg Harbor watershed	12
5. Map showing locations of U.S. Geological Survey stream gages in the Barnegat Bay-Little Egg Harbor watershed.....	13
6. Graphs showing discharge hydrographs for <i>A</i> , North Branch Metedeconk River, <i>B</i> , Toms River, <i>C</i> , Cedar Creek, and <i>D</i> , Westecunk Creek, Barnegat Bay-Little Egg Harbor watershed, water year 2010	15
7. Graph showing comparison of precipitation with annual base flow for six gaged basins in the Barnegat Bay-Little Egg Harbor watershed and for the watershed as a whole, 1989–2011	16
8. Map showing locations of water-quality sampling stations used to estimate base-flow loads of total nitrogen (TN) and total phosphorus (TP) in the Barnegat Bay-Little Egg Harbor watershed	17
9. Map showing locations of precipitation data-collection stations used to estimate runoff nutrient loads, Barnegat Bay-Little Egg Harbor watershed	20
10. Graphs showing relation between calculated and measured event-mean concentration (EMC) values for <i>A</i> , total nitrogen and <i>B</i> , total phosphorus, Barnegat Bay-Little Egg Harbor watershed	23
11. Map showing developed areas within the Barnegat Bay-Little Egg Harbor watershed based on 2007 land use, and boundaries of aerial photographic image tiles, 2007	26
12. Map showing example of image object polygons, randomly selected points, and the visually interpreted classification into turf and nonturf categories	27
13. Map showing example of the mapped output of the random forest model after quality checking and updating	28
14. Graph showing the distribution of surface-water concentrations of total nitrogen in the Barnegat Bay-Little Egg Harbor watershed by watershed segment, 1980–2011	30
15. Graph showing the distribution of surface-water concentrations of total phosphorus in the Barnegat Bay-Little Egg Harbor watershed by watershed segment, 1991–2011	30
16. Maps showing base-flow load by year and season for <i>A</i> , total nitrogen, and <i>B</i> , total phosphorus, Barnegat Bay-Little Egg Harbor watershed, 1989–2011	34
17. Maps showing annual base-flow loads for each Hydrologic Unit Code-14 (HUC-14) subbasin in the Barnegat Bay-Little Egg Harbor watershed: <i>A</i> , total nitrogen, 2002; <i>B</i> , total nitrogen, 2010; <i>C</i> , total phosphorus, 2002; <i>D</i> , total phosphorus, 2010.....	36
18. Maps showing yields of <i>A</i> , total nitrogen and <i>B</i> , total phosphorus in base flow for each Hydrologic Unit Code-14 (HUC-14) subbasin in the Barnegat Bay-Little Egg Harbor watershed, 2010.....	37
19. Maps showing annual runoff loads of total nitrogen for each Hydrologic Unit Code-14 (HUC-14) subbasin in the Barnegat Bay-Little Egg Harbor watershed for <i>A</i> , 1989, <i>B</i> , 1990, <i>C</i> , 2009, and <i>D</i> , 2010.....	38

20.	Maps showing seasonal runoff loads of total phosphorus for each Hydrologic Unit Code-14 (HUC-14) subbasin in the Barnegat Bay-Little Egg Harbor watershed for <i>A</i> , 1994 growing, <i>B</i> , 1994 nongrowing, <i>C</i> , 2009 growing, and <i>D</i> , 2008 nongrowing seasons	40
21.	Maps showing yields of <i>A</i> , total nitrogen and <i>B</i> , total phosphorus in runoff for each Hydrologic Unit Code-14 (HUC-14) subbasin in the Barnegat Bay-Little Egg Harbor watershed, 2010	41
22.	Pie chart showing percentage of turf and nonturf land cover in developed areas of the Barnegat Bay-Little Egg Harbor watershed, based on 2007 land use	42
23.	Graph showing the relation between percent turf and percent developed land in each Hydrologic Unit Code-14 (HUC-14) subbasin of the Barnegat Bay-Little Egg Harbor watershed, based on 2007 land use.....	43
24.	Graphs showing relation between percent turf and total nitrogen yield in <i>A</i> , total flow, <i>B</i> , base flow, and <i>C</i> , runoff, and between percent turf and total phosphorus yield in <i>D</i> , total flow, <i>E</i> , base flow, and <i>F</i> , runoff	45

Tables

1. Land-use distribution in HUC-14 subbasins in the Barnegat Bay-Little Egg Harbor watershed in 1986, 1995, 2002, and 2007	52
2. Land-use distributions for segments of the Barnegat Bay-Little Egg Harbor watershed	7
3. Continuous streamflow-gaging stations and base-flow indices for six streams in the Barnegat Bay-Little Egg Harbor watershed, New Jersey	14
4. Multiple linear regression coefficients for relations of land use to measured base-flow concentrations of total nitrogen and total phosphorus	18
5. Values of percent imperviousness used to calculate nutrient loads in runoff	19
6. Surface-water stations from which streamflow and water-quality data collected during runoff conditions were used to calculate event-mean concentrations	21
7. Land-use distributions for ten water-quality sampling sites used in the development of event-mean concentrations	21
8. Calculated and measured total nitrogen event-mean-concentration (EMC) values for six water-quality sampling sites, Barnegat Bay-Little Egg Harbor watershed	22
9. Calculated and measured total phosphorus event-mean-concentration (EMC) values for five water-quality sampling sites, Barnegat Bay-Little Egg Harbor watershed	22
10. Event-mean concentrations used to calculate nutrient loads in runoff for each land-use category for all, growing, and nongrowing seasons	24
11. Accuracy assessment of turf mapping, Barnegat Bay-Little Egg Harbor watershed	28
12. Summary statistics for total nitrogen (1980–2011) and total phosphorus data (1991–2011) compiled for the Barnegat Bay-Little Egg Harbor watershed	29
13. Annual and seasonal base-flow, runoff, and total concentrations, loads, and yields of total nitrogen and total phosphorus for each Hydrologic Unit Code-14 (HUC-14) subbasin in the Barnegat Bay-Little Egg Harbor watershed, 1989–2011 [table 13 Excel files accessible from the publication Web site (http://dx.doi.org/10.3133/sir20145072)]	
14. Annual and seasonal base-flow, runoff, and total nutrient loads by watershed segment for total nitrogen and total phosphorus, 1989–2011	60
15. Annual and seasonal base-flow, runoff, and total loads of total nitrogen and total phosphorus in the Barnegat Bay-Little Egg Harbor watershed, 1989–2011	32
16. Turf distribution within the Barnegat Bay-Little Egg Harbor watershed, based on 2007 land use	44
17. Multiple linear regression coefficients for relating percentage of developed nonturf, and developed turf land in the Barnegat Bay-Little Egg Harbor watershed for 2007 to calculated concentrations of total nitrogen and total phosphorus	47
18. Percent undeveloped, developed nonturf, and developed turf land (2007), and calculated concentrations of total nitrogen and total phosphorus, by watershed and watershed segment	47

Conversion Factors

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
Area		
hectare (ha)	2.471	acre
square kilometer (km ²)	247.1	acre
hectare (ha)	0.003861	square mile (mi ²)
square kilometer (km ²)	0.3861	square mile (mi ²)
kilograms (kg)	2.205	pounds, avoirdupois (lb)
Flow rate		
cubic meter per second (m ³ /s)	35.31	cubic foot per second (ft ³ /s)
Yield		
kilograms per hectare per year [(kg/ha)/yr]	0.8921	pounds per acre per year [(lb/acre)/yr]

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

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Abstract

Concentrations, loads, and yields of nutrients (total nitrogen and total phosphorus) were calculated for the Barnegat Bay-Little Egg Harbor (BB-LEH) watershed for 1989–2011 at annual and seasonal (growing and nongrowing) time scales. Concentrations, loads, and yields were calculated at three spatial scales: for each of the 81 subbasins specified by 14-digit hydrologic unit codes (HUC-14s); for each of the three BB-LEH watershed segments, which coincide with segmentation of the BB-LEH estuary; and for the entire BB-LEH watershed. Base-flow and runoff values were calculated separately and were combined to provide total values.

Available surface-water-quality data for all streams in the BB-LEH watershed for 1980–2011 were compiled from existing datasets and quality assured. Precipitation and streamflow data were used to distinguish between water-quality samples that were collected during base-flow conditions and those that were collected during runoff conditions. Base-flow separation of hydrographs of six streams in the BB-LEH watershed indicated that base flow accounts for about 72 to 94 percent of total flow in streams in the watershed.

Base-flow mean concentrations (BMCs) of total nitrogen (TN) and total phosphorus (TP) for each HUC-14 subbasin were calculated from relations between land use and measured base-flow concentrations. These relations were developed from multiple linear regression models determined from water-quality data collected at sampling stations in the BB-LEH watershed under base-flow conditions and land-use percentages in the contributing drainage basins. The total watershed base-flow volume was estimated for each year and season from continuous streamflow records for 1989–2011 and relations between precipitation and streamflow during base-flow conditions. For each year and season, the base-flow load and yield were then calculated for each HUC-14 subbasin from the BMCs, total base-flow volume, and drainage area.

The watershed-loading application PLOAD was used to calculate runoff concentrations, loads, and yields of TN and

TP at the HUC-14 scale. Flow-weighted event-mean concentrations (EMCs) for runoff were developed for each major land-use type in the watershed using storm sampling data from four streams in the BB-LEH watershed and three streams outside the watershed. The EMCs were developed separately for the growing and nongrowing seasons, and were typically greater during the growing season. The EMCs, along with annual and seasonal precipitation amounts and percent imperviousness associated with land-use types, were used as inputs to PLOAD to calculate annual and seasonal runoff concentrations, loads, and yields at the HUC-14 scale.

Over the period of study (1989–2011), total surface-water loads (base flow plus runoff) for the entire BB-LEH watershed for TN ranged from about 455,000 kilograms (kg) as N (1995) to 857,000 kg as N (2010). For TP, total loads for the watershed ranged from about 17,000 (1995) to 32,000 kg as P (2010). On average, the north segment accounted for about 66 percent of the annual TN load and 63 percent of the annual TP load, and the central and south segments each accounted for less than 20 percent of the nutrient loads. Loads and yields were strongly associated with precipitation patterns, ensuing hydrologic conditions, and land use. HUC-14 subbasins with the highest yields of nutrients are concentrated in the northern part of the watershed, and have the highest percentages of urban or agricultural land use. Subbasins with the lowest TN and TP yields are dominated by forest cover.

Percentages of turf (lawn) cover and nonturf cover were estimated for the watershed. Of the developed land in the watershed, nearly one quarter (24.9 percent) was mapped as turf cover. Because there is a strong relation between percent turf and percent developed land, percent turf in the watershed typically increases with percent development, and the amount of development can be considered a reasonable predictor of the amount of turf cover in the watershed. In the BB-LEH watershed, calculated concentrations of TN and TP were greater for developed-turf areas than for developed-nonturf areas, which, in turn, were greater than those for undeveloped areas.

Introduction

The coastal areas of New Jersey include some of the most economically and ecologically valuable resources in the State. Barnegat Bay, Manahawkin Bay, and Little Egg Harbor (fig. 1) together make up the Barnegat Bay-Little Egg Harbor (BB-LEH) estuary, a shallow, lagoonal-type estuary located along the central coast of New Jersey, separated from the Atlantic Ocean by a narrow complex of barrier islands (Kennish, 2001). Historically, the estuary has been a vital economic and recreational resource, supporting both commercial and recreational fish and shellfish industries, as well as boating and tourism. The estuary and adjacent lands offer a variety of ecologically important habitats, including sand beaches and dunes, salt marshes, submerged aquatic vegetation beds, shellfish beds, and waterfowl nesting grounds (Barnegat Bay National Estuary Program, 2002).

The ecological health of the estuary has deteriorated over the last few decades (Kennish and others, 2007), and the estuary has been classified as a highly eutrophic system as determined by application of the National Oceanic and Atmospheric Administration (NOAA) National Estuarine Eutrophication Assessment model (Bricker and others, 2007) and the trophic classification of Nixon (1995). The rapid increase in the human population in the watershed is accompanied by increasing urban development and other changes in land use; therefore, understanding the effects of land-use alteration on the estuary is becoming increasingly important. In particular, the role of nutrient (nitrogen and phosphorus) loading from the watershed on the eutrophication of this coastal estuary must be better understood if further environmental degradation is to be avoided.

The estuary has experienced increases in macroalgal growth, harmful algal blooms (HABs), and turbidity, as well as oxygen depletion, declines in harvestable fisheries, and changes in species composition, including decreases in the biomass and size of seagrass beds (Kennish and others, 2007). For example, Fertig and others (2013) observed a decline in eelgrass biomass in the estuary from 2004 to 2010. Low dissolved-oxygen concentrations [less than 4 milligrams per liter (mg/L)] also have been observed in the northern and central portions of the estuary (Barnegat Bay Partnership, 2011). HABs occurred in the BB-LEH estuary as early as 1995 and as recently as 2010 (Olsen and Mahoney, 2001; Barnegat Bay Partnership, 2011). Relations among estuarine eutrophication, HABs, and nutrient contributions from watersheds are well established (Heisler and others, 2008), and an exogenous source of nutrients (chronic or episodic) is required to sustain high-biomass blooms. All of these conditions can be caused or exacerbated by nutrient loading from the watershed. Management of nutrient inputs to the watershed can lead to improved ecosystem conditions.

An understanding of nutrient cycling, from atmospheric and watershed contributions to biotic uptake and degradation, and sediment processes is needed to fully comprehend, manage, and mitigate the occurrence and intensity of HABs, maintain dissolved-oxygen concentrations above critical levels, and avoid depletion and loss of commercially, recreationally, and ecologically important species. Therefore the U.S. Geological Survey (USGS), in cooperation with the New England Interstate Water Pollution Control Commission, conducted an investigation during 2009–13 to quantify loading of nutrients from the watershed to the estuary for years 1989–2011. In this investigation, nutrient loading from the watershed to the estuary was estimated on the basis of relations between land use and abundance (concentrations, loads, and yields) of nitrogen and phosphorus in streams that discharge to the estuary. Temporal and spatial variability of nutrient loading as a function of stream location, season, meteorology, and upstream land use were considered. Available streamflow, water-quality, precipitation, and land-use data were compiled and used in conjunction with a watershed loading application to determine nutrient loading rates on several spatial scales: for the entire BB-LEH watershed, for each of the three BB-LEH watershed segments, and for each of the 81 subbasins specified by 14-digit hydrologic unit codes (HUC-14s). HUCs, as described by Kapinos and others (1987), uniquely identify all drainage basins in the United States in a nested arrangement from largest to smallest. The 81 HUC-14 subbasins in the BB-LEH watershed are distributed among 15 larger HUC-11 subbasins.

Purpose and Scope

This report documents the influence of changes in land use on past and present nutrient export from the BB-LEH watershed to the BB-LEH estuary, and quantifies the spatial and temporal loading of nutrients. It presents detailed nutrient loading estimates for the BB-LEH watershed at a finer spatial and temporal scale than have been reported in past studies, quantifies and relates turf coverage to nutrient concentrations and loads, and quantifies runoff loading separately from base-flow loading so that a baseline assessment of the current performance of stormwater-management systems can be made.

Physical and chemical watershed data and land-use patterns are used to quantify loading of TN and TP from the watershed to the estuary. Concentrations, loads, and yields of TN and TP for 1989–2011 are documented. Load calculations on both annual and seasonal (growing and nongrowing) time scales are presented. Base-flow loads were calculated directly from streamflow, water-quality, and precipitation data, whereas the watershed-loading application PLOAD, version 3.0 (U.S. Environmental Protection Agency, 2001), was used to estimate runoff loads of nutrients.

Figure 1. Location of Barnegat Bay-Little Egg Harbor estuary and watershed, New Jersey. (HUC, hydrologic unit code)

Description of Study Area

The BB-LEH watershed covers approximately 1,445 square kilometers (km²) and the estuary covers an additional 279 km². The watershed lies entirely in the Atlantic Coastal Plain Physiographic Province, and includes the drainage basins of numerous streams and their tributaries that discharge to the BB-LEH estuary. From north to south, the major streams that discharge to the BB-LEH estuary are the Metedeconk River, Toms River, Cedar Creek, Forked River, Oyster Creek, Mill Creek, Cedar Run, Westecunk Creek, and Tuckerton Creek (fig. 1).

For this study, the watershed was divided into three segments—north, central, and south—to coincide with the natural segmentation of the estuary (Michael Kennish, Rutgers University, oral commun., 2011) (fig. 2). The north segment of the watershed covers 801.4 km² and contains the drainage basins of the Metedeconk and Toms Rivers. The central segment covers 351.6 km² and contains the drainage basins of Cedar Creek, Forked River, and Oyster Creek. The south segment covers 291.6 km² and contains the drainage basins of Mill Creek, Cedar Run, Westecunk Creek, and Tuckerton Creek.

Predominant land uses in the BB-LEH watershed vary regionally (fig. 3). The northeastern mainland area is highly developed with both residential and nonresidential land use, and includes major population centers such as Toms River and Lakewood. The southeastern mainland area contains several protected wildlife refuge and wildlife management areas and is less heavily developed than the northeastern portion of the watershed; however, this area has undergone a substantial increase in development in recent years. The complex of barrier islands on the eastern shore of the estuary is heavily developed, with the exception of Island Beach State Park. Much of the western portion of the watershed lies in the Pinelands National Reserve; this area is protected under the Pinelands Comprehensive Management Plan and is characterized by large tracts of forested land and some low-density development (Kennish, 2001; Hunchak-Kariouk and Nicholson, 2001).

The BB-LEH watershed contains 81 subbasins at the Hydrologic Unit Code (HUC)-14 scale. The percentage of land in each land-use category, determined from land-use/land-cover digital datasets produced by the New Jersey Department of Environmental Protection (1986, 2001, 2008, 2010), was quantified for each of the HUC-14 areas for 1986, 1995, 2002, and 2007 [table 1 (table 1 is in back of report)]. The land-use classification system for each of the digital datasets is derived from Anderson and others (1976). For this report, residential urban land was distinguished from nonresidential urban land (commercial, industrial, and military installations). Additionally, some transportation-related areas such as major roadways and airport facilities were classified as impervious urban.

Since the land-use survey of 1986, the amount of urban land has increased with each successive survey, accompanied by a decrease in forested and agricultural land (fig. 3). From the 1986 to the 2007 land-use survey, the proportion of urban

land within the watershed increased from 21.7 to 30.2 percent, forested land decreased from 45.7 to 39.1 percent, and agricultural land decreased from 2.0 to 1.2 percent (table 2).

In addition to being the largest of the three watershed segments, as of 2007, the north segment had the highest percentage of urban land cover (39.3 percent, of which 28.9 percent is residential, 9.8 percent is nonresidential, and 0.6 percent is impervious) and the lowest percentage of forested land cover (33.9 percent) (table 2). In comparison, the south segment is the smallest and is composed of 22.1 percent urban and 40.1 percent forested land cover. The central segment is the least developed, with 16.4 percent urban and 50.1 percent forested land cover.

Previous Studies

In a profile of Barnegat Bay (Rogers, Golden and Halpern, Inc., 1990), prepared from prior publications and other secondary sources to document the nature and extent of development effects on Barnegat Bay, tidal data, estimated bay water volume, and published reports were used to summarize bathymetry, turnover time, and circulation. Sediment characteristics and distribution and water quality were included. Concentrations of nitrogen, identified as the limiting nutrient, were reported to be generally higher north of Barnegat Inlet than in the southern portion of the bay. A general scarcity of nutrient data, especially for the estuary itself, was noted, but available watershed nutrient data indicated that nitrogen loading from undeveloped areas was lower than that from agricultural and urban areas. Additional urbanization of the watershed was stated to be the greatest threat to the water quality of the bay.

Upgrading or removal of domestic wastewater-treatment plants from streams reduced nutrient loads to streams in estuaries, particularly in the 1970s and 1980s. Hickman and Barringer (1999) studied changes in water quality of streams throughout New Jersey during 1986–95. They observed that more than half of the streams in New Jersey showed downward trends in concentrations of organic nitrogen, ammonia, and TN. In contrast, nitrate plus nitrite concentrations tended to increase with time. The decrease in TN concentration is consistent with the association between treatment-plant removal and upgrades. Some upgrades cause a portion of the ammonia and organic nitrogen to be oxidized and released as nitrate, which can increase nitrate concentration. In a follow-up study for the years 1998–2007 (Hickman and Gray, 2010), downward trends in organic nitrogen plus ammonia were reported for six stations, whereas upward trends were reported for nine. Downward trends for nitrate plus nitrite occurred at 4 stations, whereas upward trends occurred at 19 stations (including Toms and Metedeconk Rivers). From these observations it appears that, throughout New Jersey, the downward trend in reduced nitrogen caused by treatment-plant decommissioning and upgrades has leveled off, with nitrate plus nitrite concentrations continuing to increase. In view of the

Figure 2. Locations of north, central, and south segments of the Barnegat Bay-Little Egg Harbor watershed and corresponding estuary segments. (HUC, hydrologic unit code)

Figure 3. Land use in the Barnegat Bay-Little Egg Harbor watershed, 1986, 1995, 2002, and 2007. (Land-use data from New Jersey Department of Environmental Protection, 1986, 2001, 2008, and 2010)

Table 2. Land-use distributions for segments of the Barnegat Bay-Little Egg Harbor watershed.

[--, not available]

Year	Watershed segment	Segment area, in square kilometers	Land use, in percent of segment area						
			Agriculture	Barren land	Forest	Impervious urban	Non-residential urban	Residential urban	Wetlands + water
1986	North	801.4	3.2	3.4	41.8	--	8.1	20.3	23.3
1995	North	801.4	2.6	3.0	39.0	--	8.7	23.7	23.0
2002	North	801.4	2.1	2.5	36.2	0.5	8.9	27.1	22.6
2007	North	801.4	1.9	2.3	33.9	0.6	9.8	28.9	22.6
1986	Central	351.6	0.4	2.0	53.7	--	3.2	8.7	32.0
1995	Central	351.6	0.4	1.8	52.7	--	3.3	10.0	31.9
2002	Central	351.6	0.3	1.6	51.5	0.4	3.4	11.1	31.8
2007	Central	351.6	0.3	1.4	50.1	0.4	3.8	12.2	31.9
1986	South	291.6	0.5	2.9	47.0	--	4.0	10.8	34.8
1995	South	291.6	0.3	2.6	45.5	--	4.3	12.5	34.8
2002	South	291.6	0.3	2.5	42.9	0.5	4.4	14.5	34.9
2007	South	291.6	0.2	2.4	40.1	0.6	5.1	16.4	35.2
1986	Watershed	1,444.6	2.0	2.9	45.7	--	6.1	15.6	27.7
1995	Watershed	1,444.6	1.6	2.6	43.6	--	6.5	18.1	27.5
2002	Watershed	1,444.6	1.3	2.3	41.3	0.5	6.7	20.7	27.3
2007	Watershed	1,444.6	1.2	2.1	39.1	0.5	7.4	22.3	27.4

removal of treatment plants from the BB-LEH watershed, the observed increase in nitrate concentrations is likely the result of other factors related to increased development.

