Barnegat Bay National Estuary Program

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Barnegat Bay National Estuary Program

Contributions of Nitrogen to the Barnegat Bay-Little Egg Harbor Estuary: Updated Loading Estimates

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Abstract

Based on the most recent and most accurate data available through 2008, the total load of nitrogen to the Barnegat Bay-Little Egg Harbor (BB-LEH) estuary from the most substantial sources (surface water, including surface-water discharge and direct storm runoff; ground-water discharge; and atmospheric deposition) is estimated to be 650,000 kilograms of nitrogen per year (kg N/yr). Surface water contributes 66 percent (431,000 kg N/yr), direct ground-water discharge accounts for 12 percent (78,000 kg N/yr), and atmospheric deposition accounts for 22 percent (141,000 kg N/yr). This new loading estimate was compared to a previously published estimate produced by using similar methodology but less current data through 1997. Findings of the present study include a substantially lower estimate of atmospheric deposition of nitrogen to the estuary compared to the previous estimate. The study results also offer further support of the relation between land use and nitrogen levels, and indicate that the Toms and Metedeconk River basins account for more than 60 percent of the nitrogen load to the estuary from surface-water discharge. Differences between the two estimates can be attributed to both the use of more accurate and more recent data in the revised estimate, and actual changes in the magnitude of nitrogen loads from various sources. Gaps in available water-quality and hydrologic data are documented, and additional analysis and monitoring that may improve the reliability of future nitrogen loading estimates are presented.

Introduction

The Barnegat Bay-Little Egg Harbor (BB-LEH) estuary is classified as highly eutrophic, and the ecological health of the estuary is particularly susceptible to the effects of nutrient loading (Bricker and others, 1999; Bricker and others, 2007; Kennish, 2001). Nitrogen (N) is one of the primary nutrients that can adversely affect the quality of water in the estuary; excessive inputs of certain N species can lead to toxic or nuisance algal blooms, shifts in species composition, depleted dissolved oxygen, and a decline in water quality (Kennish, 2001). Nitrogen can enter the estuary by way of surface-water discharge (as base flow or storm runoff), direct storm runoff to the estuary, direct ground-water discharge, atmospheric deposition, and ocean water entering the estuary, and through the release of nitrogen contained in bottom sediments.

Nitrogen exists in the environment in many forms, depending on its source and whether it is present in water, soil, plant matter, the atmosphere, or another medium. Common forms include organic nitrogen and inorganic forms such as nitrite, nitrate, ammonia, and ammonium. In residential and commercial areas, sources of N to surface and ground waters include lawn fertilizers, septic-system wastes, leaky sewer pipes, and industrial discharge; in agricultural areas, sources include crop fertilizers, animal manure, and septic-system wastes. Additionally, nitrogen can enter the atmosphere through automobile emissions, industrial emissions, and natural N-fixation processes, with subsequent deposition on land or water surfaces (Castro and others, 2003; Gao and others, 2007).

Factors that can affect the amount of nitrogen that enters a system include land development, season (growing or nongrowing), and hydrologic condition (base flow or stormflow) (Baker and Hunchak-Kariouk, 2006). Ground-water contributions of N to most streams are relatively constant, varying only slightly with season. Storm runoff, in contrast, contributes N to streams intermittently, and loading varies substantially with season. A previous investigation of the Toms River basin within the Barnegat Bay watershed (Baker and Hunchak-Kariouk, 2006) showed significant correlation between percent land development and yields of ammonia and total nitrogen in stormwater, a reflection of the actual increase in nonpoint-source loads associated with increased land development. In the same study, no apparent relation was found between percent land development and yields of the same constituent in base flow.

This report describes the results of a study to update estimates of nitrogen loading to the BB-LEH estuary using more recent data where available. Estimates of N loads are needed to help assess the importance of N sources within the watershed and to develop nutrient-management strategies. In the context of this report, nitrogen load refers to the amount of N that is delivered to the BB-LEH estuary annually, in kilograms per year. The calculations used to update the N loads closely followed the approach of Hunchak-Kariouk and Nicholson (2001). The relative contributions to the N load from surface-water, ground-water, and atmospheric inputs were estimated.

Computation of Nitrogen Loads and Yields

Surface water

The nitrogen load from surface-water discharge was calculated for each of the 12 major river basins in the BB-LEH watershed (Figure 1). Portions of these subwatersheds that are upstream from water-quality-monitoring stations are considered to be monitored; downstream portions are considered to be unmonitored. The N load in direct storm runoff was estimated using linear regression equations developed by Baker and Hunchak-Kariouk (2006) and the percentage of urban development in the ground-water discharge area of the BB-LEH estuary.