A 2011 report on the environmental and ecological conditions in Barnegat Bay (Barnegat Bay Partnership, 2011) identified development in the watershed as an important contributing cause of environmental degradation of this resource. Substantial increases in urban development and decreases in wetland areas during the previous decade were indicated as being problematic with respect to the environmental health of Barnegat Bay. Also noted in that report was a progressive decline in many environmental indicators and important species, including shellfish, sea grass, and threatened and endangered species. Analysis of 1995 land-use patterns (Lathrop and Conway, 2001) showed that about 25 percent of the BB-LEH watershed was urban, and another 27 percent was available for development at that time. If the complete build-out scenario were to be implemented, nutrient loading attributable to urban land use could increase substantially. In addition, an increase in impervious surface throughout the watershed would affect the water quality and hydrologic characteristics of many streams in the watershed (Schueler, 1994).

Wieben and Baker (2009) quantified the watershed contributions of nutrients to the BB-LEH estuary. Using available hydrologic, water-quality, and atmospheric-deposition data, they calculated loadings of TN and dissolved nitrogen species during high- and low-flow conditions at 12 sampling locations in the BB-LEH watershed. They noted an increase

in nutrient loading with increasing land development. Median TN concentrations in basins with less than 10 percent urban land (Landscape I) were about one-third of those in basins with greater than 10 percent urban land use (Landscape II). Median values for nitrate plus nitrite concentration were more divergent: 0.02 mg/L as N for Landscape I, 0.49 mg/L as N for Landscape II. Median TN concentrations at individual sites were higher in the northern portion of the watershed, corresponding to areas with the most urban land use. Surface-water transport of nitrogen to the estuary contributes 66 percent of the total nitrogen load, direct groundwater discharge contributes 12 percent, and direct atmospheric deposition to the estuary surface contributes 22 percent.

Velinsky and others (2011) investigated the historical intensity and effects of nutrient loading to Barnegat Bay by measuring the rates of sediment nutrient accumulation at four sites in the tidal marshes. Rates ranged from 0.33 to 0.82 milligrams per square centimeter per year (mg/cm²-yr) for nitrogen and 0.013 to 0.026 mg/cm²-yr for phosphorus. They noted a decrease in the concentration of nitrogen and, to a lesser extent, phosphorus with sediment depth. The sediment record indicated an increase in sediment nitrogen accumulation rates at the northernmost sampling site beginning in the 1950s. An increase was not as apparent at the three other sites. Phosphorus accumulation increased only slightly with time at all sites. This study showed that the bay marshes can sequester a substantial nutrient mass into the bottom sediment that would otherwise flow into the estuary.

Baker and Hunchak-Kariouk (2006) quantified runoff and base-flow loading of nutrients to four tributaries of the Toms River, which terminates in the northern segment of Barnegat Bay, during 1994–99. They reported a strong correlation between nonpoint-source nutrient loading from runoff and urban development. Two streams in highly and moderately developed basins had substantially higher nutrient concentrations and loads than two streams in lightly developed and undeveloped basins. A study of six tributaries to the lower Delaware River during 2002–07 identified agricultural land use, largely absent from the BB-LEH watershed, as the most significant factor in nutrient loading (Baker and Esralew, 2010). Concentrations and loads of nitrogen and phosphorus were highest in the two agricultural basins (Alloway Creek—characterized by intense cattle production, and Blacks Creek—dominated by row crops), followed by the two urban basins (Timber Creek and Cooper River). Loading of all nutrient species was generally lowest for the two streams in undeveloped basins (Lahaway Creek tributary and Gravelly Run).

Five streams in the BB-LEH watershed were sampled in 2010 for nutrient concentrations and stable isotope composition (Wieben and others, 2013). Concentrations of total nitrogen in base flow were related to land use, such that streams in the more developed subbasins—North Branch Metedeconk and Toms Rivers—exhibited higher total nitrogen concentrations (0.84–1.36 mg/L) than streams in less developed subbasins—Cedar Creek, Mill Creek, and Westcunk Creek (0.16–0.62 mg/L). Total nitrogen concentrations were lower during runoff events than during base flow as a result of dilution from precipitation, and were generally lower in runoff during the nongrowing season than the growing season.

Gao (2002) monitored atmospheric deposition rates of nitrate and ammonia in precipitation (wet deposition) and aerosol particulates (dry deposition) at Tuckerton, N.J., near the southern end of Barnegat Bay, in 1999 and 2001. Nitrogen wet deposition rates were highest in the summers, when source strength and removal rates through precipitation were highest. Gao and others (2007) also compared deposition rates at the Tuckerton, N.J. site to those at a northern New Jersey atmospheric deposition station (Sandy Hook, N.J.). Rates were higher at the northern site than at Tuckerton, which is consistent with the presence of more intense anthropogenic nitrogen sources in the highly developed north than in the less developed southern New Jersey coastal areas.

Methods

A combination of existing data and estimation methods was used to calculate TN and TP concentrations, loads, and yields. If sufficient water-quality and hydrologic data had been available to characterize these parameters annually and seasonally, then loads and yields for the desired spatial and temporal increments could have been calculated directly. Lack of sufficient data, however, necessitated the use of multiple

linear regression models relating land use and water quality to calculate base-flow loading, and the use of PLOAD to calculate runoff loading.

Determining concentrations, loads, and yields of TN and TP required quantification of streamflow under runoff and base-flow conditions. Days when streams received direct runoff were distinguished from days when only base flow (from groundwater discharge to streams) was present. Available precipitation and streamflow data were used in conjunction with base-flow separation procedures (which distinguish the base-flow portion of a hydrograph from the runoff portion) to determine annual and seasonal (growing, nongrowing) base-flow and runoff volumes for 1989–2011 for the watershed. The dates of the growing season (April 1–October 31) and nongrowing season (November 1–March 31) were based on the average dates of the first and final frosts in New Jersey (Ruffner and Bair, 1977).

Principal land-use categories considered for this study are agriculture, barren, forest, impervious urban, residential urban, nonresidential urban, water, and wetland. The percentage of land in each land-use category for each HUC-14 subbasin was determined by using digital geodatasets for 1986, 1995, 2002, and 2007 hereafter referred to in this report as “land-use years.” Each year of water-quality data collection from 1989 to 2011 was assigned land-use percentages from the nearest land-use year. For example, water-quality data collected from 1999 to 2004 were related to land-use percentages from 2002, whereas data collected from 2005 to 2011 were related to land-use percentages from 2007. For the purpose of this report, “land-use period” refers to the range of years that corresponds to a given land-use year.

Concentrations, loads, and yields of TN and TP were calculated on an annual and seasonal basis by using water-quality data and relations between concentrations and land-use percentages for base-flow conditions, and PLOAD for runoff conditions. Concentrations are reported in milligrams per liter (mg/L), loads are reported in kilograms (kg), and yields (area-normalized loads) are reported in kilograms per hectare (kg/ha).

Water Budgets

Land-surface- and groundwater-based water budgets can be used to calculate runoff and base-flow values (Gray, 1970; Charles and others, 2001; Gordon, 2004; Walker and others, 2011). The land-surface-based water budget can be expressed as:

$$P + D_{as} \pm \Delta S_{sw} \pm \Delta S_{sm} = Q_{dr} + ET + W_s + R_s, \quad (1)$$

where

P	is precipitation,
D_{as}	is artificial discharge to surface-water bodies,
ΔS_{sw}	is change in surface-water storage,
ΔS_{sm}	is change in soil-moisture storage,

Q_{dr}	is direct runoff,
ET	is evapotranspiration,
W_s	is surface-water withdrawals/diversions, and
R_s	is recharge to the aquifer system.

This relation can be simplified by eliminating terms that do not substantially affect the water budget of the BB-LEH watershed. Little change in storage (ΔS_{sw} and ΔS_{sm}) is expected over a seasonal or annual time scale. Gordon (2004) determined that W_s [0.019 inches (in.)] and D_{as} (0.114 in.) represented a minor fraction of precipitation (44.7 in.) in a study of the hydrology of the Forked River, Cedar Creek, Mill Creek, Westecunk Creek, Tuckerton Creek, and other basins in and near the BB-LEH watershed for 1998–99. A greater total of surface water and shallow groundwater withdrawal occurs in the more highly developed Metedeconk River Basin, from which about 8.0 million gallons per day are withdrawn from the river and shallow groundwater, based on information presented by the Brick Township Municipal Authority (Specht, 2003). This is equivalent to 1.87 inches (4.2 percent) of the average annual precipitation, not a substantial fraction of the total water budget. Therefore, the land-surface-based water budget can be simplified to:

$$P \approx Q_{dr} + ET + R_s \quad (2)$$

The groundwater-based water budget can be expressed as:

$$R_g + D_{ag} \pm R_i = Q_b + W_g \pm L \pm \Delta S_{gw} \quad (3)$$

where

R_g	is recharge to the aquifer system,
D_{ag}	is artificial discharge to the aquifer system,
R_i	is groundwater inflow to/outflow from adjacent basins,
Q_b	is base flow,
W_g	is groundwater withdrawals,
L	is leakage to confined aquifers, and
ΔS_{gw}	is change in groundwater storage.

The relation in equation 3 also can be simplified by assuming no substantial change in storage (ΔS_{gw}) and no substantial effect on surface-water flows from artificial discharge to the aquifer system (D_{ag}), which was calculated to be 0.125 in. in the study area (Gordon, 2004). Leakage to confined aquifers (L) also was minor (0.22 in.). Groundwater withdrawal for each county in New Jersey was quantified by Hoffman and Lieberman (2000). The average Ocean County withdrawal from surficial aquifers from 1990–96 was 0.69 in., which is equivalent to about 1.5 percent of the average precipitation over that period (44.86 in.). Therefore, W_g can be neglected in the water budget. Groundwater inflows from adjacent basins (R_i) were assumed to be negligible for the BB-LEH watershed; however, as a result of an overlap between the groundwater and surface-water divides of the Oswego and Oyster Creek Basins, a portion of recharge in the Oswego River Basin

discharges to the Oyster Creek Basin (Gordon, 2004). In addition, because groundwater discharge to Oyster Creek exceeds precipitation, an additional input must be present. Therefore, streamflow data from the Oyster Creek streamgaging station were excluded from hydrologic calculations. The groundwater-based water-budget equations can then be simplified to:

$$Q_b = R_g \quad (4)$$

and, because R_s and R_g are two expressions of groundwater recharge (equivalent terms of the two water-budget relations), (2) and (4) can be combined:

$$Q_{dr} + Q_b \approx P - ET \quad (5)$$

In this report, Q_{dr} , Q_b , and P are used in base-flow and runoff load calculations. The important assumptions here are that there is no net change in storage in the unsaturated zone or aquifer over the time period considered, that withdrawals and artificial discharges to all the streams in the watershed are negligible compared to the flow terms, that net loss to or gain from adjacent basins is minimal (except in the case of Oyster Creek), and that virtually all recharged water is discharged back to the stream upstream from the gage.

Acquisition, Screening, and Management of Water-Quality Data

To optimize the accuracy of loading estimates, all available water-quality data of suitable quality for all sampling locations in the BB-LEH watershed were assembled in a database for use in load calculations. Available surface-water-quality data for all streams in the BB-LEH watershed for 1980–2011 were compiled from the USGS National Water Information System (NWIS) database and the U.S. Environmental Protection Agency (USEPA) Storage and Retrieval (STORET) database, which contains data collected by state and local agencies including the New Jersey Department of Environmental Protection, Brick Township Municipal Utilities Authority, and New Jersey Pinelands Commission. Data for TN and TP were evaluated. A series of quality-assurance measures was taken to ensure accuracy and compatibility among data collected by the different agencies. For example, the same site was commonly used by multiple agencies, but the site names and reported coordinates differed slightly. A geographic information system (GIS) was used to verify site locations and account for redundancy. Duplicate data in the databases were eliminated. Additionally, conversion factors were applied such that units of concentration were consistent (milligrams per liter as N or P).

Additional steps were taken to evaluate the data for applicability to current conditions, and to check for outliers. Although it was important to utilize as much data as possible, it was equally important to use data that were representative of the period of interest, 1989–2011. Data applicability may be

an issue for older data because relations between land use and nutrient concentrations in streams may change over time if the sources of contaminants change. Three regional wastewater-treatment facilities constructed in the 1970s to treat domestic wastewater from Ocean County and surrounding areas and transport the secondary effluent to the ocean approximately 1 mile offshore (Ocean County Utilities Authority, 2013) removed most wastewater point sources from the BB-LEH watershed. By 1980, nearly all domestic-wastewater discharges were removed from streams in the watershed. A decrease in nutrient concentrations and loads was evident after these point sources were removed. Therefore, data collected prior to 1980 were not used in this investigation.

Although the period of interest in this investigation is 1989–2011, water-quality and hydrologic data collected from 1980 through 1988 also were considered for inclusion in the analysis. The decision whether or not to include data collected before 1989 was addressed separately for nitrogen and phosphorus. For TN, 1980s data were included because there was no apparent decline in mean concentration from the 1980s to subsequent decades, indicating that the historic effects of sewage-treatment-plants that discharged to streams did not persist into the 1980s. Nitrogen-concentration data for 1980–2011 (corresponding to the 1986, 1995, 2002, and 2007 land-use years) were used to calculate TN loads. Variability of TP concentrations in the watershed was much greater, with more occurrences of high concentrations, during the 1980s than during subsequent years. It is likely that decades of sewage-treatment-plant operation continued to affect TP concentrations as phosphorus associated with sediment was released into the water column over time. Therefore, only phosphorus-concentration data for 1991–2011 (corresponding to the 1995, 2002, and 2007 land-use years) were used to calculate TP loads.

The dataset was examined for outliers, and unreasonably high values, considered to be errors, were not used in the analysis. These values were identified first by visually inspecting the data for extreme values, and then by using the Discordance Test (U.S. Environmental Protection Agency, 2006). The Discordance Test quantifies the number of standard deviations from the mean for the most extreme data values. The null hypothesis is that the value in question is a member of the population being examined, and this hypothesis is confirmed with a 95-percent certainty if the value falls within two standard deviations of the population mean. This test was applied separately to TN and TP concentration data for each water-quality site to identify potential outliers. Each potential outlier was then examined and either rejected as an errant value that does not represent a true value, or accepted as a reasonable concentration.

Censored data also were reviewed and accounted for in the load estimations. Reporting levels of nutrient species vary according to the analytical method applied, and generally decrease over time. For TN, there were 87 censored values out of 1,100 measurements for 1980–2011. These censored values were found only in data retrieved from the USGS

NWIS database, and are the result of the analytical method used to determine TN concentrations in USGS water-quality samples. The USGS uses a summation method in which nitrate plus nitrite is measured separately from ammonia plus organic nitrogen; nitrogen concentrations resulting from the two methods are summed to obtain the TN concentration for the sample. By convention, if the concentration of either ammonia plus organic nitrogen (as N) or nitrate plus nitrite (as N) is below the reporting level, the calculated TN value also is reported as less than that reporting level plus the value of the detected parameter. To address the need for an actual TN value for load calculations, values were assigned for the censored data as the mean of all detected values less than each reporting level for which there were censored data.

For TP, there were 154 censored values out of 817 measurements for 1991–2011. Censored TP values were found in data retrieved from both NWIS and STORET. As in the process for TN, the mean of detected values less than each reporting level was used as the TP concentrations for the censored data associated with the corresponding reporting levels.

Determination of Sample Flow Condition

Flow conditions during each calendar day for each water-quality-sampling site were needed to distinguish samples collected during base-flow, runoff, and base-flow-plus-runoff conditions. This determination was based on site location, area of the drainage basin upstream from the sampling site, and daily average precipitation totals prior to sample collection.

The sampling sites were designated “north or “south,” signifying whether they are located in the northern or southern half of the watershed. Precipitation data from nearby weather stations were used to determine the flow condition under which each sample had been collected.

The term “base-flow days” for a stream-sampling site was defined as days in which less than 0.2 in. of precipitation had fallen during the previous number of days (N) required by the stream to return to base-flow conditions after a precipitation event. Values of N varied from 2 to 4 days, depending upon the basin area. A method for calculating N reported by Linsley and others (1958) was used:

$$N = A^{0.2} \quad (6)$$

where

- N is the number of days after the peak of the previous precipitation event, and
- A is the basin area in acres.

The value of N was rounded up to the next highest number of days and an additional day was added to ensure a conservative assignment of base-flow day. The term “runoff days” was defined as days in which greater than 0.75 in. of precipitation had occurred during the previous N days. “Base-flow plus

runoff days” were days in which greater than 0.2 in. but less than 0.75 in. of precipitation had occurred.

By applying equation 6 as described, each water-quality sample was designated as “base flow,” “runoff,” or “base flow plus runoff.” Only base-flow water-quality data were used to quantify base-flow concentrations, loads, and yields for the watershed, and only runoff water-quality data were used to quantify runoff concentrations, loads, and yields.

Base-Flow Nutrient Load Calculation

Base-flow concentrations, loads, and yields were calculated at the HUC-14 scale. This process required four categories of data: daily precipitation from weather stations in or near the BB-LEH watershed; hydrologic data from continuous streamflow-gaging stations; water-quality data collected during base-flow conditions from streams in the watershed; and information about each basin in the watershed, including area and land-use percentages. As described in the following sections, precipitation and streamflow data were used to identify which water-quality data were collected during base-flow conditions. Water-quality data were then related to land-use percentages to develop the relations that were used to calculate base-flow mean concentrations (BMCs) of TN and TP at the HUC-14 scale. BMCs were then used in conjunction with hydrologic data to calculate annual and seasonal loads and yields at the HUC-14 scale. Loads were aggregated for each watershed segment and for the entire watershed.

Daily Precipitation

A subset of water-quality data containing only analyses of samples collected under base-flow conditions was needed to complete the base-flow loading estimate. Because streamflow data were not always collected concurrently with water-quality samples, precipitation records were used to determine which water-quality samples were collected under base-flow conditions. To account for spatial and temporal variability of precipitation as well as data gaps among stations, daily precipitation data for nine stations in and near the watershed (fig. 4) were retrieved from the Office of the New Jersey State Climatologist (2013) and the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (2013). Daily average precipitation amounts calculated from the northern stations were applied to base-flow calculations for the northern half of the watershed, and daily average precipitation amounts from the southern stations were applied to base-flow calculations for the southern half of the watershed. Data from the Indian Mills station were used in precipitation calculations for both the north and the south because of the station’s central location. Daily average precipitation amounts for both the northern and southern halves of the watershed were calculated for the period 1989–2011. Based on the results of base-flow separation, a subset of water-quality samples collected under base-flow conditions was developed.

Base-Flow Separation

Annual and seasonal volumetric base-flow values were required for calculating base-flow nutrient loads and yields. Daily mean discharge data for six continuous streamflow-gaging stations (fig. 5, table 3) in the BB-LEH watershed were retrieved from the USGS NWIS database. For each of the six streams, streamflow was extrapolated for years with missing data from other gages in the watershed, to cover the period of interest (1989–2011). The number of sites and number of years of streamflow data are insufficient to fully characterize the surface-water hydrology of the BB-LEH watershed (fig. 5, table 3); therefore, the simplified water-budget relation (equation 5), combined with the application of base-flow separation to the six streams with continuous streamflow data, was used to obtain base-flow volumes throughout the BB-LEH watershed.

The USGS program PART (Rutledge, 1998), was used to determine the base-flow fraction of each stream. PART scans the hydrograph for days that fit the requirements of antecedent recession, and designates those days as base flow. The base-flow fraction of flow that occurs during each runoff event is determined by linearly interpolating between flow at the beginning and end of the event, thus separating the runoff portion of flow from the base-flow portion. All base-flow portions are totaled, and the ratio of the total base-flow volume to the total streamflow volume represents the base-flow index. The PART program is applied to a long (multi-year) period of record to estimate the mean rate of groundwater discharge.

Average base-flow indices for the six basins range from 0.716 to 0.944, indicating that base flow accounts for approximately 72 to 94 percent of total streamflow for streams in the BB-LEH watershed. The Metedeconk River Basin is the most urbanized of the six basins, and the Metedeconk River has the smallest average BFI values (0.716 and 0.719 for the North and South Branches, respectively). Impervious surfaces resulting from the presence of structures and pavement, soil compaction, and other urban characteristics increase flashiness and decrease recharge and base flow in streams (Aichele, 2005). The small base-flow volume is evident in the discharge hydrograph for North Branch Metedeconk River (fig. 6A), which shows flow returning to low levels soon after runoff events, in contrast to the recession patterns of the other streams (fig. 6B–D). Runoff, which contributes nearly 30 percent of flow volume in the Metedeconk River, is more significant in this stream than in streams in less urbanized basins. If urban development in other basins were increased to the extent of urban development in the Metedeconk River Basin, more runoff, less recharge to groundwater, and smaller proportions of base flow to total flow would be expected.

The Toms River Basin above station 01408500 is the largest of the six basins (319 km²) and is less urbanized than the Metedeconk River Basin, and has a base-flow index of 0.853. The discharge hydrograph for the Toms River for water

Figure 4. Locations of precipitation data-collection stations used to estimate base-flow nutrient loads, Barnegat Bay-Little Egg Harbor watershed.

Figure 5. Locations of U.S. Geological Survey stream gages in the Barnegat Bay-Little Egg Harbor watershed.

Table 3. Continuous streamflow-gaging stations and base-flow indices for six streams in the Barnegat Bay-Little Egg Harbor watershed, New Jersey.

U.S. Geological Survey station number	Station name	Period of record	Base-flow index ¹
01408120	North Branch Metedeconk River near Lakewood, NJ	10/01/1972 to present	0.716
01408150	South Branch Metedeconk River near Lakewood, NJ	06/12/1992 to 03/31/1999	0.719
01408500	Toms River near Toms River, NJ	10/02/1928 to present	0.853
01409000	Cedar Creek at Lanoka Harbor, NJ	07/07/1932 to 09/30/1958 10/01/1970 to 09/30/1971 09/12/2003 to present	0.906
01409095	Oyster Creek near Brookville, NJ	07/02/1965 to 01/16/1985	0.913
01409280	Westecunk Creek at Stafford Forge, NJ	10/01/1973 to 10/12/1988 07/08/2003 to present	0.944

¹As determined using PART, A Computer Program for Calculating Groundwater Discharge from Streamflow Records (Rutledge, 1998)

year¹ 2010 (fig. 6B) is similar to that of the Metedeconk River, as the same runoff events are represented; however, a more gradual recession after runoff results in a higher base-flow index. In addition to the smaller percentage of urban land, the longer flow paths in this larger basin allow for more time and distance for recharge, leading to a higher base-flow index.

Discharge hydrographs for Cedar Creek and Westecunk Creek (fig. 6 C, D) are dominated by base flow (base-flow indices of 0.906 and 0.944, respectively), reflecting the low levels of urban development in their basins. These two streams have gradual baseline recessions.

From available discharge data and results of base-flow separation, average base-flow volume normalized by basin area was calculated for each year and season. Annual base-flow values for the six gaged basins and an average for the entire watershed (excluding Oyster Creek) over the period of analysis (1989–2011) follow similar patterns (fig. 7). Base flow at North Branch Metedeconk River tends to be slightly less than that of other local streams, and base flow at Westecunk Creek tends to be slightly greater. The differences in base flow among the streams correspond to different degrees of urban development and impervious surface among the basins. For some years, there is an observable time lag between fluctuations in precipitation and fluctuations in base flow. Base flow at Oyster Creek, as previously mentioned, is substantially higher than that at other streams in the watershed because the creek receives base-flow contributions from the Oswego River. Total base flow does not vary substantially among the other five streams, indicating that the average of their area-weighted base-flow values is a reasonable approximation of base flow for the entire BB-LEH watershed. Area-weighted annual and seasonal values of base flow were calculated for the watershed

and applied to each HUC-14 subbasin for the calculation of base-flow loads.

Determination of Base-Flow Mean Concentrations of Total Nitrogen and Total Phosphorus in Streams

Relations between measured concentrations of TN and TP and percentages of land uses in basins upstream from sampling locations were used to calculate BMCs for each HUC-14 basin. As described earlier, on the basis of geographic location (north or south), drainage area above a water-quality sampling site, and daily average precipitation amounts for up to 4 days prior to the date of sample collection, a subset of water-quality samples collected under base-flow conditions was developed. Only sites at which four or more base-flow samples were collected within a land-use period were used in the calculation of TN and TP base-flow loads. Sites that met this criterion varied by constituent. Figure 8 shows the sampling sites for which four or more TN and TP values are available for one or more land-use periods. Several sites in the north, central, and south watershed segments were sampled during multiple land-use periods, and in several streams, more than one reach was sampled. Therefore, the variability in TN and TP over time, among segments, and with land use was reflected in the water-quality data. The average measured concentration at each site during each land-use period was related to land use percentages by determining the best-fit multiple linear regression model. Combinations of eight potential explanatory variables (percent agricultural, barren, forest, impervious urban, nonresidential urban, residential urban, water, and wetlands) were explored in multiple linear regression models. The parameters evaluated when selecting the best-fit regression equations were:

1. statistical significance of explanatory variables, as indicated by t- and p-values;
2. model correlation coefficient (r^2);

¹A water year is the 12-month period beginning October 1 of any given year and extending through September 30 of the following year. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 2007, is called the “2007 water year”.

Figure 6. Discharge hydrographs for *A*, North Branch Metedeconk River, *B*, Toms River, *C*, Cedar Creek, and *D*, Westecunk Creek, Barnegat Bay-Little Egg Harbor watershed, water year 2010.

Figure 7. Comparison of precipitation with annual base flow for six gaged basins in the Barnegat Bay-Little Egg Harbor watershed and for the watershed as a whole, 1989–2011.

3. colinearity among variables, as indicated by variance inflation factors (VIFs); and
4. difference between calculated and measured concentrations.

Not all explanatory variables for the selected TN model were statistically significant at a 95-percent confidence level (p -value < 0.05). For the overall model, the calculated and measured values were correlated with an r^2 of 0.65. All explanatory variables for the TP model were statistically significant at a 95-percent confidence level, with an r^2 of 0.77. Colinearity among explanatory variables in the selected models was minimal as indicated by low VIFs; all VIFs were less than 8 for the TN model and less than 3 for the TP model. Measured and calculated concentrations were compared graphically by means of a scatter plot; for both the TN and TP models, the r^2 between the measured and calculated values was greater than 0.6.

The combination of explanatory variables that resulted in the best-fit model for TN was percent agriculture, forest, and total urban (the sum of percent impervious, residential, and nonresidential urban) (table 4). Percent agriculture, total urban, and wetlands were the explanatory variables that yielded the best-fit model for TP (table 4).

The best-fit regression equations were applied to the land-use percentages in each HUC-14 subbasin for each land-use year to calculate BMCs for each subbasin, such that, for TN:

$$\text{BMC}_{\text{HUC14}} = 0.7369 + 0.0658 * \text{AgPct} - 0.0055 * \text{ForPct} + 0.0048 * \text{TotalUrbPct} \quad (7)$$

where

$\text{BMC}_{\text{HUC14}}$ is base-flow mean concentration for the HUC-14 subbasin,
 AgPct is percent agricultural land in the HUC-14 subbasin,
 ForPct is percent forest in the HUC-14 subbasin, and
 TotalUrbPct is percent total urban in the HUC-14 subbasin; and, for TP:

$$\ln \text{BMC}_{\text{HUC14}} = -5.3217 + 0.1115 * \text{AgPct} + 0.0196 * \text{TotalUrbPct} + 0.0259 * \text{WetPct} \quad (8)$$

where

$\ln \text{BMC}_{\text{HUC14}}$ is natural log of the base-flow mean concentration for the HUC-14 subbasin,
 AgPct is percent agricultural land in the HUC-14 subbasin,
 TotalUrbPct is percent total urban in the HUC-14 subbasin, and
 WetPct is percent wetlands in the HUC-14 subbasin.

The TN relation (equation 7) indicates that agricultural land has the greatest influence on increasing TN concentrations,

Figure 8. Locations of water-quality sampling stations used to estimate base-flow loads of total nitrogen (TN) and total phosphorus (TP) in the Barnegat Bay-Little Egg Harbor watershed.

Table 4. Multiple linear regression coefficients for relations of land use to measured base-flow concentrations of total nitrogen and total phosphorus.

[--, not included in the linear regression model]

Land use	Total nitrogen	Natural log total phosphorus
Intercept	0.7369	-5.3217
Agriculture	0.0658	0.1115
Forest	-0.0055	--
Total urban ¹	0.0048	0.0196
Wetlands	--	0.0259
Multiple R ²	0.653	0.771

¹Impervious, nonresidential, and residential urban

urban land is intermediate in influence, and forested land has the least influence. The TP relation (equation 8) indicates that agricultural land has the greatest influence, followed by wetland, and urban land.

Because land-use percentages differ among land-use years, this calculation was done for each HUC-14/land-use-year combination. Base-flow loads for each HUC-14 sub-basin were then calculated as the product of the BMC for the subbasin and the average base flow for the watershed, with a unit conversion. Yields were calculated as the HUC-14 load divided by the HUC-14 area.

Runoff Nutrient Load Calculation

PLOAD, version 3.0 (U.S. Environmental Protection Agency, 2001), was used to quantify nutrients in runoff. PLOAD is a GIS-based application in which land-use percentages, contaminant intensity, and percent impervious surface associated with each land-use type are used as explanatory variables for calculating concentrations, loads, and yields of selected contaminants in runoff to lakes and streams. Although it is a powerful tool for calculating contaminant loads over long time frames, not all variability in nutrient loading can be explained by the variables used by PLOAD. Additionally, PLOAD does not account for in-stream processes that may increase or attenuate concentrations and loads of contaminants during transport through a watershed; however, it is a suitable tool for comparing loads of nutrients in a watershed among seasons and years.

The PLOAD application requires the following data inputs: land-use data; watershed delineations; percent imperviousness for each land-use type; annual or seasonal precipitation; and annual or seasonal event-mean concentrations (EMCs) of nutrients for each land-use type. The two equations used by PLOAD to calculate loads with the USEPA “Simple Method” (U.S. Environmental Protection Agency, 2001)—a runoff coefficient equation and a loading equation—are given below. Runoff coefficients are calculated as:

$$R_{VU} = 0.05 + (0.009 \times I_U) \quad , \quad (9)$$

where

R_{VU} is runoff coefficient for land-use type U , in inches_{runoff}/inches_{rain}; and
 I_U is percent imperviousness.

The pollutant loads are then calculated with the following equation:

$$L_p = \sum_U (P \times P_j \times R_{VU} \times EMC_U \times A_U \times 2.72 / 12) \quad , \quad (10)$$

where

L_p is pollutant load, in pounds;
 P is precipitation, in inches/year;
 P_j is fraction of storms producing runoff (default = 0.9);
 R_{VU} is runoff coefficient for land-use type U , in inches_{runoff}/inches_{rain};
 EMC_U is event-mean concentration for land-use type U , in milligrams/liter; and
 A_U is area of land-use type U , in acres.

Loads and yields from PLOAD were converted to metric units.

Percent Imperviousness

Percent imperviousness (I_U) is a function of land use, with more impervious surface being attributed to urban land than to agricultural and forested land. Percent imperviousness values range from 0 to 95 percent for the eight land-use categories used in this investigation (table 5). Although the PLOAD manual does not provide guidance for selecting I_U values, an example table of percent imperviousness values was provided in the PLOAD documentation. Published values are also available from literature sources (Washburn and others, 2010; Prisloe and others, 2003; City of Redmond, Washington, 2009). Residential I_U for the BB-LEH watershed was set at 31 percent on the basis of medium-density residential land use of about 1.6 units per acre (Lathrop and Conway, 2001; Ocean County Agriculture Development Board, 2008). This value is consistent with the California I_U of 1.6 units per acre (Washburn and others, 2010) and also with the I_U of 30.5 percent determined for residential, single-unit, medium-density land use in the upper Delaware River watershed (North Jersey Resource Conservation & Development, 2002). Nonresidential urban land use was assigned an I_U value of 60 percent, reflecting a composition of retail, office, industrial, and public nonresidential land uses, which have I_U values ranging from 50 to 86 percent (Washburn and others, 2010). I_U for agricultural, forested, barren, and wetland categories was given a value of 2 percent, which is consistent with the values assigned to the open space and agriculture categories of Washburn and others (2010), which range from 2 to 4 percent. Impervious urban

Table 5. Values of percent imperviousness used to calculate nutrient loads in runoff.

Land use	Percent imperviousness
Agriculture	2
Barren land	2
Forest	2
Impervious urban	95
Residential urban	31
Nonresidential urban	60
Water	0
Wetlands	2

land was given a value of 95 percent because impervious urban surfaces such as pavement and structures commonly are not perfect water barriers as a result of the presence of cracks and other imperfections. Open water was given an I_U value of 0 percent.

Monthly, Seasonal, and Annual Precipitation

Monthly precipitation data were retrieved from the Office of the New Jersey State Climatologist and from the National Climatic Data Center. These data were used to calculate growing season, nongrowing season, and annual precipitation totals for the entire watershed, which were subsequently used as input to PLOAD. PLOAD utilizes a single precipitation amount for the entire area (in this case, the BB-LEH watershed) for each year. Precipitation records from eight stations were used (fig. 9). Averages of precipitation totals from two southern stations (Atlantic City Airport and Atlantic City Marina), four western stations (Hammonton, Pemberton, Mount Holly, and Indian Mills), and two northern stations (Toms River and Lakehurst) were averaged together to obtain an overall average precipitation total, by year and by season, for the BB-LEH watershed for 1989–2011. Precipitation records from most stations are incomplete (that is, missing months or years of data); however, data from at least four stations were used to calculate each average annual and seasonal precipitation total.

Determination of Event-Mean Concentrations of Total Nitrogen and Total Phosphorus in Streams

Event-mean concentrations (EMCs) are flow-weighted concentrations of water-quality constituents under runoff or high-flow conditions, and are used in watershed-based calculations and models for calculating contaminant loads (Lin, 2004; Baird and others, 1996). The EMC for a given constituent can vary widely as a function of land use, geographic location, seasonality, and other variables. For this study, an EMC value

was developed for each combination of land-use type and season. The EMCs were input into PLOAD to calculate runoff loads and yields for each HUC-14 subbasin.

EMC values can be determined from local water-quality and streamflow records, or can be assigned from literature values (for example, Syed and Jodoin, 2006). For this report, local water-quality and streamflow data were used to develop the EMC values for TN and TP. The process of determining land-use EMCs involved the following steps:

1. select basins representative of the study area for which sufficient water-quality and hydrologic data are available,
2. determine the land-use percentage in each basin upstream from a sampling location,
3. compile water-quality and hydrologic data for days in which storm runoff occurred,
4. determine streamflow for each sample date and time,
5. calculate the flow-weighted EMC for each constituent of interest at each site, and
6. use a stepwise regression procedure to calculate the EMC for each land-use category.

For TN and TP, seasonal and annual EMCs were developed for each land-use category: agricultural, forested, barren, impervious urban, residential urban, nonresidential urban, wetland, and water. Water-quality and streamflow data from two studies with a large number of storm-flow samples were used to develop the EMCs. Only water-quality data from runoff samples were used to determine EMCs. In one study, locations on Long Swamp Creek, Davenport Branch, and Wrangle Brook, all in the BB-LEH watershed and all tributaries to the Toms River, were sampled for nutrients multiple times during 15 to 19 storms from 1994 to 1999 (Baker and Hunchak-Kariouk, 2006) (table 6). Data from that study provided extensive storm-flow water-quality and hydrologic data. In another study, five sites located on tributaries to the lower Delaware River (also located in the New Jersey Coastal Plain) were sampled in an intensive investigation of water quality and hydrology from 2002 to 2007 (Baker and Esralew, 2010) (table 6). The water-quality data from these two studies were collected by the New Jersey Department of Environmental Protection, and are archived in the USEPA STORET database. The hydrologic data are archived in the USGS NWIS database. Water-quality data from the continuous monitoring stations at Toms River and McDonalds Branch were used to supplement the data from these two studies.

The GIS land-use datasets that corresponded most closely to the years of water-quality sampling were used to determine land-use percentages for each basin: 1995 land use for the Toms River watershed sites and 2002 land use for the lower Delaware River watershed sites. Basins were delineated by using the USGS application StreamStats (Ries and others, 2004), and basin land-use percentages were obtained from GIS coverages for all but two stations (01482890 and

Figure 9. Locations of precipitation data-collection stations used to estimate runoff nutrient loads, Barnegat Bay-Little Egg Harbor watershed.

Table 6. Surface-water stations from which streamflow and water-quality data collected during runoff conditions were used to calculate event-mean concentrations.

[LDR, lower Delaware River; BB-LEH, Barnegat Bay-Little Egg Harbor estuary; A, Baker and Esralew (2010); B, Baker and Hunchak-Kariouk (2006); TN, total nitrogen; TP, total phosphorus; --, not applicable]

U.S. Geological Survey station number	Station name	Watershed	Range of sampling dates	Water-quality investigation	Number of sampling events	Parameter
¹ 01482890	Alloway Creek near Watsons Corner, NJ	LDR	09/27/03 to 03/16/07	A	8	TN, TP
¹ 0146452750	Blacks Creek near Chesterfield, NJ	LDR	10/27/03 to 03/17/07	A	6	TN, TP
01467148	Cooper River at Route 561 at Haddonfield, NJ	LDR	11/19/03 to 03/16/07	A	8	TN,TP
01411955	Gravelly Run at Laurel Lake, NJ	LDR	10/27/03 to 03/16/07	A	8	TN, TP
² 01466500	McDonalds Branch in Byrne State Forest, NJ	LDR	11/12/81 to 08/05/09	--	--	TP
01467327	SB Big Timber Creek trib at Grenloch, NJ	LDR	10/27/03 to 03/16/07	A	7	TN, TP
01408620	Davenport Branch near Dover Forge, NJ	BB-LEH	09/22/94 to 03/01/99	B	16	TN
01408728	Long Swamp Creek at Toms River, NJ	BB-LEH	07/15/94 to 08/20/99	B	19	TN
² 01408500	Toms River near Toms River, NJ	BB-LEH	11/11/82 to 09/01/09	--	--	TP
01408600	Wrangle Brook near Toms River, NJ	BB-LEH	07/15/94 to 08/20/99	B	19	TN

¹Data from this station were used to calculate the event-mean concentration for agriculture only.

²Water-quality data were retrieved from the U.S. Geological Survey National Water Information System (NWIS) database and are not from any specific water-quality investigation.

0146452750) for which land-use percentages were obtained from Baker and Esralew (2010) (table 7).

The EMCs were calculated as the total mass of a constituent divided by the total flow volume during monitored runoff events. For each event, each measured concentration value was multiplied by the streamflow and by the time increment between samples. The sum of these values is the total mass of that constituent for all monitored events. The ratio of the total

mass divided by total flow volume gives the flow-weighted EMC for that sampling location. This procedure was completed for annual and seasonal conditions for TN and TP.

Because EMC values were required for land-use categories, a relation between EMCs and land use for the 10 stations listed in table 6 was required. The sum of area-weighted land-use EMC (EMC_{LU}) values in a basin is equal to the EMC for the basin (EMC_{basin}):

Table 7. Land-use distributions for ten water-quality sampling sites used in the development of event-mean concentrations.

[--, not available]

U.S. Geological Survey station number	Year	Land use, in percent of drainage basin								Wetlands
		Agriculture	Barren land	Forest	Impervious urban	Non-residential urban	Residential urban	Urban	Water	
¹ 01482890	2002	76.6	1.1	8.2	--	--	--	7.5	0.3	6.2
¹ 0146452750	2002	55.4	0.2	14.1	--	--	--	10.0	1.6	18.6
01467148	2002	1.4	1.7	17.8	0.7	22.7	44.5	--	1.1	10.1
01411955	2002	5.7	0.0	79.1	0.0	0.9	0.1	--	0.0	14.2
01466500	2002	0.0	0.9	87.8	0	0.0	0.0	--	0.0	11.3
01467327	2002	4.0	0.2	14.6	0.4	19.3	53.4	--	1.5	6.6
01408620	1995	0.5	0.2	66.6	--	2.9	20.0	--	1.2	8.6
01408728	1995	3.5	1.8	25.8	--	22.5	43.8	--	0.5	2.0
01408500	1995	3.4	4.4	50.2	--	6.6	10.8	--	1.3	23.4
01408600	1995	0.7	3.5	49.4	--	6.9	22.4	--	1.9	15.2

¹Land-use percentages for these sites are from Baker and Esralew (2010), in which no distinction was made among urban subcategories.

$$EMC_{\text{basin}} = (A_{LU1} \times EMC_{LU1} + A_{LU2} \times EMC_{LU2} + A_{LU3} \times EMC_{LU3} + A_{LU4} \times EMC_{LU4} + \dots) / A_T \quad (11)$$

where

A_{LU1} ,
 A_{LU2} , ... are areas of land-use 1, land-use 2...;
 EMC_{LU1} ,
 EMC_{LU2} , ... are the event-mean concentrations for land-use 1, land-use 2...; and
 A_T is the total basin area.

Basins with little agricultural land were used to determine EMC_{LU} values for forested, wetland, and residential and non-residential urban categories. For TN, six basins, each composed of more than 94 percent of these land-use categories, were used to determine the EMC_{LU} values; for TP, five basins, each composed of more than 92 percent of these land-use categories, were used to determine EMC_{LU} values. For both TN and TP, EMC_{LU} values were initially assigned default values suggested by the PLOAD application. A stepwise procedure was developed to adjust the default EMC_{LU} values so that they were more reflective of measured concentrations in the study area; EMC_{LU} values were raised or lowered incrementally such that the difference between EMC_{basin} values calculated from equation 11 (referred to as the “calculated EMC_{basin} ”) and those determined from water-quality and hydrologic data (referred to as the “measured EMC_{basin} ”) was minimized, and the correlation coefficient between the calculated and measured EMC_{basin} values was maximized. Tables 8 and 9 and figure 10 (*A* and *B*) show the results of applying this procedure for determining the final EMC_{LU} values for TN and TP. Barren land was given the same EMC_{LU} value as forested land, as both categories are undeveloped and not affected by urban or agricultural activities. EMC_{LU} values used as input to PLOAD are shown in table 10 for year-round, growing, and nongrowing seasons.

Although the total percentage of agricultural land use in the BB-LEH watershed during this investigation was small, the amount of agricultural land in some HUC-14 areas may be sufficient to affect surface-water quality. Two sites in the lower Delaware River watershed were used to determine agricultural EMCs because of a scarcity of water-quality data for predominantly agricultural areas in the BB-LEH watershed. As of 2002, sites 0146452750 (Blacks Creek near Chesterfield, NJ) and 01482890 (Alloway Creek near Watsons Corner, NJ) had 55.4 and 76.6 percent agricultural land use, respectively (Baker and Esralew, 2010). Agriculture in the Blacks Creek Basin is mostly row crops. Cattle production is practiced in the Alloway Creek Basin, and cattle were frequently observed in and around Alloway Creek during water-quality sampling events (Baker and Esralew, 2010). Using water-quality data from these two streams in the determination of the agricultural EMCs ensures that the effects of a variety of agricultural activities are considered. The relation shown in equation 11 was modified to determine agricultural EMC_{LU} values, with a

Table 8. Calculated and measured total nitrogen event-mean-concentration (EMC) values for six water-quality sampling sites, Barnegat Bay-Little Egg Harbor watershed.