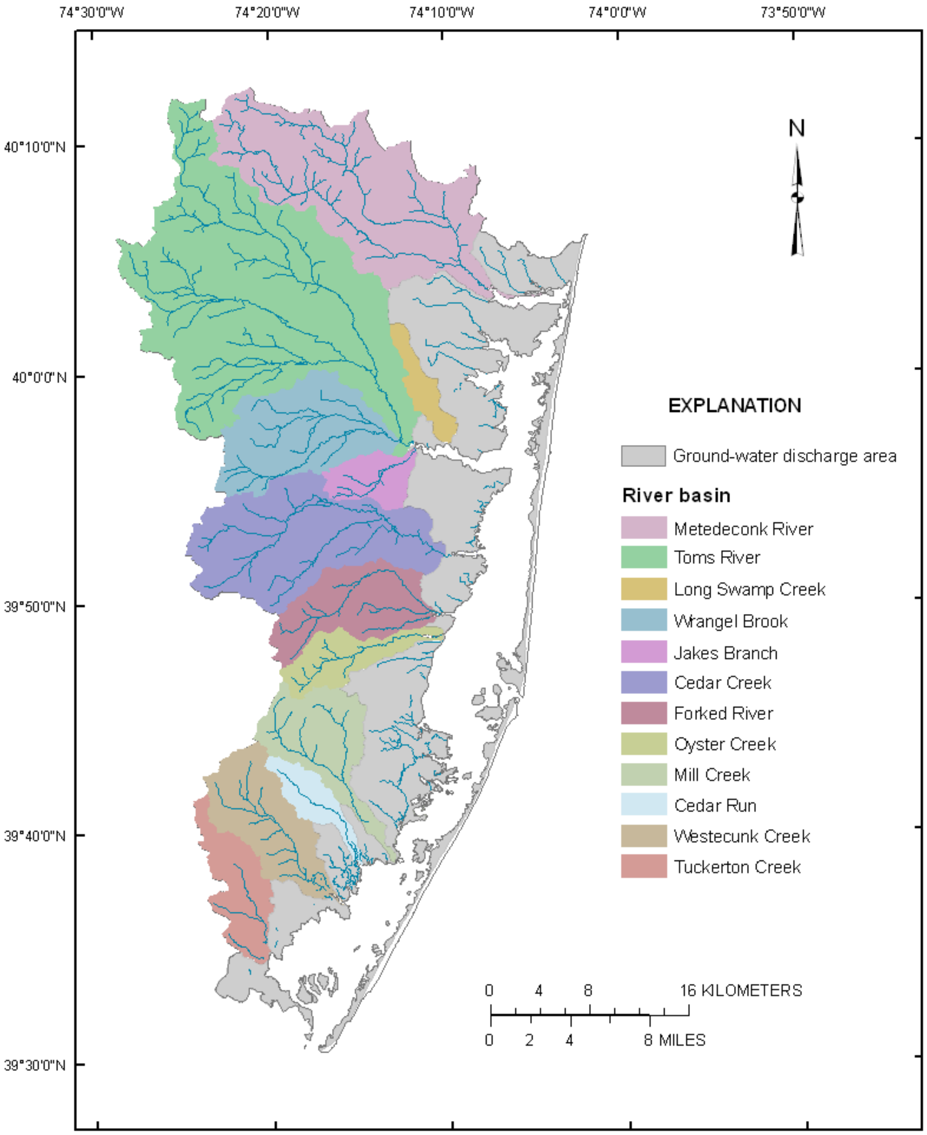

Figure 1. Location of the Barnegat Bay-Little Egg Harbor estuary and watershed, major river basins, and areas contributing direct ground-water discharge to the estuary and minor tributaries.

Surface-water discharge, monitored reaches

The load is calculated by multiplying values of concentration (mass per volume, expressed as milligrams per liter, mg/L), by instantaneous streamflow (volume per time, expressed as cubic meters per second, m^3/s). Available water-quality data for all streams in the BB-LEH watershed for the 1987-2008 water years[1] were compiled from the data resources maintained by the New Jersey Department of Environmental Protection, the New Jersey Pinelands Commission, and the U.S. Geological Survey. Data for N-containing constituents including total nitrogen (TN), nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3), and organic nitrogen (ON) were evaluated. Only sampling stations with at least 3 years of N data for water years 1987-2008 were included in the load calculations. Censored data values were considered equal to their absolute value for analysis because of changes in the detection limits over time and the unavailability of censoring information for some data sets. Water-quality data for the sampling station located farthest downstream on each of the major rivers were used in the load calculation; locations of the 12 stations are shown in Figure 2.