[mg/L, milligrams per liter; R^2 (correlation coefficient) between calculated and measured values equals 0.78]

U.S. Geological Survey station number	Calculated EMC, in mg/L	Measured EMC, in mg/L
01467327	0.836	0.879
01408620	0.467	0.371
01411955	0.343	0.363
01467148	0.836	0.857
01408728	0.755	0.827
01408600	0.571	0.816
Mean	0.623	0.686

Table 9. Calculated and measured total phosphorus event-mean-concentration (EMC) values for five water-quality sampling sites, Barnegat Bay-Little Egg Harbor watershed.

[mg/L, milligrams per liter; R^2 (correlation coefficient) between calculated and measured values equals 0.89]

U.S. Geological Survey station number	Calculated EMC, in mg/L	Measured EMC, in mg/L
01467327	0.064	0.076
01466500	0.012	0.009
01411955	0.012	0.025
01467148	0.057	0.058
01408500	0.028	0.021
Mean	0.038	0.035

term added for agricultural land use and for all urban categories combined.

As a means of evaluating the reasonableness of the EMCs used in the runoff calculations, mean runoff concentrations were calculated for each of the basins upstream from water-quality sampling stations with four or more samples during one or more land-use periods, as the sum of the same EMC_{LU} values input into the PLOAD calculation (table 10) multiplied by the percentage of the respective land uses in each sampled basin. For TN, the average percent difference between the measured mean concentration and the calculated mean concentration was 27.4 percent. The average mean TN concentration at the watershed scale (24 site/land-use-year combinations) was 0.64 mg/L for measured values and 0.66 mg/L for calculated values. The average mean TN concentration for sites in the north segment was 0.84 and 0.82 mg/L for measured and

Figure 10. Relation between calculated and measured event-mean concentration (EMC) values for *A*, total nitrogen and *B*, total phosphorus, Barnegat Bay-Little Egg Harbor watershed. (R^2 , correlation coefficient)

Table 10. Event-mean concentrations used to calculate nutrient loads in runoff for each land-use category for all, growing, and nongrowing seasons.

[mg/L, milligrams per liter]

Land use	Percent impervious	Total nitrogen, in mg/L	Total phosphorus, in mg/L
All seasons/annual			
Residential urban	31	0.956	0.105
Nonresidential urban	60	1.142	0.025
Impervious urban	95	1.142	0.025
Agriculture	2	5.581	0.789
Forest	2	0.220	0.011
Water	0	0.933	0.020
Wetland	2	1.117	0.021
Barren land	2	0.220	0.011
Growing season			
Residential urban	31	1.050	0.135
Nonresidential urban	60	1.250	0.030
Impervious urban	95	1.250	0.030
Agriculture	2	5.583	1.131
Forest	2	0.200	0.011
Water	0	0.970	0.024
Wetland	2	1.325	0.023
Barren land	2	0.200	0.011
Nongrowing season			
Residential urban	31	0.825	0.063
Nonresidential urban	60	0.990	0.019
Impervious urban	95	0.990	0.019
Agriculture	2	5.573	0.312
Forest	2	0.248	0.013
Water	0	0.897	0.016
Wetland	2	0.825	0.019
Barren land	2	0.248	0.013

calculated values, respectively. For the central segment, the average mean TN concentration was 0.35 and 0.46 mg/L for measured and calculated values, respectively, and for the south segment, it was 0.43 and 0.47 mg/L, respectively. This agreement between the measured and calculated values indicates that the EMCs developed for TN are reasonable on a watershed scale as well as at the segment level, although there may be some overestimation in the less developed central segment.

Like mean TN runoff concentrations, mean TP runoff concentrations for streams from which four or more samples had been collected during a land-use period (20 site/land-use-year combinations) were compared to TP concentrations calculated from EMCs. Although the relation between the measured and calculated TP concentrations was good

($r^2 = 0.79$), the EMCs systematically overestimated the concentrations, resulting in an average ratio of 0.57:1 for measured:calculated values. This result reflects the fact that, although similar, current and historical land-use patterns in the lower Delaware River watershed are different from those in the BB-LEH watershed. For example, more land was and continues to be used for agriculture in the lower Delaware River watershed than in the BB-LEH watershed. To account for the overestimation and to more accurately reflect the actual water-quality conditions in the BB-LEH watershed, TP concentrations calculated from the EMCs were adjusted by applying a calibration factor of 0.57. After calibration, the average mean TP concentration at the watershed scale was 0.038 mg/L for measured values and 0.036 mg/L for calculated values. The average mean TP concentration for sites in the north segment was 0.043 and 0.040 mg/L for measured and calculated values, respectively. For the central segment, it was 0.005 and 0.007 mg/L for measured and calculated values, respectively, and for the south segment, it was 0.009 and 0.014 mg/L, respectively. The agreement between measured and calibrated values at the watershed and segment scale indicates that the EMCs developed for TP are reasonable when a correction factor is applied; however, there may be some overestimation in the less developed segments.

Calibration

The equations used in PLOAD calculate loads from EMCs, precipitation, and relations between land use and permeability. These relations may not represent the conditions in the particular watershed being simulated if permeabilities, and therefore runoff volumes, are different from those associated with the various land uses. In the case of the BB-LEH watershed, hydrologic records and base-flow separation indicate that only about 6 to 28 percent of flow in most streams is contributed by runoff.

To calibrate the nutrient loads and yields output from PLOAD to actual runoff in the watershed, runoff was calculated from PLOAD results and compared to that calculated from the hydrologic record and base-flow separation. The average annual runoff for the BB-LEH watershed calculated from the hydrologic record (1989–2011) by base-flow separation was 4.32 in., whereas the average annual runoff calculated from PLOAD results was 8.27 in. This overestimation may be attributed to the extremely flat topography of the BB-LEH watershed (and the entire New Jersey Coastal Plain), and the highly permeable, sandy soils that underlie the watershed, both of which enhance recharge (Watt, 2000). PLOAD is designed to apply to typical conditions, where the base-flow index would tend to be lower, and runoff values would be higher. Therefore, all load and yield values calculated by using PLOAD were multiplied by a factor of 0.522 (ratio of runoff calculated from the hydrologic record to that calculated from PLOAD results) to account for PLOAD's overestimation of flow and to more accurately reflect the hydrologic conditions in the watershed. By applying this correction factor, the

accuracy of TN and TP loading in runoff from available water-quality, precipitation, and other hydrologic data was optimized within the limitations of the PLOAD application.

Turf Analysis

A substantial portion of the BB-LEH watershed consists of single-family dwellings or other types of land use with extensive areas covered by turf. Previous work in Barnegat Bay and in Buzzards Bay, Massachusetts, indicates that managed lawns or other turf areas can be sources of substantial amounts of nitrogen runoff to estuarine waters (Bowen and others, 2007; Buzzards Bay National Estuary Program, 2012). The objective of the turf analysis was to identify and quantify turf land cover in the study area.

Remote-sensing data and GIS were used to map and quantify turf areas across the BB-LEH watershed. The New Jersey Department of Environmental Protection (NJDEP) spring 2007 color infrared aerial photography was used as the basis for the image analysis. The 2007 New Jersey land use/land cover dataset was used to identify and extract developed land-use areas for turf analysis (fig. 11).

The eCognition software package (Definiens Developer 7) was used to segment the aerial photographic imagery into relatively small homogeneous image objects (that is, groups of image pixels with similar spectral color and pattern on the order of 0.25 to 0.5 acre in size). These image objects were then displayed as GIS polygons overlain on the original aerial photographic imagery (fig. 12).

A subset of the developed land-use area was used to develop a training dataset of more than 1,000 randomly selected GIS polygons. The polygons were classified by on-screen visual interpretation of the 2007 aerial photography as either (1) more intensively managed turf, (2) less intensively managed turf, or (3) nonturf. This training dataset also was used with a random forest version of the Cartographic and Regression Tree (CART) analysis to classify each image object polygon of the entire dataset into one of the three categories. Random forest uses a bootstrap version of the CART

model without replacement. Bootstrapping involves randomly subsampling the training dataset, running a CART model, and then using the remaining training dataset to compute an accuracy assessment. The random forest model was developed within a MATLAB script. This technique provides an unbiased accuracy assessment while allowing the full training dataset to be used in the final model creation. A reference manual for this statistical technique is located at <http://cran.r-project.org/web/packages/randomForest/randomForest.pdf>. A visual assessment of the random forest classification results indicated that more intensively managed and less intensively managed turf could not be reliably distinguished; therefore, these two classes were grouped into a single category and re-designated simply as “developed—turf”. The classified image object polygons were overlain on the 2007 aerial photographic imagery and further quality checked, and the turf classification was modified as necessary (fig. 13).

An accuracy assessment of the turf-mapping procedure described above was conducted by randomly selecting 510 image object polygons dispersed across the study area and manually classifying them as developed—turf or developed—nonturf. Results of this independent classification represent the reference dataset, and were compared to results of the previously described classification using random forest (the mapped dataset) for the same 510 polygons. Table 11 shows the results of the two methods of classification. Of the 510 polygons, 100 polygons were identified as developed—turf using both methods, and 361 polygons were identified as developed—nonturf using both methods, indicating that turf could be mapped with approximately 90-percent accuracy (kappa statistic of 0.74). The remaining 49 polygons were identified as developed—turf using one method, but not the other. The turf mapping was deemed of sufficiently high accuracy to be used to investigate relations between turf area and nutrient loads in the watershed. A visual assessment indicated that the turf coverage was highest in newer, large-lot residential areas with minimal tree cover. Some underestimation of turf growing under a canopy of shade trees may have occurred, especially in older residential neighborhoods.

Figure 11. Developed areas within the Barnegat Bay-Little Egg Harbor watershed based on 2007 land use, and boundaries of aerial photographic image tiles, 2007.

Figure 12. Example of image object polygons, randomly selected points, and the visually interpreted classification into turf and nonturf categories.

Figure 13. Example of the mapped output of the random forest model after quality checking and updating.

Table 11. Accuracy assessment of turf mapping, Barnegat Bay-Little Egg Harbor watershed.

Mapped data	Reference data		Row total
	Developed–turf	Developed–nonturf	
Developed–turf	100	30	130
Developed–nonturf	19	361	380
Column total	119	391	510

Overall accuracy = $461/510 = 90.4$ percent

Kappa = 0.74, considered borderline excellent

Evaluation of Available Water-Quality Data

This section summarizes the compiled TN and TP concentration data and compares differences in measured concentrations among the watershed segments. The data used in this analysis are pooled—that is, they include concentration values measured in base-flow and runoff samples collected during all seasons. Although water-quality samples were collected over an extended period and sampling locations were not distributed uniformly throughout each segment, comparing summary statistics of nutrient concentrations among the three segments is informative.

TN data available for 1980–2011 consisted of 1,100 quality-assured values from 50 sites throughout the watershed (table 12). The north segment was sampled most frequently (848 values from 34 sites), followed by the central segment (171 values from 9 sites) and the south segment (81 values from 7 sites). Median TN concentrations were 0.79, 0.23, and 0.31 mg/L as N for the north, central, and south segments, respectively (table 12). The ANOVA by ranks test, followed by a Tukey multiple comparison test, was used to test the null hypothesis of no difference among segments and to rank the segments by median TN concentration. The null hypothesis was rejected at the 5-percent significance level ($P < 0.05$), and the order of median TN concentrations among segments determined from available water-quality data is

$$TN_{\text{north}} > TN_{\text{south}} > TN_{\text{central}} \quad (12)$$

The median TN concentration in the highly developed north segment is significantly higher than that in the south segment, which in turn is significantly higher than that in the central segment (fig. 14).

A total of 817 TP values for 1991–2011 were available for 82 sites in the BB-LEH watershed. Of those sites, 63 are in the north segment (667 values), 11 are in the central segment

(117 values), and 8 are in the south segment (33 values). TP data also were evaluated for differences among segments. Median TP concentrations were 0.030, < 0.010 , and < 0.015 mg/L as P in the north, central, and south segments, respectively (table 12). The ANOVA by ranks test rejected the null hypothesis of no difference among segments at the 5-percent significance level ($P < 0.05$). The Tukey multiple comparison test ranked median TP concentrations by segment such that:

$$TP_{\text{north}} > (TP_{\text{south}} = TP_{\text{central}}) \quad (13)$$

The median TP concentration in the highly developed north segment is significantly higher than that in the two less developed segments, which cannot be statistically distinguished from each other (fig. 15).

Greater median concentrations of both TN and TP in the north segment (fig. 14, 15) are consistent with a greater percentage of developed (agricultural plus urban) land in the north segment (table 2). These relations demonstrate well-established effects of development on water quality. On the basis of previous investigations in the watershed (Hunchak-Kariouk and Nicholson, 2001; Baker and Hunchak-Kariouk, 2006; Wieben and Baker, 2009) and the analysis of existing data, future increases in development in the central and south segments will likely lead to higher concentrations and loads of nutrients in the streams located in those areas. Given that concentrations are a primary factor in determining loads, the higher concentrations that result from land use in the north are reflected in the loads (described in more detail below).

A single EMC value was used for each land-use category during each season, regardless of sampling location or stream-flow. Previous water-quality investigations of the BB-LEH watershed have shown that concentrations of nutrient species can vary substantially over the course of a storm event (Baker and Hunchak-Kariouk, 2006; Wieben and others, 2013). Run-off data used to develop the EMCs were collected during various storms and at various times during storms (rising, peak,

Table 12. Summary statistics for total nitrogen (1980–2011) and total phosphorus data (1991–2011) compiled for the Barnegat Bay–Little Egg Harbor watershed.

[Concentration in milligrams per liter; --, not applicable; <, less than]

Segment	Number of water-quality sampling stations	Number of analyses	Minimum	Maximum	Mean	Median
Total nitrogen						
North	34	848	0.13	5.29	0.84	0.79
Central	9	171	0.06	1.56	0.26	0.23
South	7	81	0.12	1.50	0.41	0.31
Total phosphorus						
North	63	667	<0.002	0.66	--	0.030
Central	11	117	<0.004	0.06	--	< 0.010
South	8	33	<0.004	0.16	--	< 0.015

Figure 14. Distribution of surface-water concentrations of total nitrogen in the Barnegat Bay-Little Egg Harbor watershed by watershed segment, 1980–2011.

Figure 15. Distribution of surface-water concentrations of total phosphorus in the Barnegat Bay-Little Egg Harbor watershed by watershed segment, 1991–2011. (Outliers of 0.66 and 0.38 milligrams per liter total phosphorus in the north watershed segment are not shown on the graph)

and falling limbs of the hydrograph); therefore, results of the calculations reflect the variability in runoff concentrations.

As described above, relations between land-use categories and TN and TP concentrations are significant and consistent for both base flow and runoff, and are appropriate for calculating nutrient loads for annual and seasonal time steps in this study. Annual and seasonal variability of TN and TP loading from the BB-LEH watershed can be predicted from land-use percentages and the hydrologic record. These relations are applicable to the watershed as a whole as well as to the three segments.

Estimates of Total Nutrient Loads

Concentration, load, and yield values were calculated at the HUC-14 scale for base-flow and runoff conditions [table 13 (table 13 Excel files accessible from the publication Web site)]. Loads also were aggregated for the watershed segment scale [table 14 (table 14 is in back of report)] and for the entire watershed (table 15). The primary factors that control loading at these three spatial scales are land use (and associated contaminant concentrations) and streamflow volume (determined in large part by drainage area). These factors dictate that loads should be highest in the north segment. During the period of study (1989–2011), total surface-water loads (base flow plus runoff) of TN for the entire BB-LEH watershed ranged from about 455,000 kg as N (1995) to 857,000 kg as N (2010) (table 15). The north segment accounted for an average of 65.7 percent of the annual TN load, and the central and south segments accounted for 17.7 and 16.6 percent, respectively. TP loads for the watershed ranged from 17,000 (1995) to 32,000 kg as P (2010). Similar to the TN load, about 63.4 percent of the TP load was contributed by the north segment, with 18.4 and 18.2 percent contributed by the central and south segments, respectively. The large percentage of loads discharging from the north segment is attributed to a combination of factors: the north segment is more than twice the size of the central or south segment; contains the Toms and Metedeconk Rivers, which together account for more than 60 percent of the streamflow in the watershed; and contains greater proportions of agricultural, and residential and non-residential urban lands, each of which is associated with greater nutrient concentrations than undeveloped land. The corresponding north segment of the estuary is the smallest of the three estuarine segments (fig. 2). The large ratio of watershed area to estuarine area likely contributes to higher nitrogen concentrations in the northern part of the estuary, as previously reported by Seitzinger and others (2001) and Kennish and Fertig (2012). Loads for the central and south segments of the watershed are similar because the central segment is larger but less developed.

From 1989 to 2011, total nutrient loads fluctuated depending upon precipitation and hydrologic conditions and patterns, with precipitation having a short-term and immediate

effect on runoff loads and a longer term effect on base-flow loads. For the entire period (on average), 82.2 percent of the total TN and TP load was attributed to base flow and 17.8 percent was attributed to runoff. The fact that the loads of both constituents are larger in base flow than in runoff is consistent with the hydrologic record and the base-flow separation results.

Base-Flow Loads on the Watershed Scale

By using annual and seasonal base-flow amounts calculated from base-flow separation together with relations between base-flow mean concentrations and land use, nutrient base-flow loads were calculated for each HUC-14 sub-basin in the BB-LEH watershed for 1989–2011 by year and season. Annual TN base-flow loads for the watershed ranged from 339,000 kg as N (2002) to 740,000 kg as N (2010), and annual TP base-flow loads ranged from 12,600 kg as P (2002) to 27,700 kg as P (2010) (table 15, fig. 16). For both TN and TP, the lowest base-flow load occurred in 2002 following the driest year in the period of study (2001, precipitation = 34.58 in.) indicating a delayed effect of low or high precipitation years on base-flow loads. Base-flow loads of both TN and TP were highest in 2010, one of the driest years in the period of study (precipitation = 43.23 in.), which followed the wettest year (2009, precipitation = 59.92 in.). The increase in base-flow loads from 2009 to 2010 despite a substantial decrease in precipitation is likely the result of the continued seepage of large amounts of recharge resulting from precipitation in 2009 through the surficial aquifer to the streams. The years of greatest base flow and greatest precipitation do not necessarily coincide (fig. 16).

The apparent gradual increase in base-flow loads during 1989–2011 shown in figure 16 is masked by a large amount of interyear variability resulting from precipitation patterns. Although precipitation patterns are strongly related to streamflow volume and base-flow loads, load also is a function of land use. The gradual increase in base-flow nutrient loads can be attributed in part to increases in urban development in the watershed over time in conjunction with the strong positive relation between urban land use and concentrations of nutrients measured in base flow.

The relative contribution of base-flow loads of both TN and TP during the growing and nongrowing seasons is similar, with the growing season accounting for an average of 52.5 percent and the nongrowing season accounting for an average of 47.5 percent of the annual base-flow loads. Although loads might be expected to be smaller during the nongrowing season because it is shorter than the growing season, a greater percentage of precipitation is recharged during the nongrowing season because rates of evapotranspiration and agricultural and urban water use are lower. This seasonal recharge, in turn, results in proportionally higher base flows during the nongrowing season.

Table 15. Annual and seasonal base-flow, runoff, and total loads of total nitrogen and total phosphorus in the Barnegat Bay-Little Egg Harbor watershed, 1989–2011.