Daily streamflow data for the continuous-record gaging station on the Toms River near Toms River, NJ (01408500), for water years 1960-2008 were retrieved from the USGS National Water Information System (NWIS) database. Following the procedure of Hunchak-Kariouk and Nicholson (2001), the median flow at the Toms River gaging station was calculated; flows at the station greater than the median were considered to be high-flow values and flows at the station less than the median were considered to be low-flow values. Except for the Toms River station, flow data generally were not available for dates and times of water-quality sample collection. For this reason, each water-quality sample for each station was assigned a flow condition (high or low) based on the corresponding flow condition at the Toms River gaging station for the same date. For each water-quality station, a median concentration during high flow (C_H) and a median concentration during low flow (C_L), in milligrams per liter, were determined from samples collected on the high- and low-flow dates, respectively (Table 1).

The 25th-percentile and 75th-percentile flow-duration values were determined for each water-quality station (Table 2), with the 25th-percentile flow-duration value representing high streamflow (F_H) and the 75th-percentile flow-duration value representing low streamflow (F_L), in cubic meters per second. At the Toms River near Toms River gaging station (01408500), F_H and F_L were estimated from flow-duration analyses using daily mean discharges for water years 1960-2008. Instantaneous measurements of streamflow available at partial-record stations within the watershed also were obtained from NWIS. These measurements were correlated to daily mean flow at continuous-record gaging stations using the Maintenance of Variance Extension Type 1 (MOVE1) method of correlation analysis (Hirsch, 1982) to estimate flow-duration statistics from nearby continuous-record gaging stations. At ungaged stations, a drainage-area adjustment from a nearby gaging station or a regional average of flow per square mile was used to estimate flow duration.

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[1] A water year is the 12-month period, October 1 through September 30. 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, 2008 is called the 2008 water year.