[All loads in kilograms; A, all/annual; G, growing; NG, nongrowing]

Year	Season	Precipitation, in inches	Load of total nitrogen in:			Load of total phosphorus in:		
			Base flow	Runoff	Total	Base flow	Runoff	Total
1989	A	53.83	564,000	116,000	681,000	21,400	4,270	25,600
1990	A	43.18	523,000	93,300	616,000	19,800	3,420	23,200
1991	A	45.14	451,000	105,000	555,000	16,900	3,890	20,700
1992	A	42.94	369,000	99,400	469,000	13,800	3,700	17,500
1993	A	42.35	521,000	98,000	619,000	19,500	3,660	23,200
1994	A	46.50	566,000	108,000	673,000	21,200	4,010	25,200
1995	A	37.66	368,000	87,200	455,000	13,800	3,250	17,000
1996	A	56.26	621,000	130,000	752,000	23,200	4,850	28,100
1997	A	46.14	543,000	107,000	650,000	20,300	3,980	24,300
1998	A	45.56	621,000	106,000	727,000	23,200	3,930	27,200
1999	A	45.82	446,000	116,000	562,000	16,600	4,320	20,900
2000	A	47.39	452,000	120,000	571,000	16,800	4,470	21,200
2001	A	34.58	431,000	87,300	519,000	16,000	3,260	19,300
2002	A	48.07	339,000	121,000	460,000	12,600	4,530	17,100
2003	A	53.72	623,000	136,000	759,000	23,100	5,060	28,200
2004	A	46.82	589,000	118,000	708,000	21,900	4,420	26,300
2005	A	48.40	616,000	131,000	747,000	23,000	4,860	27,900
2006	A	51.47	681,000	139,000	820,000	25,400	5,170	30,600
2007	A	44.51	620,000	120,000	740,000	23,200	4,470	27,600
2008	A	47.57	532,000	128,000	661,000	19,900	4,770	24,700
2009	A	59.92	669,000	162,000	831,000	25,000	6,010	31,000
2010	A	43.23	740,000	117,000	857,000	27,700	4,340	32,000
2011	A	57.32	595,000	155,000	749,000	22,200	5,760	28,000
1989	G	37.44	362,000	88,500	450,000	13,700	3,790	17,500
1990	G	28.78	304,000	68,000	372,000	11,500	2,910	14,400
1991	G	26.10	218,000	66,200	285,000	8,170	2,860	11,000
1992	G	26.53	193,000	67,300	260,000	7,200	2,910	10,100
1993	G	22.85	271,000	58,000	329,000	10,100	2,510	12,600
1994	G	22.67	289,000	57,500	347,000	10,800	2,490	13,300
1995	G	22.57	167,000	57,200	224,000	6,250	2,480	8,730
1996	G	35.33	312,000	89,600	402,000	11,700	3,880	15,600
1997	G	25.91	277,000	65,700	343,000	10,400	2,840	13,200
1998	G	24.85	357,000	63,000	420,000	13,300	2,730	16,100
1999	G	25.48	215,000	70,500	285,000	7,980	3,050	11,000
2000	G	30.86	248,000	85,500	334,000	9,220	3,700	12,900
2001	G	18.96	226,000	52,500	278,000	8,380	2,270	10,700
2002	G	28.46	161,000	78,800	239,000	5,960	3,410	9,370
2003	G	33.62	326,000	93,100	419,000	12,100	4,020	16,100
2004	G	30.16	315,000	83,500	398,000	11,700	3,610	15,300
2005	G	29.82	326,000	88,300	415,000	12,200	3,800	16,000
2006	G	33.43	327,000	98,900	426,000	12,200	4,260	16,500

Table 15. Annual and seasonal base-flow, runoff, and total loads of total nitrogen and total phosphorus in the Barnegat Bay-Little Egg Harbor watershed, 1989–2011.—Continued

[All loads in kilograms; A, all/annual; G, growing; NG, nongrowing]

Year	Season	Precipitation, in inches	Load of total nitrogen in:			Load of total phosphorus in:		
			Base flow	Runoff	Total	Base flow	Runoff	Total
2007	G	26.09	334,000	77,200	411,000	12,500	3,320	15,800
2008	G	23.75	248,000	70,300	318,000	9,270	3,030	12,300
2009	G	39.95	359,000	118,000	477,000	13,400	5,090	18,500
2010	G	18.81	368,000	55,700	424,000	13,800	2,400	16,200
2011	G	38.05	310,000	113,000	423,000	11,600	4,850	16,400
1989	NG	16.39	202,000	30,800	233,000	7,640	819	8,460
1990	NG	14.40	217,000	27,100	244,000	8,210	721	8,930
1991	NG	19.04	227,000	38,200	265,000	8,500	1,040	9,540
1992	NG	16.41	174,000	32,900	207,000	6,500	895	7,400
1993	NG	19.50	246,000	39,100	285,000	9,190	1,070	10,300
1994	NG	23.83	271,000	47,800	319,000	10,100	1,300	11,500
1995	NG	15.09	196,000	30,300	226,000	7,340	823	8,160
1996	NG	20.94	303,000	42,000	345,000	11,300	1,140	12,500
1997	NG	20.22	261,000	40,600	301,000	9,750	1,110	10,900
1998	NG	20.71	261,000	41,600	302,000	9,760	1,130	10,900
1999	NG	20.34	226,000	44,500	271,000	8,400	1,220	9,620
2000	NG	16.53	200,000	36,100	236,000	7,430	989	8,420
2001	NG	15.62	202,000	34,100	236,000	7,490	936	8,430
2002	NG	19.61	174,000	42,900	217,000	6,450	1,170	7,630
2003	NG	20.10	292,000	44,000	336,000	10,900	1,200	12,100
2004	NG	16.67	275,000	36,400	311,000	10,200	998	11,200
2005	NG	18.57	290,000	43,300	334,000	10,800	1,180	12,000
2006	NG	18.05	353,000	42,100	395,000	13,200	1,150	14,300
2007	NG	18.42	287,000	43,000	330,000	10,700	1,180	11,900
2008	NG	23.82	284,000	55,600	340,000	10,600	1,520	12,100
2009	NG	19.97	311,000	46,600	357,000	11,600	1,270	12,900
2010	NG	24.42	372,000	57,000	429,000	13,900	1,550	15,500
2011	NG	19.27	263,000	45,000	308,000	9,810	1,230	11,000

Base-Flow Loads on a Segment Scale

Annual base-flow loads of TN from the north segment ranged from approximately 220,000 to 478,000 kg as N, constituting an average of 65.1 percent of the annual TN base-flow load for the watershed (table 14). The central segment contributed 61,400 to 135,000 kg as N and the south segment contributed 57,600 to 127,000 kg as N, accounting for an average of 18.1 and 16.8 percent of the annual TN base-flow load, respectively (table 14). Annual base-flow loads of TP from the north segment ranged from 7,720 to 16,900 kg as P, accounting for an average of 61.4 percent of the annual TP base-flow load for the watershed. The central segment

contributed 2,430 to 5,410 kg as P and the south segment contributed 2,430 to 5,330 kg as P, accounting for an average of 19.5 and 19.1 percent of the annual TP base-flow load for the watershed, respectively. Base-flow loads contributed by the north segment are substantially higher than those contributed by the other two segments in part because the drainage area of the north segment is considerably larger, the volume of streamflow in the north segment is substantially greater, and the amount of urban and agricultural development in the north segment is greater. The central segment contributes a similar or slightly higher proportion of nutrients from base flow than the south segment despite being less developed because the drainage area of the central segment is larger.

Figure 16. Base-flow load by year and season for *A*, total nitrogen, and *B*, total phosphorus, Barnegat Bay-Little Egg Harbor watershed, 1989–2011.

Base-Flow Loads on a HUC-14 Scale

Annual base-flow TN and TP loads for each HUC-14 subbasin in the BB-LEH watershed for 2002 and 2010 (fig. 17) demonstrate the differences in the distribution of base-flow loads during the most extreme hydrologic conditions that occurred in the watershed during 1989–2011. Comparison of the low-flow and high-flow years shows the effects of stream-flow volume on the distribution of base-flow loads in that the number of HUC-14 subbasins with large nutrient loads was greater during the high-flow year than during the low-flow year. For example, in 2010, 22 HUC-14 subbasins contributed more than 12,000 kg as N to the total base-flow load, whereas in 2002, no HUC-14 subbasins contributed more than 12,000 kg as N. Similarly, in 2010, 21 HUC-14 subbasins contributed more than 450 kg as P to the base-flow load, whereas in 2002, 3 HUC-14 subbasins contributed more than 450 kg as P to base flow. Although nutrient loads from streams to the estuary may be lower during low-flow years, low-flow conditions can also cause undesirable effects, including reduced dilution of contaminants in streams, reduced flushing in the estuary, and reduced water availability to support the ecosystem and surface-water withdrawals. More subbasins in the north segment contributed large loads (during either dry or wet years); however, subbasins in the central and south segments, particularly along the coast, also contributed large loads.

Base-Flow Yields on a HUC-14 Scale

Loads are a measure of the total contribution of nutrients from a given area, whereas yields (loads normalized by area) are a measure of the intensity of the contribution. Yields of nutrients are typically a reflection of land use. Estimated yields for all HUC-14 subbasins in the watershed for 1989–2011 are listed in table 13. The distribution of the HUC-14 subbasins with the highest yields of TN or TP for 2010 (fig. 18) differs from that of the HUC-14 subbasins with the highest loads for the same year (fig. 17 *B* and *D*). In 2010, TN yields in base flow at the HUC-14 scale ranged from 1.72 to 9.30 kilograms per hectare per year (kg/ha/yr) (table 13) and TP yields ranged from 0.06 to 0.49 kg/ha/yr. Subbasins with the highest base-flow yields are concentrated in the northern part of the watershed, where agricultural and urban land uses predominate. Subbasins with the lowest yields, in contrast, are dominated by forest cover.

Runoff Loads on the Watershed Scale

PLOAD was used to calculate runoff nutrient loads for each HUC-14 subbasin in the BB-LEH watershed for 1989–2011 by year and season. From 1989 to 2011, runoff loads of TN ranged from approximately 87,200 kg (1995) to 162,000 kg (2009) as N, with the two greatest loads occurring during very wet, recent land-use years (2009 and 2011; table 15), indicating an immediate effect of precipitation

on runoff loads. On average, the growing season accounts for 65.2 percent, and the nongrowing season accounts for 34.8 percent, of the annual TN runoff load. Runoff loads of TP ranged from approximately 3,250 kg (1995) to 6,010 kg (2009) as P. The pattern of TP loads in runoff is similar to that of TN, with loads increasing with precipitation and increasing development. On average, the growing season accounts for 74.8 percent, and the nongrowing season accounts for 25.2 percent, of the annual TP runoff load. Both TN and TP loads in runoff are greater during the growing season than during the nongrowing season because nutrient application rates are higher during the growing season and because the growing season is 2 months longer than the nongrowing season, which in turn affects precipitation amounts and runoff volumes.

Runoff Loads on a Segment Scale

Annual runoff loads of TN for the north segment ranged from approximately 60,000 to 110,000 kg as N (table 14), contributing an average of 68.6 percent of the annual runoff load for the watershed. Annual TN runoff loads for the central and south segments had similar ranges [13,400–26,000 kg as N (table 14)], each contributing an average of 15.7 percent of the annual TN runoff load. Annual runoff loads of TP for the north segment ranged from 2,350 to 4,290 kg as P (table 14), accounting for an average of 72.1 percent of the annual runoff load for the watershed. The central and south segments contributed between 1,040 and 2,090 kg as P annually (table 14), accounting for an average of 13.8 and 14.1 percent of the annual TP runoff load, respectively.

Runoff Loads on a HUC-14 Scale

In general, the HUC-14 subbasins with the greatest runoff loads are in the northern portion of the watershed and along the eastern edge of the mainland part of the watershed (fig. 19). Annual conditions in 1989 and 1990 (fig. 19*A* and *B*) correspond to those in an early land-use year (1986) under relatively wet (annual precipitation = 53.83 in.) and dry (43.18 in.) conditions, respectively. Annual conditions in 2009 and 2010 (fig. 19*C* and *D*) correspond to those in the most recent land-use year (2007) under relatively wet (annual precipitation = 59.92 in.) and dry (43.23 in.) conditions, respectively.

Comparison of the wet and dry years that occurred during the 1986 and 2007 land-use periods shows the effects of precipitation on the distribution of runoff loads; that is, the number of HUC-14 subbasins with high TN loads is greater during the wet years (1989 and 2009) than during the dry years (1990 and 2010). For example, in 2009 9 HUC-14 subbasins contributed more than 4,000 kg as N in their runoff load, whereas in 2010, a year marked by substantially less precipitation but in the same land-use period, 1 HUC-14 subbasin contributed more than 4,000 kg as N (fig. 19).

Figure 17. Annual base-flow loads for each Hydrologic Unit Code-14 (HUC-14) subbasin in the Barnegat Bay-Little Egg Harbor watershed: *A*, total nitrogen, 2002; *B*, total nitrogen, 2010; *C*, total phosphorus, 2002; *D*, total phosphorus, 2010.

Figure 18. Yields of A, total nitrogen and B, total phosphorus in base flow for each Hydrologic Unit Code-14 (HUC-14) subbasin in the Barnegat Bay-Little Egg Harbor watershed, 2010.

Figure 19. Annual runoff loads of total nitrogen for each Hydrologic Unit Code-14 (HUC-14) subbasin in the Barnegat Bay-Little Egg Harbor watershed for A, 1989, B, 1990, C, 2009, and D, 2010.

Comparison of the different land-use years with similar precipitation totals demonstrates the effects of land use on the distribution of runoff loads; that is, the number of HUC-14 subbasins with high TN loads is greater during the more recent land-use periods than during earlier years when there was less urban land use. For example, in 2010 9 HUC-14 subbasins contributed more than 3,000 kg as N in their runoff load, whereas in 1990 (a year with a similar amount of total precipitation), 3 HUC-14 subbasins contributed more than 3,000 kg as N.

Maps of seasonal runoff loads of TP at the HUC-14 scale in 1994 (fig. 20*A* and *B*) show that both the EMCs (table 10) and the number of days in the growing and nongrowing seasons are directly related to the differences in TP loads in the growing and nongrowing seasons. Although precipitation in the watershed during the 1994 growing and nongrowing seasons was similar, the TP runoff load exceeded 50 kg as P in 14 HUC-14 subbasins during the growing season, but in only 2 HUC-14 subbasins during the nongrowing season.

Total precipitation for the watershed during the 2009 growing season was 39.95 in., the greatest of any seasonal precipitation amount for 1989–2011. The combination of increased urban development, growing-season EMCs, and extreme wet conditions resulted in the TP runoff load exceeding 50 kg as P in 42 HUC-14 subbasins (more than half the

HUC-14 subbasins in the watershed) and 150 kg as P in 5 HUC-14 subbasins (fig. 20*C*).

A comparison of figure 20*B* and *D* shows the effects of land use on seasonal runoff loads of TP, which are similar to the effects of land use on annual runoff loads of TN described previously. Approximately 23.8 in. of precipitation fell on the watershed during both the 1994 and 2008 nongrowing seasons. The greater frequency of high TP runoff loads during the 2008 nongrowing season is caused by increased urban development in the watershed over time.

Runoff Yields on a HUC-14 Scale

TN and TP yields in runoff were generally greater in the northern, highly urban HUC-14 subbasins than in the more forested southern HUC-14 subbasins of the BB-LEH watershed in 2010 (fig. 21). TN yields in runoff at the HUC-14 scale ranged from 0.12 to 1.82 kg/ha/yr in 2010 (table 13). TP yields in runoff ranged from 0.00 to 0.08 kg/ha/yr. These values are considerably lower than those for base flow (fig. 20). Subbasins with the highest yields in runoff are located primarily in the northeastern corner of the watershed, and are dominated by urban land uses. Subbasins with the lowest yields are predominantly forested (tables 1, 13).

Figure 20. Seasonal runoff loads of total phosphorus for each Hydrologic Unit Code-14 (HUC-14) subbasin in the Barnegat Bay-Little Egg Harbor watershed for *A*, 1994 growing, *B*, 1994 nongrowing, *C*, 2009 growing, and *D*, 2008 nongrowing seasons.

Figure 21. Yields of *A*, total nitrogen and *B*, total phosphorus in runoff for each Hydrologic Unit Code-14 (HUC-14) subbasin in the Barnegat Bay-Little Egg Harbor watershed, 2010.

Relations among Turf Coverage, Land Use, and Nutrient Loads

The importance of turf (lawn) cover in contributing TN and TP to the BB-LEH estuary was investigated by redefining land use in the watershed as being in one of three categories: undeveloped, developed–nonturf, and developed–turf. These categories were established during the turf analysis process that was conducted for 2007. Regression models relating percentages of developed–turf and developed–nonturf land to concentrations of TN and TP were then used to explore relative contributions of nutrients from these land-use categories.

Through analysis of satellite imagery for 2007, 67.8 percent of the watershed area was classified as undeveloped and contains essentially no turf, 8.0 percent was classified as developed–turf, and 24.2 percent was classified as developed–nonturf. Therefore, nearly one quarter of the developed land was mapped as turf and three quarters was mapped as nonturf (fig. 22). There is a strong relation between percent turf and percent developed land (fig. 23) in the watershed, such that percent developed–turf typically increases with percent development, and the percentage or area of total developed land can be considered a reasonable predictor of the percentage or area of developed–turf land in the watershed. This relation does not hold true for 11 subbasins, all of which are located along the coast and the barrier islands, which are characterized by a high percentage of developed land but a very low percentage of turf (table 16). This dichotomy is the result of the close proximity of these subbasins to coastal areas, where residential landscaping typically does not include lawns. Additionally, one inland subbasin (02040301070080) in the vicinity of the Lakehurst Naval Air Warfare Center is characterized by a high percentage of developed land, of which a disproportionately high percentage is turf, likely because much of the area near the landing strips and a nearby golf course is

turf. These 12 subbasins (table 16, fig. 23) are considered to be outliers (atypical of turf-coverage patterns in the rest of the watershed) and were excluded from the remainder of the turf analysis.

A strong relation between percent turf and annual yields of TN and TP in the BB-LEH watershed was observed for 2007 (fig. 24). The relation is stronger for runoff yields than for base-flow yields, and the difference is greater for TP than for TN. The graphs in figure 24 illustrate that storm runoff volume from urban turf is strongly related to yields of nutrients delivered to the estuary.

Multiple linear regression models were used to relate the percentage of developed–turf and developed–nonturf land in each HUC-14 subbasin to total streamflow, base-flow, and runoff TN and TP concentrations calculated for 2007 (table 13) to determine the relative importance of developed–turf and developed–nonturf land in contributing nutrients to the estuary. The best-fit regression equations for relating the calculated 2007 TN and TP concentrations to turf percentages are (table 17):

$$[TN]_t = 0.444 + 0.0077 (NT) + 0.0139(T) \quad (14)$$

$$[TP]_r = 0.0117 + 0.0001(NT) + 0.0115(T) \quad (15)$$

where

- $[TN]_t$ is calculated TN concentration, in milligrams/liter for total streamflow;
- $[TP]_r$ is calculated TP concentration, in milligrams/liter for runoff;
- NT is percent developed–nonturf; and
- T is percent developed–turf.

The relation between calculated TN concentrations under base-flow conditions and percent developed–turf also is significant (table 17). The relation between TP and turf variables under base-flow conditions is not significant, likely as a result of the high frequency of nondetect values for TP in samples collected under base-flow conditions. As indicated by the r^2 values of the best-fit equations (table 17), not all variability in TN and TP concentrations is explained by the variability in percentages of developed–turf and developed–nonturf land; however, concentrations of TN and TP at the watershed and segment scales are adequately predicted by the regression equations. Outputs from the regression relations were compared to concentrations previously calculated from water-quality and hydrologic data as a quality check of the regression methodology. At the watershed scale, the average TN concentration was 0.75 mg/L as N when calculated using both methods, and the calculated concentration of TP determined by both methods was similar (0.026 and 0.027 mg/L) (table 18). When analyzed by watershed segment, the TN concentrations calculated from the regression equation for total streamflow were 0.83, 0.61, and 0.64 mg/L as N for the north, central, and south segments, respectively; TP concentrations for runoff

Figure 22. Percentage of turf and nonturf land cover in developed areas of the Barnegat Bay-Little Egg Harbor watershed, based on 2007 land use. (Land-use data from New Jersey Department of Environmental Protection, 2010)

Figure 23. Relation between percent turf and percent developed land in each Hydrologic Unit Code-14 (HUC-14) subbasin of the Barnegat Bay-Little Egg Harbor watershed, based on 2007 land use. (Land-use data from New Jersey Department of Environmental Protection, 2010; R^2 , correlation coefficient)

were 0.031, 0.019, and 0.020 mg/L as P, respectively. These values are comparable to those obtained from estimations using water-quality data (table 18).

The values of the regression coefficients indicate the relative influence of the turf categories on nutrient concentrations. For both TN and TP, the coefficients for developed-turf are substantially greater than those for developed-nonturf land, indicating that developed areas with turf cover contribute a proportionally greater fraction of TN and TP than developed areas without turf cover. The regression models were used to calculate concentrations for three single land-use scenarios for 2007: 100-percent undeveloped, developed-nonturf, and developed-turf (table 17). For TN, the calculated concentrations for a single land-use area are 0.44 mg/L as N for undeveloped, 1.21 mg/L for developed-nonturf, and 1.83 mg/L for developed-turf areas for total flow. For TP under runoff

conditions, the calculated concentrations are 0.012, 0.022, and 0.162 mg/L as P for 100 percent undeveloped, developed-nonturf, and developed-turf areas, respectively.

Although there are no single-land-use subbasins in the BB-LEH watershed, this analysis provides evidence that developed areas contribute more nitrogen and phosphorus than less developed areas, and that developed-turf areas contribute more nitrogen and phosphorus than developed-nonturf areas. The higher TN (total flow and base flow) and TP (runoff) concentrations and loads associated with developed-turf areas are likely the result of fertilizer products being applied to lawns. The higher predicted nutrient concentrations in developed-nonturf areas than in undeveloped areas show that other factors, such as atmospheric deposition and leaky sewer pipes, are contributing nutrient loads above background levels to streamflow in developed areas.

Table 16. Turf distribution within the Barnegat Bay-Little Egg Harbor watershed, based on 2007 land use.

[HUC-14, Hydrologic Unit Code-14; *, outlier value excluded from further analysis]

HUC-14	Drainage-basin area, in square kilometers	Percent developed	Percent turf	Outlier
North segment				
02040301020010	22.1	25.2	5.5	
02040301020020	28.1	60.2	17.2	
02040301020030	15.8	50.4	16.0	
02040301020040	12.5	41.4	10.7	
02040301020050	20.5	63.1	17.4	
02040301030010	13.0	14.5	5.3	
02040301030020	14.6	34.7	8.9	
02040301030030	19.6	50.1	15.5	
02040301030040	20.2	60.1	16.7	
02040301030050	12.4	55.5	10.4	
02040301040010	20.4	72.1	21.1	
02040301040020	19.7	59.0	9.7	
02040301040030	6.8	73.8	16.3	
02040301050010	15.6	63.1	17.0	
02040301050020	21.9	66.3	17.4	
02040301050030	8.2	25.7	4.1	
02040301050040	33.0	54.8	14.7	
02040301050050	7.5	67.6	2.7	*
02040301060010	19.6	38.1	10.1	
02040301060020	25.0	28.8	9.0	
02040301060030	19.4	38.7	13.0	
02040301060040	15.2	8.9	2.1	
02040301060050	20.5	44.8	15.2	
02040301060060	17.3	33.0	6.6	
02040301060070	17.8	59.8	17.0	
02040301060080	21.2	58.1	13.7	
02040301070010	31.3	14.5	4.0	
02040301070020	15.7	12.4	4.7	
02040301070030	26.0	25.0	7.7	
02040301070040	12.9	47.8	12.2	
02040301070050	14.6	10.0	2.9	
02040301070060	14.4	13.1	1.8	
02040301070070	13.0	16.9	1.1	
02040301070080	17.1	49.1	23.7	*
02040301070090	18.5	37.6	10.8	
02040301080010	14.2	7.1	0.5	
02040301080020	14.1	35.4	9.7	
02040301080030	19.3	27.5	6.1	
02040301080040	17.6	38.8	11.6	
02040301080050	24.1	47.2	14.7	
02040301080060	13.2	55.8	13.7	
02040301080070	24.8	14.6	4.1	
02040301080080	17.4	79.0	27.0	
02040301080090	25.4	71.8	16.9	

Table 16. Turf distribution within the Barnegat Bay-Little Egg Harbor watershed, based on 2007 land use.—Continued

[HUC-14, Hydrologic Unit Code-14; *, outlier value excluded from further analysis]

HUC-14	Drainage-basin area, in square kilometers	Percent developed	Percent turf	Outlier
Central segment				
02040301090010	18.7	0.5	0.0	
02040301090020	24.3	1.8	0.0	
02040301090030	23.6	6.8	1.2	
02040301090040	32.4	6.1	0.7	
02040301090050	20.6	10.4	1.5	
02040301090060	21.8	37.9	11.5	
02040301100010	20.6	42.4	10.0	
02040301100020	12.6	37.4	7.1	
02040301100030	8.2	17.1	1.3	*
02040301110010	22.3	0.8	0.2	
02040301110020	18.7	24.7	5.2	
02040301110030	25.7	21.9	4.1	
02040301110040	19.4	6.1	1.5	
02040301110050	14.0	12.1	1.6	
02040301120010	23.1	45.3	11.6	
02040301120020	37.3	14.3	3.2	
02040301120030	8.3	36.5	1.2	*
South segment				
02040301130010	21.4	45.1	11.9	
02040301130020	26.8	24.5	5.8	
02040301130030	37.1	27.6	3.7	
02040301130040	21.6	14.8	2.5	
02040301130050	41.0	0.5	0.0	
02040301130060	23.9	22.5	2.7	
02040301130070	12.8	7.8	0.8	
02040301130080	6.2	35.8	2.0	*
02040301140010	12.7	0.7	0.1	
02040301140020	13.1	15.1	3.6	
02040301140030	15.5	58.1	11.7	
02040301140040	17.9	21.5	4.4	
02040301140050	15.3	21.2	3.8	
02040301140060	8.4	12.9	0.7	*
02040301910010	1.1	39.4	2.1	*
02040301910020	3.0	70.9	0.5	*
02040301910030	5.3	20.0	0.2	*
02040301920010	2.6	56.6	0.8	*
02040301920020	3.0	18.8	0.3	*
02040301920030	2.9	21.3	1.1	*

Figure 24. Relation between percent turf and total nitrogen yield in *A*, total flow, *B*, base flow, and *C*, runoff, and between percent turf and total phosphorus yield in *D*, total flow, *E*, base flow, and *F*, runoff. (R^2 , correlation coefficient)

Figure 24. Relation between percent turf and total nitrogen yield in A, total flow, B, base flow, and C, runoff, and between percent turf and total phosphorus yield in D, total flow, E base flow, and F, runoff. (R^2 , correlation coefficient)—Continued

Table 17. Multiple linear regression coefficients for relating percentage of developed nonturf, and developed turf land in the Barnegat Bay-Little Egg Harbor watershed for 2007 to calculated concentrations of total nitrogen and total phosphorus.[Concentrations are in milligrams per liter; R^2 , correlation coefficient]

Nutrient	Flow condition	Regression coefficient			Multiple R^2	Land-use scenario		
		Intercept	Percent developed nonturf	Percent developed turf		100-percent undeveloped	100-percent developed nonturf	100-percent developed turf
Total nitrogen	Total	0.4440	0.0077	0.0139	0.60	0.44	1.21	1.83
Total nitrogen	Base	0.4252	0.0078	0.0157	0.64	0.43	1.21	2.00
Total phosphorus	Runoff	0.0117	0.0001	0.0015	0.62	0.012	0.022	0.162

Table 18. Percent undeveloped, developed nonturf, and developed turf land (2007), and calculated concentrations of total nitrogen and total phosphorus, by watershed and watershed segment.

[mg/L, milligrams per liter; HUC-14, Hydrologic Unit Code-14]

Segment	Land use, in percent of segment			Total nitrogen, in mg/L, for total flow		Total phosphorus, in mg/L, for runoff	
	Undeveloped	Developed nonturf	Developed turf	Calculated from regression	Average of estimated HUC-14 concentrations	Calculated from regression	Average of estimated HUC-14 concentrations
North	59.6	29.8	10.6	0.83	0.85	0.031	0.032
Central	82.1	13.9	4.0	0.61	0.56	0.019	0.016
South	79.1	17.0	4.0	0.64	0.61	0.020	0.017
Watershed	67.8	24.2	8.0	0.75	0.75	0.027	0.026

Summary and Conclusions

Concentrations, loads, and yields of total nitrogen (TN) and total phosphorus (TP) in the Barnegat Bay-Little Egg Harbor (BB-LEH) watershed for 1989–2011 were calculated from water-quality, land-use, precipitation, and streamflow data. Available surface-water-quality data for streams in the BB-LEH watershed for 1980–2011 were compiled from the U.S. Geological Survey (USGS) National Water Information System (NWIS) database and the U.S. Environmental Protection Agency (USEPA) Storage and Retrieval (STORET) database. Precipitation data were retrieved from the Office of the New Jersey State Climatologist and from the National Climatic Data Center. Daily mean discharge data for continuous streamflow-gaging stations in the watershed were retrieved from the USGS NWIS database, and geographic information system coverages of land-use data for 1986, 1995, 2002, and 2007 were obtained from the N.J. Department of Environmental Protection. These data were used to calculate surface-water loads of TN and TP for the BB-LEH estuary at a finer spatial and temporal scale than had been previously reported. Concentrations, loads, and yields were calculated at three spatial scales: for each of the 81 subbasins specified by a 14-digit

hydrologic unit code (HUC-14); for each of the three BB-LEH watershed segments; and for the entire BB-LEH watershed. The temporal scale was annual and seasonal (growing and nongrowing).

The BB-LEH watershed lies entirely in the Atlantic Coastal Plain Physiographic Province and includes the drainage basins of numerous streams and tributaries that discharge to the BB-LEH estuary. The watershed was divided into three segments—north, central, and south—to coincide with the natural segmentation of the estuary. The north segment is the largest (801.4 square kilometers (km²)), is the most developed, and contains the drainage basins of the Metedeconk and Toms Rivers. The central segment covers 351.6 km², is the least developed, and contains the drainage basins of Cedar Creek, Forked River, and Oyster Creek. The south segment is the smallest (291.6 km²) and contains the drainage basins of Mill Creek, Cedar Run, Westecunk Creek, and Tuckerton Creek.

Base-flow separation of hydrographs of six streams in the BB-LEH watershed indicated that base flow accounts for about 72 to 94 percent of total flow in streams in the watershed. The predominance of the base-flow component of streamflow is characteristic of the flat terrain and highly permeable, sandy soil in the watershed. Base flow accounts for a

smaller percentage of flow in the highly developed basins, and a larger percentage of flow in the less developed basins.

Concentrations, loads, and yields of nutrients were calculated at the HUC-14 scale on an annual and seasonal basis with the use of available water-quality data and relations between concentrations and land-use percentages. Base-flow and runoff loading were calculated separately. For base flow, multiple linear regression models were used to determine relations of TN and TP concentrations measured at sampling stations during base flow to land use in the contributing basins. These relations were applied to the land-use percentages in each HUC-14 subbasin to obtain calculated base-flow concentrations for each subbasin. Base-flow loads were then calculated as the product of the calculated concentration and base flow. For runoff, flow-weighted event-mean concentrations (EMCs) were developed for each land-use type and season combination from relations between land use and measured runoff concentrations. The land-use EMCs, along with annual and seasonal precipitation amounts and percent imperviousness associated with land-use types, were applied by using PLOAD to obtain calculated runoff concentrations, loads, and yields at the HUC-14 scale. Land-use EMCs were greater during the growing season than during the nongrowing season.

On the basis of an evaluation of available surface-water-quality data, the median measured concentrations of TN (0.79 mg/L) and TP (0.030 mg/L) were greatest in the north segment of the BB-LEH watershed. Median concentrations were significantly smaller in the central (0.23 mg/L TN and < 0.010 TP) and south (0.31 mg/L TN and < 0.015 TP) segments. The order of median TN concentrations among the watershed segments is consistent with the order of percent-developed-land values. Over the period of study 1989–2011, total surface-water (base flow plus runoff) loads of TN for the entire BB-LEH watershed ranged from about 455,000 kilograms (kg) as N to 857,000 kg as N. Total loads of TP for the watershed ranged from 17,000 to 32,000 kg as P. A greater proportion of the total load of both nutrients was contributed by base flow (82 percent) than by runoff (18 percent), which is consistent with the hydrologic record and the base-flow-separation results. Total loads fluctuated with precipitation and hydrologic conditions and patterns, with precipitation having a short-term and immediate effect on runoff loads and a longer-term and sometimes delayed effect on base-flow loads. However, loads also were a function of land use. Increases in the amount of developed land in the watershed over time in conjunction with the strong relation between increased development and higher nutrient concentrations indicate that the increase in loads in more recent years can be attributed at least in part to increases in development in the watershed.

On average, the north segment accounted for about 66 percent of the annual TN load and 63 percent of the annual TP to the estuary. The corresponding northern estuary segment is the smallest of the three estuary segments, which may further contribute to elevated nutrient concentrations in the northern part of the estuary. The HUC-14 subbasins with the highest yields of nutrients are concentrated in the northern part

of the watershed, and have the highest percentages of urban or agricultural land use. Subbasins with the lowest TN and TP yields are dominated by forest cover.

The objective of assessing the contributions of TN and TP from turf (lawn) coverage was addressed by first quantifying the aerial coverage of turf throughout the watershed, and relating the calculated concentrations, loads, and yields of TN and TP to developed land with and without turf. Turf coverage in the watershed was quantified by using land-use data for 2007, and the contribution of turf to TN and TP loads was evaluated. There is a strong relation between percent turf and percent developed land in the watershed, such that the percentage or area of total developed land can be considered a reasonable predictor of the percentage or area of developed-turf land in the watershed. There also is a strong relation between percent turf and runoff yield, particularly for TP. In the BB-LEH watershed, calculated concentrations of TN and TP were greater for developed-turf areas than for developed-nonturf areas, which, in turn, were greater than those for undeveloped areas. The higher calculated nutrient concentrations in developed-nonturf areas than in undeveloped areas shows that factors other than turf are contributing nutrient loads above background levels in developed areas. This preliminary turf assessment indicates that controlling nutrient loads attributable to lawn care may be an effective way to reduce total loads. Given that nutrient loading to the estuary is controlled by water quality (as determined largely by land use and surface activities) and by flow volume, the most effective strategies for reducing nutrient loads would include controlling development and activities such as the application of commercial fertilizers, preserving forested areas and riparian buffers, and management of storm water.

Much of the land in the southern portion of the watershed is protected from intense development. On the basis of previous investigations in the watershed and the analysis of existing data as part of this study, future increases in development in the central and south segments will likely lead to higher concentrations and loads of nutrients in the streams located in those areas, thereby increasing nutrient inputs to the estuary.

In this analysis, nutrient loads for the BB-LEH watershed were estimated by year and by season at the HUC-14 scale. The loading estimates produced in this investigation are most suitable for making comparisons among seasons and years, and among subbasins. A more complete understanding of nutrient cycling in the watershed could be achieved with the use of additional, targeted water-quality monitoring in conjunction with a watershed water-quality model that considers in-stream processes, incorporates shorter time steps, and targets individual streams and reaches.

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Table 1. Land-use distribution in HUC-14 subbasins in the Barnegat Bay-Little Egg Harbor watershed in 1986, 1995, 2002, and 2007.

[--, not available; HUC-14, Hydrologic Unit Code-14]

Watershed segment	Year	HUC-14	Drainage area, in square kilometers	Land use, in percent of subbasin (HUC-14) area						
				Agriculture	Barren land	Forest	Impervious urban	Non-residential urban	Residential urban	Water + Wetlands
North	1986	02040301020010	22.1	6.9	0.4	26.8	--	2.8	9.1	54.1
North	1986	02040301020020	28.1	4.4	0.9	23.9	--	9.3	37.8	23.7
North	1986	02040301020030	15.8	4.7	2.6	21.4	--	5.1	30.5	35.7
North	1986	02040301020040	12.5	12.9	4.7	40.3	--	4.4	8.3	29.4
North	1986	02040301020050	20.5	4.0	1.3	27.5	--	17.5	34.1	15.6
North	1986	02040301030010	13.0	5.9	0.6	35.3	--	3.2	2.6	52.4
North	1986	02040301030020	14.6	4.3	0.8	48.4	--	6.4	8.4	31.7
North	1986	02040301030030	19.6	10.1	0.2	40.5	--	3.7	17.4	28.1
North	1986	02040301030040	20.2	1.1	2.5	38.6	--	10.1	32.8	14.9
North	1986	02040301030050	12.4	0.1	1.2	42.8	--	16.2	20.0	19.6
North	1986	02040301040010	20.4	0.8	0.9	16.9	--	10.2	53.5	17.8
North	1986	02040301040020	19.7	0.3	2.1	30.3	--	19.4	28.7	19.2
North	1986	02040301040030	6.8	0.0	0.0	1.3	--	17.4	66.2	15.2
North	1986	02040301050010	15.6	2.9	1.1	51.2	--	10.9	25.6	8.3
North	1986	02040301050020	21.9	1.8	1.5	29.3	--	8.5	41.6	17.3
North	1986	02040301050030	8.2	0.0	0.0	11.7	--	5.5	17.2	65.6
North	1986	02040301050040	33.0	0.4	1.1	14.3	--	7.7	45.2	31.3
North	1986	02040301050050	7.5	0.0	0.8	0.8	--	14.2	61.6	22.7
North	1986	02040301060010	19.6	13.1	0.4	44.3	--	2.1	9.7	30.4
North	1986	02040301060020	25.0	0.5	0.7	66.7	--	2.2	10.2	19.7
North	1986	02040301060030	19.4	6.5	0.3	44.9	--	3.1	9.7	35.5
North	1986	02040301060040	15.2	3.6	0.0	53.2	--	1.6	2.1	39.5
North	1986	02040301060050	20.5	5.4	1.4	50.6	--	4.1	10.2	28.3
North	1986	02040301060060	17.3	4.7	17.9	45.7	--	3.4	4.8	23.5
North	1986	02040301060070	17.8	3.3	18.4	54.3	--	3.6	12.2	8.3
North	1986	02040301060080	21.2	5.9	7.3	45.6	--	10.7	20.1	10.5
North	1986	02040301070010	31.3	10.2	0.2	50.2	--	1.8	2.9	34.6
North	1986	02040301070020	15.7	5.1	1.9	61.2	--	6.1	0.6	25.1
North	1986	02040301070030	26.0	0.7	7.6	47.1	--	9.1	4.0	31.5
North	1986	02040301070040	12.9	3.7	8.1	56.4	--	3.4	16.2	12.2
North	1986	02040301070050	14.6	0.4	0.7	77.1	--	7.0	0.0	14.8
North	1986	02040301070060	14.4	1.9	2.4	66.7	--	1.1	3.9	23.9
North	1986	02040301070070	13.0	0.9	26.6	39.7	--	0.8	2.5	29.4
North	1986	02040301070080	17.1	0.4	2.1	33.5	--	40.7	2.9	20.4
North	1986	02040301070090	18.5	0.4	5.0	45.4	--	3.9	22.5	22.7
North	1986	02040301080010	14.2	0.1	9.4	58.0	--	0.9	0.1	31.5
North	1986	02040301080020	14.1	2.1	0.0	52.4	--	6.5	24.6	14.3
North	1986	02040301080030	19.3	0.5	0.2	71.0	--	2.6	15.9	9.8
North	1986	02040301080040	17.6	0.0	2.9	62.2	--	7.3	20.8	6.9
North	1986	02040301080050	24.1	0.1	2.3	44.7	--	9.4	33.1	10.4
North	1986	02040301080060	13.2	0.2	1.7	25.8	--	24.4	29.6	18.2
North	1986	02040301080070	24.8	0.3	1.8	64.1	--	3.2	8.8	21.8
North	1986	02040301080080	17.4	5.6	1.6	34.9	--	21.6	33.2	3.0

Table 1. Land-use distribution in HUC-14 subbasins in the Barnegat Bay-Little Egg Harbor watershed in 1986, 1995, 2002, and 2007.—Continued

[--, not available; HUC-14, Hydrologic Unit Code-14]

Watershed segment	Year	HUC-14	Drainage area, in square kilometers	Land use, in percent of subbasin (HUC-14) area						
				Agriculture	Barren land	Forest	Impervious urban	Non-residential urban	Residential urban	Water + Wetlands
North	1986	02040301080090	25.4	0.1	9.9	18.4	--	13.0	48.9	9.8
Central	1986	02040301090010	18.7	0.6	0.0	85.9	--	0.3	0.2	13.1
Central	1986	02040301090020	24.3	0.6	2.7	81.3	--	0.2	0.1	15.1
Central	1986	02040301090030	23.6	0.0	0.2	75.7	--	4.3	1.1	18.6
Central	1986	02040301090040	32.4	0.7	5.5	72.7	--	0.1	0.8	20.2
Central	1986	02040301090050	20.6	0.4	7.4	62.6	--	1.9	2.1	25.5
Central	1986	02040301090060	21.8	0.6	2.8	43.9	--	7.2	16.3	29.2
Central	1986	02040301100010	20.6	0.4	1.4	22.6	--	5.4	23.8	46.4
Central	1986	02040301100020	12.6	3.2	0.0	14.4	--	3.8	26.9	51.7
Central	1986	02040301100030	8.2	0.0	1.1	0.4	--	5.5	13.6	79.4
Central	1986	02040301110010	22.3	0.0	0.6	87.2	--	0.1	0.0	12.1
Central	1986	02040301110020	18.7	0.0	1.8	56.3	--	4.0	19.8	18.1
Central	1986	02040301110030	25.7	0.1	0.9	49.4	--	6.1	13.0	30.5
Central	1986	02040301110040	19.4	0.3	2.7	76.7	--	0.6	1.1	18.5
Central	1986	02040301110050	14.0	0.0	0.9	58.3	--	5.6	3.4	31.7
Central	1986	02040301120010	23.1	0.5	1.2	55.9	--	5.6	15.9	20.9
Central	1986	02040301120020	37.3	0.3	0.8	10.7	--	2.5	6.6	79.1
Central	1986	02040301120030	8.3	0.0	0.6	1.1	--	6.3	31.8	60.2
South	1986	02040301130010	21.4	1.8	2.8	75.5	--	4.2	9.3	6.3
South	1986	02040301130020	26.8	0.0	3.2	76.2	--	2.4	9.0	9.2
South	1986	02040301130030	37.1	0.4	1.2	12.2	--	8.0	13.1	65.1
South	1986	02040301130040	21.6	0.3	1.8	69.3	--	1.7	3.2	23.7
South	1986	02040301130050	41.0	0.5	1.3	78.0	--	0.7	0.1	19.4
South	1986	02040301130060	23.9	1.7	2.1	50.6	--	3.7	6.3	35.5
South	1986	02040301130070	12.8	0.3	0.4	16.6	--	1.2	1.5	79.9
South	1986	02040301130080	6.2	0.0	0.0	1.9	--	15.2	47.6	35.4
South	1986	02040301140010	12.7	0.0	0.1	89.8	--	0.7	0.0	9.4
South	1986	02040301140020	13.1	0.2	0.8	83.6	--	1.7	1.1	12.6
South	1986	02040301140030	15.5	1.4	2.3	50.1	--	7.6	20.3	18.2
South	1986	02040301140040	17.9	0.6	0.3	20.3	--	2.7	8.6	67.4
South	1986	02040301140050	15.3	0.0	0.4	5.1	--	2.8	14.4	77.3
South	1986	02040301140060	8.4	0.0	2.3	0.2	--	5.9	20.0	71.6
South	1986	02040301910010	1.1	0.0	36.7	0.0	--	11.3	51.1	0.8
South	1986	02040301910020	3.0	0.0	22.9	0.1	--	11.6	63.1	2.2
South	1986	02040301910030	5.3	0.0	24.2	0.0	--	7.1	12.6	56.2
South	1986	02040301920010	2.6	0.0	22.6	1.2	--	3.1	55.6	17.5
South	1986	02040301920020	3.0	0.0	19.6	1.0	--	12.4	63.6	3.3
South	1986	02040301920030	2.9	0.0	22.5	0.0	--	8.9	59.1	9.5
North	1995	02040301020010	22.1	6.4	0.6	26.0	--	3.4	9.8	53.8
North	1995	02040301020020	28.1	3.8	0.8	21.7	--	9.6	41.6	22.6
North	1995	02040301020030	15.8	4.2	1.3	19.1	--	5.3	36.0	34.1
North	1995	02040301020040	12.5	12.9	3.5	41.4	--	4.4	9.0	28.8
North	1995	02040301020050	20.5	4.0	0.9	25.4	--	16.9	37.6	15.3

Table 1. Land-use distribution in HUC-14 subbasins in the Barnegat Bay-Little Egg Harbor watershed in 1986, 1995, 2002, and 2007.—Continued

[--, not available; HUC-14, Hydrologic Unit Code-14]

Watershed segment	Year	HUC-14	Drainage area, in square kilometers	Land use, in percent of subbasin (HUC-14) area						
				Agriculture	Barren land	Forest	Impervious urban	Non-residential urban	Residential urban	Water + Wetlands
North	1995	02040301030010	13.0	5.6	0.8	35.5	--	2.6	3.1	52.3
North	1995	02040301030020	14.6	4.1	0.7	45.4	--	7.1	11.5	31.3
North	1995	02040301030030	19.6	7.3	0.9	36.3	--	3.4	24.6	27.4
North	1995	02040301030040	20.2	0.8	2.1	32.5	--	10.5	39.4	14.7
North	1995	02040301030050	12.4	0.1	1.1	35.8	--	22.9	20.9	19.2
North	1995	02040301040010	20.4	0.1	1.1	12.0	--	10.7	59.2	17.0
North	1995	02040301040020	19.7	0.2	3.0	24.6	--	23.2	30.1	18.9
North	1995	02040301040030	6.8	0.0	0.4	1.1	--	17.3	66.6	14.6
North	1995	02040301050010	15.6	2.1	2.5	38.9	--	14.8	33.7	7.9
North	1995	02040301050020	21.9	1.2	2.2	22.0	--	9.6	48.2	16.7
North	1995	02040301050030	8.2	0.0	0.0	11.0	--	5.3	19.6	64.1
North	1995	02040301050040	33.0	0.2	0.4	12.1	--	8.0	49.0	30.3
North	1995	02040301050050	7.5	0.0	0.8	0.8	--	13.8	61.8	22.7
North	1995	02040301060010	19.6	8.5	1.0	40.0	--	3.2	17.5	29.9
North	1995	02040301060020	25.0	0.6	0.4	62.6	--	2.4	14.7	19.3
North	1995	02040301060030	19.4	5.2	0.5	40.2	--	3.2	16.0	34.8
North	1995	02040301060040	15.2	2.2	0.0	54.8	--	1.1	2.4	39.5
North	1995	02040301060050	20.5	4.5	1.0	48.0	--	3.4	15.1	28.0
North	1995	02040301060060	17.3	4.0	14.8	46.3	--	2.7	6.5	25.8
North	1995	02040301060070	17.8	2.5	14.8	54.2	--	4.8	15.3	8.4
North	1995	02040301060080	21.2	4.5	6.6	39.5	--	13.1	26.0	10.3
North	1995	02040301070010	31.3	8.5	0.7	49.5	--	1.8	4.9	34.6
North	1995	02040301070020	15.7	5.0	1.9	61.6	--	5.6	0.8	25.1
North	1995	02040301070030	26.0	0.8	5.9	47.6	--	9.2	4.7	31.8
North	1995	02040301070040	12.9	4.1	9.5	51.3	--	3.9	19.1	12.2
North	1995	02040301070050	14.6	0.4	0.1	77.7	--	6.9	0.1	14.8
North	1995	02040301070060	14.4	1.5	2.2	66.7	--	1.6	4.0	23.9
North	1995	02040301070070	13.0	0.2	19.6	47.1	--	1.0	2.6	29.4
North	1995	02040301070080	17.1	0.4	1.8	33.1	--	41.2	2.9	20.5
North	1995	02040301070090	18.5	0.3	2.0	42.9	--	5.3	26.8	22.7
North	1995	02040301080010	14.2	0.1	8.4	59.0	--	0.9	0.1	31.5
North	1995	02040301080020	14.1	2.3	1.1	50.3	--	6.5	25.5	14.3
North	1995	02040301080030	19.3	0.5	0.2	66.6	--	2.9	20.0	9.8
North	1995	02040301080040	17.6	0.0	0.7	50.0	--	7.5	34.8	7.0
North	1995	02040301080050	24.1	0.1	2.0	42.0	--	11.0	34.8	10.1
North	1995	02040301080060	13.2	0.1	1.7	23.7	--	25.9	30.3	18.3
North	1995	02040301080070	24.8	0.3	1.9	63.1	--	3.1	9.7	21.9
North	1995	02040301080080	17.4	3.4	1.7	25.9	--	22.3	43.8	2.8
North	1995	02040301080090	25.4	0.1	10.2	15.5	--	14.0	50.8	9.4
Central	1995	02040301090010	18.7	0.6	0.0	85.9	--	0.4	0.0	13.1
Central	1995	02040301090020	24.3	0.5	2.5	81.6	--	0.2	0.1	15.2
Central	1995	02040301090030	23.6	0.0	0.9	75.4	--	4.0	1.2	18.6
Central	1995	02040301090040	32.4	0.7	5.1	72.9	--	0.1	1.0	20.2

Table 1. Land-use distribution in HUC-14 subbasins in the Barnegat Bay-Little Egg Harbor watershed in 1986, 1995, 2002, and 2007.—Continued

[--, not available; HUC-14, Hydrologic Unit Code-14]

Watershed segment	Year	HUC-14	Drainage area, in square kilometers	Land use, in percent of subbasin (HUC-14) area						
				Agriculture	Barren land	Forest	Impervious urban	Non-residential urban	Residential urban	Water + Wetlands
Central	1995	02040301090050	20.6	0.6	7.6	61.7	--	1.8	2.5	25.7
Central	1995	02040301090060	21.8	0.4	2.6	38.2	--	8.3	21.7	28.8
Central	1995	02040301100010	20.6	0.3	0.6	19.5	--	6.0	27.9	45.7
Central	1995	02040301100020	12.6	2.6	0.0	12.5	--	3.9	29.8	51.2
Central	1995	02040301100030	8.2	0.0	1.0	0.4	--	5.5	13.7	79.4
Central	1995	02040301110010	22.3	0.0	0.6	87.1	--	0.2	0.0	12.2
Central	1995	02040301110020	18.7	0.0	1.8	55.1	--	4.5	20.6	18.0
Central	1995	02040301110030	25.7	0.1	0.9	49.0	--	5.7	13.9	30.4
Central	1995	02040301110040	19.4	0.2	2.2	76.4	--	0.8	1.9	18.5
Central	1995	02040301110050	14.0	0.0	0.6	59.6	--	4.0	4.1	31.7
Central	1995	02040301120010	23.1	0.3	0.4	52.7	--	6.2	19.9	20.5
Central	1995	02040301120020	37.3	0.1	0.7	9.3	--	3.0	7.9	78.9
Central	1995	02040301120030	8.3	0.0	0.4	1.0	--	6.2	32.8	59.7
South	1995	02040301130010	21.4	0.7	3.1	71.0	--	4.4	14.1	6.6
South	1995	02040301130020	26.8	0.0	2.6	72.2	--	2.3	13.7	9.2
South	1995	02040301130030	37.1	0.2	1.2	10.7	--	8.9	14.1	65.0
South	1995	02040301130040	21.6	0.1	2.1	67.9	--	2.3	4.1	23.5
South	1995	02040301130050	41.0	0.5	0.3	79.1	--	0.7	0.1	19.4
South	1995	02040301130060	23.9	1.1	1.7	49.8	--	4.3	7.5	35.5
South	1995	02040301130070	12.8	0.0	0.7	16.0	--	1.6	1.7	79.9
South	1995	02040301130080	6.2	0.0	0.0	1.3	--	15.2	48.5	35.0
South	1995	02040301140010	12.7	0.0	0.1	89.9	--	0.7	0.0	9.4
South	1995	02040301140020	13.1	0.0	1.4	81.9	--	1.9	2.1	12.6
South	1995	02040301140030	15.5	0.4	3.1	44.7	--	8.7	25.0	18.1
South	1995	02040301140040	17.9	0.2	0.3	18.3	--	3.0	10.9	67.3
South	1995	02040301140050	15.3	0.0	0.4	4.0	--	2.9	15.6	77.1
South	1995	02040301140060	8.4	0.0	1.7	0.2	--	5.9	20.4	71.8
South	1995	02040301910010	1.1	0.0	37.5	0.0	--	10.2	51.0	1.3
South	1995	02040301910020	3.0	0.0	22.5	0.1	--	12.2	63.3	1.9
South	1995	02040301910030	5.3	0.0	23.2	0.0	--	7.3	12.5	57.0
South	1995	02040301920010	2.6	0.0	19.9	0.8	--	3.0	58.8	17.5
South	1995	02040301920020	3.0	0.0	18.8	0.8	--	12.5	63.8	4.1
South	1995	02040301920030	2.9	0.0	15.9	0.0	--	9.0	59.2	15.8
North	2002	02040301020010	22.1	6.6	1.0	24.4	0.1	3.6	11.4	52.8
North	2002	02040301020020	28.1	3.9	1.4	18.6	1.2	8.7	45.5	20.8
North	2002	02040301020030	15.8	4.4	0.3	17.7	0.5	5.5	38.6	33.0
North	2002	02040301020040	12.5	10.4	4.1	33.6	0.0	6.3	18.5	27.1
North	2002	02040301020050	20.5	2.9	1.3	22.8	1.0	16.1	41.1	14.7
North	2002	02040301030010	13.0	5.7	0.5	35.0	0.9	2.0	3.9	51.9
North	2002	02040301030020	14.6	2.8	4.2	42.2	1.6	6.6	11.9	30.7
North	2002	02040301030030	19.6	5.6	2.5	28.2	0.5	4.0	32.6	26.7
North	2002	02040301030040	20.2	0.8	1.6	27.6	0.0	12.1	43.4	14.4
North	2002	02040301030050	12.4	0.2	2.2	30.5	0.2	24.5	23.4	18.9

Table 1. Land-use distribution in HUC-14 subbasins in the Barnegat Bay-Little Egg Harbor watershed in 1986, 1995, 2002, and 2007.—Continued

[--, not available; HUC-14, Hydrologic Unit Code-14]

Watershed segment	Year	HUC-14	Drainage area, in square kilometers	Land use, in percent of subbasin (HUC-14) area						
				Agriculture	Barren land	Forest	Impervious urban	Non-residential urban	Residential urban	Water + Wetlands
North	2002	02040301040010	20.4	0.0	0.2	7.6	1.0	12.4	63.5	15.3
North	2002	02040301040020	19.7	0.0	1.9	22.6	2.9	22.7	30.9	19.1
North	2002	02040301040030	6.8	0.0	0.1	1.0	0.0	17.9	67.0	14.1
North	2002	02040301050010	15.6	0.7	1.1	34.4	1.5	13.7	41.0	7.6
North	2002	02040301050020	21.9	1.1	1.0	16.9	0.8	9.2	54.8	16.3
North	2002	02040301050030	8.2	0.0	0.0	10.5	0.0	5.6	20.3	63.5
North	2002	02040301050040	33.0	0.1	0.5	11.0	0.6	7.5	50.2	30.1
North	2002	02040301050050	7.5	0.0	0.7	0.2	0.2	14.6	60.3	24.0
North	2002	02040301060010	19.6	7.9	0.3	36.1	0.7	3.3	23.0	28.8
North	2002	02040301060020	25.0	0.8	1.0	55.5	0.0	1.4	22.6	18.7
North	2002	02040301060030	19.4	4.3	0.1	33.7	0.0	3.9	24.9	33.1
North	2002	02040301060040	15.2	2.1	0.1	53.8	0.0	1.2	3.4	39.4
North	2002	02040301060050	20.5	3.8	4.0	33.0	0.0	6.9	23.9	28.3
North	2002	02040301060060	17.3	3.6	12.6	44.0	0.0	6.2	7.8	25.9
North	2002	02040301060070	17.8	2.4	9.6	38.3	0.0	10.3	30.9	8.5
North	2002	02040301060080	21.2	3.0	6.7	34.9	0.2	13.1	32.0	10.2
North	2002	02040301070010	31.3	4.6	0.5	52.0	0.0	1.8	6.6	34.5
North	2002	02040301070020	15.7	4.1	1.4	63.0	0.0	5.4	1.0	25.1
North	2002	02040301070030	26.0	0.6	5.9	45.6	0.0	9.9	5.5	32.5
North	2002	02040301070040	12.9	3.3	7.7	45.6	0.0	6.8	24.3	12.2
North	2002	02040301070050	14.6	0.2	0.1	78.4	0.0	6.5	0.1	14.7
North	2002	02040301070060	14.4	1.1	1.4	66.8	0.0	2.8	3.9	24.0
North	2002	02040301070070	13.0	0.3	12.0	54.6	0.0	1.2	2.5	29.5
North	2002	02040301070080	17.1	0.2	1.3	33.8	0.2	40.8	2.8	20.9
North	2002	02040301070090	18.5	0.4	2.2	39.4	0.2	5.9	29.3	22.6
North	2002	02040301080010	14.2	0.0	6.2	61.8	0.0	0.5	0.1	31.4
North	2002	02040301080020	14.1	0.2	0.2	53.8	0.0	4.7	26.9	14.3
North	2002	02040301080030	19.3	0.4	0.1	64.0	0.0	3.1	22.7	9.7
North	2002	02040301080040	17.6	0.0	0.0	50.8	0.8	6.5	34.8	7.1
North	2002	02040301080050	24.1	0.0	1.2	40.4	0.9	10.7	36.8	10.0
North	2002	02040301080060	13.2	0.2	0.4	23.1	2.5	23.0	32.2	18.5
North	2002	02040301080070	24.8	0.1	1.1	63.7	1.0	2.3	9.8	22.0
North	2002	02040301080080	17.4	2.0	1.3	19.4	1.4	20.8	52.4	2.8
North	2002	02040301080090	25.4	0.0	10.1	14.6	0.4	14.3	52.4	8.1
Central	2002	02040301090010	18.7	0.0	0.0	86.5	0.0	0.4	0.0	13.1
Central	2002	02040301090020	24.3	0.0	0.9	83.7	0.0	0.1	0.1	15.2
Central	2002	02040301090030	23.6	0.0	0.3	74.9	1.3	3.3	1.7	18.6
Central	2002	02040301090040	32.4	0.7	3.1	74.3	0.0	0.2	1.1	20.5
Central	2002	02040301090050	20.6	0.5	5.3	63.3	0.3	1.8	2.5	26.2
Central	2002	02040301090060	21.8	0.3	1.8	36.1	1.2	8.6	23.6	28.5
Central	2002	02040301100010	20.6	0.4	0.6	14.8	0.0	6.4	33.5	44.3
Central	2002	02040301100020	12.6	2.0	0.2	10.2	0.0	4.1	32.3	51.2
Central	2002	02040301100030	8.2	0.0	1.4	0.4	0.1	5.7	14.0	78.4

Table 1. Land-use distribution in HUC-14 subbasins in the Barnegat Bay-Little Egg Harbor watershed in 1986, 1995, 2002, and 2007.—Continued

[--, not available; HUC-14, Hydrologic Unit Code-14]

Watershed segment	Year	HUC-14	Drainage area, in square kilometers	Land use, in percent of subbasin (HUC-14) area						
				Agriculture	Barren land	Forest	Impervious urban	Non-residential urban	Residential urban	Water + Wetlands
Central	2002	02040301110010	22.3	0.0	0.6	87.1	0.0	0.1	0.0	12.1
Central	2002	02040301110020	18.7	0.0	1.3	55.0	0.4	4.6	20.8	17.9
Central	2002	02040301110030	25.7	0.0	0.9	47.7	1.1	5.3	14.7	30.3
Central	2002	02040301110040	19.4	0.2	1.9	76.4	0.0	1.0	1.9	18.6
Central	2002	02040301110050	14.0	0.0	0.8	57.4	0.9	4.6	4.5	31.8
Central	2002	02040301120010	23.1	0.2	4.3	42.6	0.8	7.1	24.9	20.2
Central	2002	02040301120020	37.3	0.1	1.0	7.5	0.0	3.0	9.5	78.9
Central	2002	02040301120030	8.3	0.0	1.1	0.8	0.0	6.2	32.2	59.8
South	2002	02040301130010	21.4	0.7	2.8	59.8	1.4	4.8	23.8	6.6
South	2002	02040301130020	26.8	0.0	1.6	67.2	0.1	3.0	18.9	9.2
South	2002	02040301130030	37.1	0.3	1.1	9.0	1.1	8.4	15.4	64.7
South	2002	02040301130040	21.6	0.0	2.2	64.7	0.8	2.5	6.1	23.6
South	2002	02040301130050	41.0	0.2	0.2	80.1	0.0	0.1	0.1	19.2
South	2002	02040301130060	23.9	1.3	2.5	47.4	1.3	3.7	8.2	35.6
South	2002	02040301130070	12.8	0.1	1.4	13.6	0.0	2.0	2.9	80.0
South	2002	02040301130080	6.2	0.0	0.4	1.4	1.1	14.9	46.9	35.3
South	2002	02040301140010	12.7	0.0	0.0	90.2	0.4	0.0	0.0	9.4
South	2002	02040301140020	13.1	0.0	2.3	77.5	0.9	3.8	2.8	12.6
South	2002	02040301140030	15.5	0.4	3.2	39.0	0.0	8.6	31.1	17.7
South	2002	02040301140040	17.9	0.3	0.1	16.0	0.0	4.7	11.7	67.1
South	2002	02040301140050	15.3	0.1	0.2	2.5	0.0	3.3	17.2	76.7
South	2002	02040301140060	8.4	0.0	1.6	0.4	0.0	4.8	20.7	72.5
South	2002	02040301910010	1.1	0.0	36.5	0.0	0.0	9.3	54.0	0.2
South	2002	02040301910020	3.0	0.0	22.1	0.0	0.0	13.4	62.8	1.6
South	2002	02040301910030	5.3	0.0	20.5	0.0	0.0	7.1	13.4	59.0
South	2002	02040301920010	2.6	0.0	14.7	0.8	0.0	6.3	54.0	24.2
South	2002	02040301920020	3.0	0.0	15.5	0.0	0.0	12.4	63.9	8.2
South	2002	02040301920030	2.9	0.0	12.4	0.0	0.0	8.9	59.3	19.5
North	2007	02040301020010	22.1	6.8	0.6	23.0	0.2	3.9	12.8	52.7
North	2007	02040301020020	28.1	3.8	0.5	16.8	1.7	9.0	47.7	20.3
North	2007	02040301020030	15.8	4.3	0.2	15.7	0.7	6.9	39.8	32.5
North	2007	02040301020040	12.5	10.1	3.7	32.3	0.0	6.8	20.3	26.8
North	2007	02040301020050	20.5	2.4	1.0	19.9	1.2	17.1	43.8	14.5
North	2007	02040301030010	13.0	5.7	0.6	34.1	0.9	2.7	4.3	51.7
North	2007	02040301030020	14.6	2.6	4.0	36.2	1.6	7.8	17.4	30.5
North	2007	02040301030030	19.6	2.7	2.5	23.0	0.5	5.8	39.1	26.4
North	2007	02040301030040	20.2	0.8	0.9	24.4	0.0	14.0	45.6	14.3
North	2007	02040301030050	12.4	0.1	1.8	24.4	0.3	26.7	28.2	18.6
North	2007	02040301040010	20.4	0.0	0.2	6.8	1.4	12.4	64.2	15.1
North	2007	02040301040020	19.7	0.0	1.5	19.0	3.4	24.8	32.1	19.1
North	2007	02040301040030	6.8	0.0	0.2	0.8	0.0	18.3	66.5	14.2
North	2007	02040301050010	15.6	0.1	1.4	28.7	1.8	16.1	44.7	7.2
North	2007	02040301050020	21.9	1.0	0.9	14.7	0.9	10.2	56.0	16.3

Table 1. Land-use distribution in HUC-14 subbasins in the Barnegat Bay-Little Egg Harbor watershed in 1986, 1995, 2002, and 2007.—Continued

[--, not available; HUC-14, Hydrologic Unit Code-14]

Watershed segment	Year	HUC-14	Drainage area, in square kilometers	Land use, in percent of subbasin (HUC-14) area						
				Agriculture	Barren land	Forest	Impervious urban	Non-residential urban	Residential urban	Water + Wetlands
North	2007	02040301050030	8.2	0.0	0.0	10.0	0.0	6.1	20.6	63.3
North	2007	02040301050040	33.0	0.0	0.4	10.5	0.7	8.1	50.4	29.9
North	2007	02040301050050	7.5	0.0	0.6	0.3	0.2	14.9	60.1	24.0
North	2007	02040301060010	19.6	7.6	0.4	33.8	0.8	3.7	25.2	28.5
North	2007	02040301060020	25.0	0.9	0.6	53.1	0.0	1.8	25.0	18.6
North	2007	02040301060030	19.4	3.5	1.8	29.3	0.0	4.5	28.2	32.6
North	2007	02040301060040	15.2	2.2	0.0	52.4	0.0	1.4	4.6	39.4
North	2007	02040301060050	20.5	3.9	0.7	28.4	0.0	7.1	31.9	27.9
North	2007	02040301060060	17.3	3.6	10.8	41.6	0.0	7.1	10.2	26.8
North	2007	02040301060070	17.8	2.2	6.0	32.4	0.0	11.9	38.9	8.5
North	2007	02040301060080	21.2	1.7	7.3	30.8	0.3	14.2	35.5	10.2
North	2007	02040301070010	31.3	4.4	0.6	51.2	0.0	2.2	7.1	34.5
North	2007	02040301070020	15.7	3.4	0.9	62.9	0.0	6.3	1.2	25.1
North	2007	02040301070030	26.0	0.6	5.5	43.5	0.0	12.0	5.9	32.5
North	2007	02040301070040	12.9	2.1	9.6	41.1	0.0	7.2	27.5	12.5
North	2007	02040301070050	14.6	1.3	0.0	75.8	0.0	7.8	0.1	14.9
North	2007	02040301070060	14.4	1.1	2.5	63.5	0.0	4.4	4.4	24.0
North	2007	02040301070070	13.0	0.3	12.1	54.4	0.0	1.4	2.3	29.6
North	2007	02040301070080	17.1	0.8	2.5	30.9	0.2	42.0	2.8	20.9
North	2007	02040301070090	18.5	0.4	2.1	38.0	0.2	6.2	30.3	22.7
North	2007	02040301080010	14.2	0.0	5.8	61.6	0.0	0.6	0.1	31.9
North	2007	02040301080020	14.1	0.2	0.1	51.5	0.0	5.5	28.5	14.3
North	2007	02040301080030	19.3	0.4	0.3	63.2	0.0	3.7	22.7	9.7
North	2007	02040301080040	17.6	0.0	0.0	50.8	0.8	6.4	35.0	7.1
North	2007	02040301080050	24.1	0.0	0.9	39.3	1.1	11.0	37.5	10.1
North	2007	02040301080060	13.2	0.2	1.1	21.8	3.4	22.7	32.2	18.5
North	2007	02040301080070	24.8	0.1	1.7	62.6	1.1	2.6	9.9	22.0
North	2007	02040301080080	17.4	1.8	0.4	15.3	1.6	21.9	56.2	2.8
North	2007	02040301080090	25.4	0.0	8.2	13.9	0.4	16.0	53.1	8.4
Central	2007	02040301090010	18.7	0.0	0.0	86.5	0.0	0.4	0.0	13.1
Central	2007	02040301090020	24.3	0.0	1.4	83.1	0.0	0.2	0.1	15.2
Central	2007	02040301090030	23.6	0.0	0.2	74.7	1.3	3.3	1.8	18.6
Central	2007	02040301090040	32.4	0.8	3.5	73.4	0.0	0.3	1.2	20.9
Central	2007	02040301090050	20.6	0.6	4.5	62.9	0.4	2.1	2.4	27.3
Central	2007	02040301090060	21.8	0.2	1.4	33.0	1.1	9.7	26.2	28.4
Central	2007	02040301100010	20.6	0.4	0.6	11.7	0.0	7.5	36.0	43.8
Central	2007	02040301100020	12.6	2.5	1.0	8.5	0.0	3.7	32.7	51.5
Central	2007	02040301100030	8.2	0.0	0.7	0.2	0.1	5.6	14.3	79.1
Central	2007	02040301110010	22.3	0.0	0.5	87.1	0.0	0.1	0.1	12.2
Central	2007	02040301110020	18.7	0.0	1.2	54.7	0.6	4.6	21.1	17.9
Central	2007	02040301110030	25.7	0.0	0.6	47.0	1.1	5.7	15.4	30.2
Central	2007	02040301110040	19.4	0.4	1.7	75.6	0.0	1.4	2.0	18.8
Central	2007	02040301110050	14.0	0.0	0.4	56.4	1.2	5.4	4.8	32.0

Table 1. Land-use distribution in HUC-14 subbasins in the Barnegat Bay-Little Egg Harbor watershed in 1986, 1995, 2002, and 2007.—Continued

[--, not available; HUC-14, Hydrologic Unit Code-14]

Watershed segment	Year	HUC-14	Drainage area, in square kilometers	Land use, in percent of subbasin (HUC-14) area						
				Agriculture	Barren land	Forest	Impervious urban	Non-residential urban	Residential urban	Water + Wetlands
Central	2007	02040301120010	23.1	0.3	2.9	34.0	0.8	9.5	32.4	20.1
Central	2007	02040301120020	37.3	0.2	0.4	6.6	0.0	3.3	10.7	78.8
Central	2007	02040301120030	8.3	0.0	0.4	0.3	0.0	6.6	32.3	60.4
South	2007	02040301130010	21.4	0.3	3.1	47.1	1.5	7.1	34.0	6.9
South	2007	02040301130020	26.8	0.2	2.5	64.6	0.1	3.7	19.6	9.3
South	2007	02040301130030	37.1	0.2	0.8	6.9	1.6	9.2	16.8	64.5
South	2007	02040301130040	21.6	0.0	2.9	62.0	0.8	3.2	7.4	23.5
South	2007	02040301130050	41.0	0.1	0.1	80.1	0.0	0.1	0.1	19.4
South	2007	02040301130060	23.9	1.2	4.2	43.2	1.4	4.8	9.5	35.7
South	2007	02040301130070	12.8	0.1	1.8	12.4	0.0	2.0	3.6	80.1
South	2007	02040301130080	6.2	0.0	0.3	0.7	1.2	14.6	47.5	35.8
South	2007	02040301140010	12.7	0.1	0.0	90.0	0.4	0.2	0.0	9.4
South	2007	02040301140020	13.1	0.0	1.8	74.3	1.0	5.9	4.2	12.8
South	2007	02040301140030	15.5	0.3	2.5	30.8	0.0	9.6	39.5	17.3
South	2007	02040301140040	17.9	0.3	0.5	13.3	0.0	5.4	13.6	66.9
South	2007	02040301140050	15.3	0.1	0.1	2.5	0.0	3.4	17.2	76.7
South	2007	02040301140060	8.4	0.0	1.2	0.4	0.0	4.2	21.5	72.8
South	2007	02040301910010	1.1	0.0	24.2	0.0	0.0	6.6	57.0	12.2
South	2007	02040301910020	3.0	0.0	16.0	0.0	0.0	12.6	64.2	7.2
South	2007	02040301910030	5.3	0.0	16.0	0.0	0.0	8.2	13.2	62.5
South	2007	02040301920010	2.6	0.0	10.0	0.8	0.0	6.2	53.8	29.1
South	2007	02040301920020	3.0	0.0	14.9	0.0	0.0	12.1	63.9	9.0
South	2007	02040301920030	2.9	0.0	10.5	0.0	0.0	9.0	57.9	22.6

Table 14. Annual and seasonal base-flow, runoff, and total nutrient loads by watershed segment for total nitrogen and total phosphorus, 1989–2011.

[All loads in kilograms; A, all/annual; G, growing; NG, nongrowing]

Year	Season	Segment	Precipitation, in inches	Load of total nitrogen in:			Load of total phosphorus in:		
				Base flow	Runoff	Total	Base flow	Runoff	Total
1989	A	North	53.83	371,000	79,700	451,000	13,300	3,100	16,400
1989	A	Central	53.83	100,000	18,600	119,000	4,080	585	4,660
1989	A	South	53.83	92,600	18,000	111,000	4,020	583	4,600
1990	A	North	43.18	344,000	63,900	408,000	12,300	2,480	14,800
1990	A	Central	43.18	93,000	14,900	108,000	3,780	471	4,250
1990	A	South	43.18	85,800	14,500	100,000	3,720	467	4,190
1991	A	North	45.14	295,000	72,000	367,000	10,400	2,830	13,200
1991	A	Central	45.14	81,300	16,500	97,700	3,300	534	3,830
1991	A	South	45.14	74,000	16,100	90,100	3,200	530	3,730
1992	A	North	42.94	242,000	68,500	311,000	8,500	2,690	11,200
1992	A	Central	42.94	66,600	15,600	82,300	2,700	510	3,210
1992	A	South	42.94	60,600	15,300	75,900	2,620	506	3,130
1993	A	North	42.35	342,000	67,500	409,000	12,000	2,660	14,600
1993	A	Central	42.35	94,000	15,400	109,000	3,810	502	4,310
1993	A	South	42.35	85,500	15,100	101,000	3,700	499	4,200
1994	A	North	46.5	371,000	74,200	445,000	13,000	2,910	15,900
1994	A	Central	46.5	102,000	16,900	119,000	4,140	553	4,690
1994	A	South	46.5	92,800	16,600	109,000	4,010	546	4,560
1995	A	North	37.66	241,000	60,100	301,000	8,460	2,360	10,800
1995	A	Central	37.66	66,300	13,700	80,100	2,690	446	3,140
1995	A	South	37.66	60,300	13,400	73,800	2,610	443	3,050
1996	A	North	56.26	407,000	89,700	497,000	14,300	3,520	17,800
1996	A	Central	56.26	112,000	20,500	133,000	4,550	669	5,210
1996	A	South	56.26	102,000	20,000	122,000	4,410	661	5,070
1997	A	North	46.14	356,000	73,600	430,000	12,500	2,890	15,400
1997	A	Central	46.14	97,900	16,800	115,000	3,970	549	4,520
1997	A	South	46.14	89,100	16,500	106,000	3,850	539	4,390
1998	A	North	45.56	407,000	72,700	480,000	14,300	2,860	17,200
1998	A	Central	45.56	112,000	16,600	129,000	4,550	541	5,090
1998	A	South	45.56	102,000	16,200	118,000	4,410	534	4,940
1999	A	North	45.82	289,000	79,500	369,000	10,200	3,120	13,300
1999	A	Central	45.82	80,800	18,100	98,900	3,210	590	3,800
1999	A	South	45.82	75,900	18,300	94,200	3,200	612	3,810
2000	A	North	47.39	293,000	82,200	375,000	10,300	3,230	13,500
2000	A	Central	47.39	81,900	18,700	101,000	3,240	611	3,850
2000	A	South	47.39	76,800	18,900	95,600	3,230	633	3,870
2001	A	North	34.58	280,000	60,000	340,000	9,830	2,350	12,200
2001	A	Central	34.58	78,200	13,600	91,800	3,100	445	3,540
2001	A	South	34.58	73,300	13,800	87,100	3,090	462	3,550
2002	A	North	48.07	220,000	83,400	303,000	7,720	3,270	11,000
2002	A	Central	48.07	61,400	18,900	80,300	2,430	620	3,050
2002	A	South	48.07	57,600	19,100	76,700	2,430	643	3,070

Table 14. Annual and seasonal base-flow, runoff, and total nutrient loads by watershed segment for total nitrogen and total phosphorus, 1989–2011.—Continued

[All loads in kilograms; A, all/annual; G, growing; NG, nongrowing]

Year	Season	Segment	Precipitation, in inches	Load of total nitrogen in:			Load of total phosphorus in:		
				Base flow	Runoff	Total	Base flow	Runoff	Total
2003	A	North	53.72	404,000	93,200	498,000	14,200	3,650	17,900
2003	A	Central	53.72	113,000	21,200	134,000	4,480	693	5,170
2003	A	South	53.72	106,000	21,400	127,000	4,470	717	5,180
2004	A	North	46.82	382,000	81,200	464,000	13,400	3,180	16,600
2004	A	Central	46.82	107,000	18,400	125,000	4,230	603	4,840
2004	A	South	46.82	100,000	18,600	119,000	4,220	628	4,850
2005	A	North	48.4	398,000	89,200	487,000	14,100	3,470	17,600
2005	A	Central	48.4	113,000	20,400	133,000	4,500	674	5,180
2005	A	South	48.4	106,000	21,000	127,000	4,440	714	5,150
2006	A	North	51.47	439,000	94,800	534,000	15,600	3,690	19,300
2006	A	Central	51.47	124,000	21,600	146,000	4,970	718	5,690
2006	A	South	51.47	117,000	22,400	139,000	4,890	761	5,660
2007	A	North	44.51	400,000	82,000	482,000	14,200	3,190	17,400
2007	A	Central	44.51	113,000	18,700	132,000	4,520	621	5,140
2007	A	South	44.51	107,000	19,400	126,000	4,470	659	5,130
2008	A	North	47.57	343,000	87,600	431,000	12,200	3,410	15,600
2008	A	Central	47.57	97,400	20,000	117,000	3,890	661	4,550
2008	A	South	47.57	91,600	20,700	112,000	3,830	704	4,540
2009	A	North	59.92	432,000	110,000	542,000	15,300	4,290	19,600
2009	A	Central	59.92	122,000	25,200	148,000	4,890	835	5,720
2009	A	South	59.92	115,000	26,000	141,000	4,820	885	5,710
2010	A	North	43.23	478,000	79,700	557,000	16,900	3,100	20,000
2010	A	Central	43.23	135,000	18,200	154,000	5,410	603	6,010
2010	A	South	43.23	127,000	18,800	146,000	5,330	638	5,970
2011	A	North	57.32	384,000	106,000	489,000	13,600	4,110	17,700
2011	A	Central	57.32	109,000	24,100	133,000	4,340	800	5,140
2011	A	South	57.32	102,000	24,900	127,000	4,280	848	5,130
1989	G	North	37.44	238,000	60,400	298,000	8,500	2,770	11,300
1989	G	Central	37.44	64,300	14,200	78,500	2,610	506	3,120
1989	G	South	37.44	59,400	13,800	73,200	2,580	508	3,080
1990	G	North	28.78	200,000	46,400	246,000	7,130	2,130	9,260
1990	G	Central	28.78	53,900	10,900	64,900	2,190	386	2,580
1990	G	South	28.78	49,800	10,600	60,500	2,160	391	2,550
1991	G	North	26.1	143,000	45,500	189,000	5,020	2,100	7,120
1991	G	Central	26.1	39,400	10,400	49,800	1,600	384	1,980
1991	G	South	26.1	35,800	10,300	46,100	1,550	380	1,930
1992	G	North	26.53	126,000	46,200	172,000	4,430	2,130	6,560
1992	G	Central	26.53	34,700	10,600	45,400	1,410	391	1,800
1992	G	South	26.53	31,600	10,400	42,000	1,370	389	1,760
1993	G	North	22.85	178,000	39,800	218,000	6,240	1,830	8,070
1993	G	Central	22.85	48,900	9,160	58,000	1,980	337	2,320
1993	G	South	22.85	44,500	8,990	53,400	1,920	336	2,260

Table 14. Annual and seasonal base-flow, runoff, and total nutrient loads by watershed segment for total nitrogen and total phosphorus, 1989–2011.—Continued

[All loads in kilograms; A, all/annual; G, growing; NG, nongrowing]

Year	Season	Segment	Precipitation, in inches	Load of total nitrogen in:			Load of total phosphorus in:		
				Base flow	Runoff	Total	Base flow	Runoff	Total
1994	G	North	22.67	190,000	39,500	229,000	6,650	1,820	8,470
1994	G	Central	22.67	52,100	9,090	61,200	2,120	334	2,450
1994	G	South	22.67	47,400	8,920	56,400	2,050	332	2,380
1995	G	North	22.57	110,000	39,300	149,000	3,840	1,810	5,660
1995	G	Central	22.57	30,100	9,040	39,200	1,220	333	1,560
1995	G	South	22.57	27,400	8,870	36,300	1,190	331	1,520
1996	G	North	35.33	205,000	61,500	266,000	7,180	2,840	10,000
1996	G	Central	35.33	56,300	14,200	70,400	2,280	524	2,810
1996	G	South	35.33	51,200	13,900	65,100	2,210	518	2,730
1997	G	North	25.91	182,000	45,200	227,000	6,380	2,080	8,460
1997	G	Central	25.91	50,000	10,400	60,400	2,030	384	2,420
1997	G	South	25.91	45,500	10,200	55,700	1,970	378	2,350
1998	G	North	24.85	234,000	43,300	277,000	8,210	2,000	10,200
1998	G	Central	24.85	64,300	9,960	74,300	2,610	367	2,980
1998	G	South	24.85	58,500	9,780	68,300	2,530	365	2,900
1999	G	North	25.48	139,000	48,300	188,000	4,890	2,220	7,110
1999	G	Central	25.48	38,900	11,000	50,000	1,540	407	1,950
1999	G	South	25.48	36,600	11,200	47,700	1,540	427	1,970
2000	G	North	30.86	161,000	58,600	220,000	5,660	2,680	8,340
2000	G	Central	30.86	45,000	13,400	58,400	1,780	496	2,280
2000	G	South	30.86	42,200	13,500	55,800	1,780	517	2,300
2001	G	North	18.96	146,000	36,000	182,000	5,140	1,650	6,790
2001	G	Central	18.96	40,900	8,210	49,100	1,620	303	1,930
2001	G	South	18.96	38,400	8,320	46,700	1,620	316	1,930
2002	G	North	28.46	104,000	54,000	158,000	3,660	2,480	6,130
2002	G	Central	28.46	29,100	12,300	41,500	1,150	455	1,610
2002	G	South	28.46	27,300	12,500	39,800	1,150	477	1,630
2003	G	North	33.62	211,000	63,800	275,000	7,420	2,920	10,300
2003	G	Central	33.62	59,100	14,600	73,600	2,340	539	2,880
2003	G	South	33.62	55,400	14,700	70,100	2,340	563	2,900
2004	G	North	30.16	204,000	57,200	261,000	7,170	2,620	9,800
2004	G	Central	30.16	57,100	13,100	70,100	2,260	484	2,740
2004	G	South	30.16	53,500	13,200	66,700	2,250	507	2,760
2005	G	North	29.82	210,000	60,200	271,000	7,460	2,730	10,200
2005	G	Central	29.82	59,700	13,800	73,500	2,380	521	2,900
2005	G	South	29.82	56,100	14,300	70,400	2,350	550	2,900
2006	G	North	33.43	211,000	67,400	278,000	7,480	3,060	10,500
2006	G	Central	33.43	59,800	15,500	75,300	2,390	581	2,970
2006	G	South	33.43	56,300	16,000	72,300	2,350	621	2,970
2007	G	North	26.09	215,000	52,600	268,000	7,630	2,390	10,000
2007	G	Central	26.09	61,100	12,100	73,100	2,440	454	2,890
2007	G	South	26.09	57,400	12,500	69,900	2,400	483	2,890

Table 14. Annual and seasonal base-flow, runoff, and total nutrient loads by watershed segment for total nitrogen and total phosphorus, 1989–2011.—Continued

[All loads in kilograms; A, all/annual; G, growing; NG, nongrowing]

Year	Season	Segment	Precipitation, in inches	Load of total nitrogen in:			Load of total phosphorus in:		
				Base flow	Runoff	Total	Base flow	Runoff	Total
2008	G	North	23.75	160,000	47,900	208,000	5,670	2,180	7,850
2008	G	Central	23.75	45,400	11,000	56,400	1,810	411	2,220
2008	G	South	23.75	42,700	11,400	54,100	1,790	440	2,230
2009	G	North	39.95	232,000	80,600	312,000	8,210	3,660	11,900
2009	G	Central	39.95	65,600	18,500	84,100	2,620	694	3,320
2009	G	South	39.95	61,800	19,200	80,900	2,590	740	3,330
2010	G	North	18.81	238,000	38,000	276,000	8,420	1,720	10,100
2010	G	Central	18.81	67,400	8,700	76,000	2,690	326	3,020
2010	G	South	18.81	63,400	9,010	72,400	2,650	350	3,000
2011	G	North	38.05	200,000	76,800	277,000	7,090	3,480	10,600
2011	G	Central	38.05	56,700	17,600	74,300	2,260	663	2,930
2011	G	South	38.05	53,300	18,300	71,600	2,230	704	2,940
1989	NG	North	16.39	133,000	21,200	154,000	4,750	578	5,320
1989	NG	Central	16.39	35,900	4,880	40,800	1,460	122	1,580
1989	NG	South	16.39	33,200	4,710	37,900	1,440	119	1,560
1990	NG	North	14.4	143,000	18,600	161,000	5,100	507	5,600
1990	NG	Central	14.4	38,500	4,290	42,800	1,570	109	1,680
1990	NG	South	14.4	35,600	4,140	39,700	1,540	105	1,650
1991	NG	North	19.04	149,000	26,400	175,000	5,230	734	5,960
1991	NG	Central	19.04	41,000	5,970	47,000	1,660	154	1,820
1991	NG	South	19.04	37,300	5,810	43,100	1,610	150	1,760
1992	NG	North	16.41	114,000	22,800	137,000	4,000	634	4,630
1992	NG	Central	16.41	31,300	5,140	36,500	1,270	132	1,400
1992	NG	South	16.41	28,500	5,000	33,500	1,230	129	1,360
1993	NG	North	19.5	161,000	27,100	188,000	5,650	754	6,400
1993	NG	Central	19.5	44,300	6,110	50,400	1,800	158	1,960
1993	NG	South	19.5	40,300	5,950	46,300	1,740	154	1,890
1994	NG	North	23.83	178,000	33,100	211,000	6,240	921	7,160
1994	NG	Central	23.83	48,900	7,470	56,400	1,980	194	2,180
1994	NG	South	23.83	44,500	7,260	51,800	1,920	187	2,110
1995	NG	North	15.09	129,000	21,000	150,000	4,510	582	5,090
1995	NG	Central	15.09	35,400	4,730	40,100	1,440	122	1,560
1995	NG	South	15.09	32,200	4,600	36,800	1,390	120	1,510
1996	NG	North	20.94	199,000	29,100	228,000	6,980	808	7,780
1996	NG	Central	20.94	54,700	6,560	61,300	2,220	169	2,390
1996	NG	South	20.94	49,800	6,380	56,100	2,150	166	2,320
1997	NG	North	20.22	171,000	28,100	199,000	5,990	784	6,780
1997	NG	Central	20.22	47,000	6,340	53,300	1,900	165	2,070
1997	NG	South	20.22	42,700	6,170	48,900	1,850	159	2,010
1998	NG	North	20.71	171,000	28,800	200,000	6,000	798	6,800
1998	NG	Central	20.71	47,000	6,490	53,500	1,910	167	2,070
1998	NG	South	20.71	42,800	6,320	49,100	1,850	164	2,010

Table 14. Annual and seasonal base-flow, runoff, and total nutrient loads by watershed segment for total nitrogen and total phosphorus, 1989–2011.—Continued

[All loads in kilograms; A, all/annual; G, growing; NG, nongrowing]

Year	Season	Segment	Precipitation, in inches	Load of total nitrogen in:			Load of total phosphorus in:		
				Base flow	Runoff	Total	Base flow	Runoff	Total
1999	NG	North	20.34	147,000	30,600	177,000	5,160	859	6,010
1999	NG	Central	20.34	41,000	6,900	47,900	1,630	177	1,800
1999	NG	South	20.34	38,500	6,940	45,400	1,620	180	1,800
2000	NG	North	16.53	130,000	24,900	155,000	4,560	697	5,260
2000	NG	Central	16.53	36,300	5,600	41,900	1,440	145	1,580
2000	NG	South	16.53	34,000	5,630	39,700	1,430	147	1,580
2001	NG	North	15.62	131,000	23,500	154,000	4,600	660	5,260
2001	NG	Central	15.62	36,600	5,300	41,900	1,450	137	1,590
2001	NG	South	15.62	34,300	5,320	39,600	1,440	139	1,580
2002	NG	North	19.61	113,000	29,500	142,000	3,960	826	4,790
2002	NG	Central	19.61	31,500	6,650	38,200	1,250	172	1,420
2002	NG	South	19.61	29,600	6,680	36,300	1,240	175	1,420
2003	NG	North	20.1	190,000	30,300	220,000	6,660	850	7,510
2003	NG	Central	20.1	53,000	6,820	59,800	2,100	175	2,270
2003	NG	South	20.1	49,700	6,850	56,600	2,090	177	2,270
2004	NG	North	16.67	178,000	25,100	203,000	6,260	704	6,960
2004	NG	Central	16.67	49,800	5,650	55,500	1,980	146	2,120
2004	NG	South	16.67	46,800	5,680	52,500	1,970	148	2,120
2005	NG	North	18.57	187,000	29,700	217,000	6,640	829	7,470
2005	NG	Central	18.57	53,100	6,730	59,800	2,120	173	2,290
2005	NG	South	18.57	49,900	6,910	56,800	2,090	181	2,270
2006	NG	North	18.05	228,000	28,900	257,000	8,080	804	8,880
2006	NG	Central	18.05	64,600	6,530	71,100	2,580	170	2,750
2006	NG	South	18.05	60,700	6,720	67,400	2,540	176	2,720
2007	NG	North	18.42	185,000	29,400	214,000	6,550	825	7,380
2007	NG	Central	18.42	52,400	6,670	59,100	2,090	172	2,260
2007	NG	South	18.42	49,300	6,850	56,200	2,060	180	2,240
2008	NG	North	23.82	183,000	38,100	221,000	6,500	1,060	7,560
2008	NG	Central	23.82	52,000	8,620	60,600	2,080	223	2,300
2008	NG	South	23.82	48,900	8,860	57,800	2,040	232	2,280
2009	NG	North	19.97	200,000	31,900	232,000	7,100	888	7,990
2009	NG	Central	19.97	56,800	7,230	64,000	2,270	187	2,460
2009	NG	South	19.97	53,400	7,440	60,900	2,240	195	2,430
2010	NG	North	24.42	240,000	39,000	279,000	8,520	1,090	9,610
2010	NG	Central	24.42	68,100	8,850	77,000	2,720	230	2,950
2010	NG	South	24.42	64,100	9,080	73,100	2,680	236	2,920
2011	NG	North	19.27	169,000	30,800	200,000	6,000	863	6,860
2011	NG	Central	19.27	48,000	6,980	55,000	1,920	181	2,100
2011	NG	South	19.27	45,200	7,180	52,300	1,890	187	2,080

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