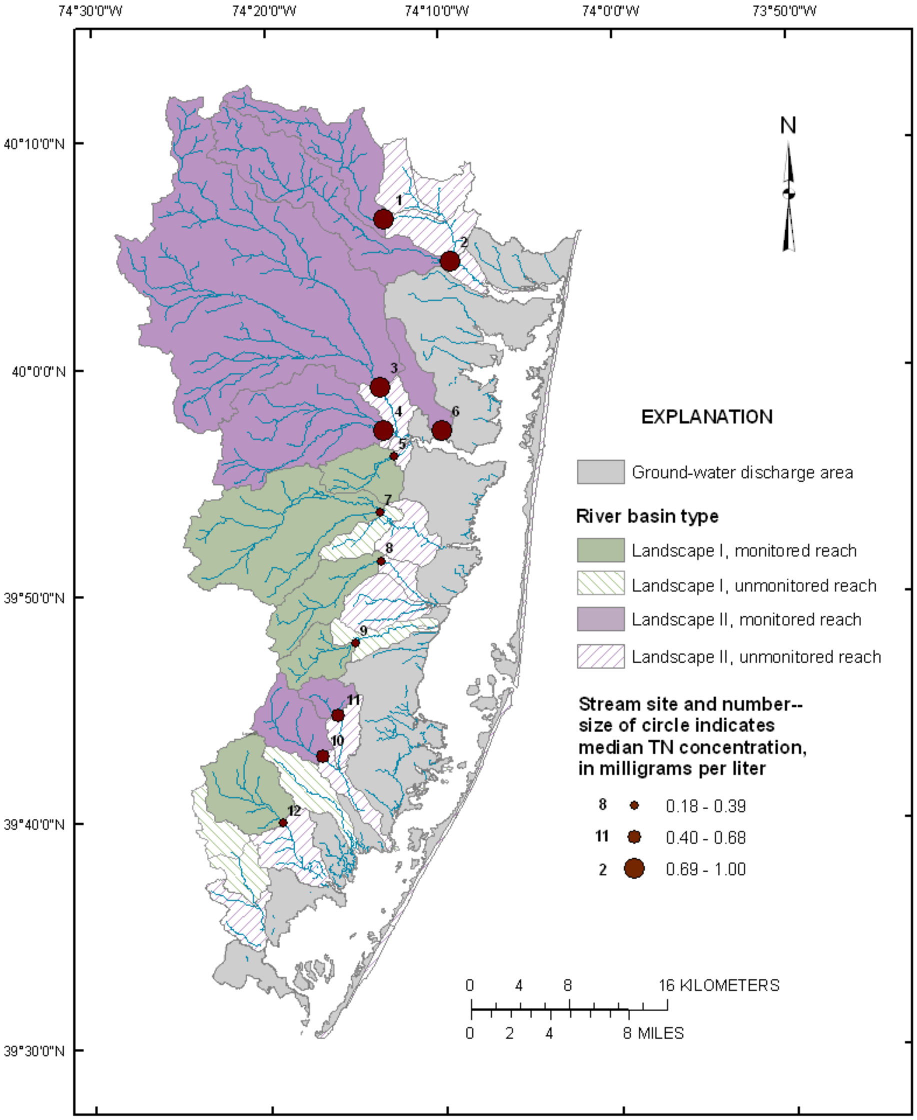

Figure 2. Median concentrations of total nitrogen (TN) at 12 stream sites in the Barnegat Bay-Little Egg Harbor watershed, water years 1987-2008. (Monitoring stations listed in Table 1.)

For each station, the nitrogen load (L_L) during low-flow conditions at 75^{th}-percentile flow duration was calculated as

L_L (kilograms per 6 months) = $C_L * F_L * Z$

and the nitrogen load (L_H) during high-flow conditions at 25^{th}-percentile flow duration was calculated as

L_H (kilograms per 6 months) = $C_H * F_H * Z$,

where Z is a unit conversion factor derived from the following equation:

$$Z = (60\ \text{s/min})(60\ \text{min/hr})(24\ \text{hr/day}) \times (183\ \text{days/6 months})(\text{kg}/10^6\ \text{mg}) \times (1{,}000\ \text{L/m}^3)$$
$$= 15{,}811.2\ (\text{s}\cdot\text{kg}\cdot\text{L})/(6\ \text{months}\cdot\text{mg}\cdot\text{m}^3)\ .$$

The annual load for each station was computed by summing the low-flow and high-flow loads:

Load (kilograms per year) = $L_L + L_H$.

Annual yields were then computed by dividing the annual loads for each station by the corresponding drainage area:

Yield (kilograms per year per square kilometer) = Load/Area .

Surface-water discharge, unmonitored reaches

Relations among hydrologic, water-quality, and land-use characteristics for the monitored portions of the BB-LEH watershed were used to calculate the nitrogen loads for areas for which hydrologic or water-quality data were not available. The 12 water-quality stations used to calculate the load for the monitored areas were grouped into one of two landscape types based on the percentage of urban land cover in each basin, as determined from a Geographic Information System (GIS) analysis of 2002 land-use/land-cover data (New Jersey Department of Environmental Protection, 2007). Five stations were designated as Landscape Type I (less than 10 percent urban land cover); 7 stations were designated as Landscape Type II (greater than 10 percent urban land cover). The average of the yields for each landscape type was calculated.

The landscape type also was determined for the unmonitored areas downstream from each sampling station, as well as for the Tuckerton Creek and Cedar Run watersheds, which are entirely unmonitored. To estimate load for the unmonitored regions, the average yield for each landscape type of the monitored regions was multiplied by the drainage area of the unmonitored regions of the same landscape type. The loads for the monitored and unmonitored areas of each river basin were summed; the resulting loads for 12 major river basins in the BB-LEH watershed are shown in Table 3. The yield represents the load per unit area; yields for each of the basins draining to the downstream-most stations are shown in Table 4. The yield to a specific station on a given river may differ from the yield over an entire basin, because water quality and land use can vary among the subbasins along the length of a stream.

Surface-water discharge median concentrations and loads of nitrogen species

Total nitrogen (TN) consists of ammonia, nitrate, nitrite, and organic forms. TN accounts for all dissolved and particulate forms of N transported by way of surface water, and is used to compute the surface-water contribution of the N load to the estuary. The distribution of the median concentration of TN at each of the downstream-most sampling stations is presented in Figure 2. The median value of a given N-containing constituent is not necessarily associated with the same sample as the median value of another N-containing constituent; for this reason, it is possible for the median TN concentration to be lower than the median concentration of another N-containing constituent.

In general, concentrations of TN were greater at Landscape II (developed) sites than at Landscape I (undeveloped) sites. At the Landscape I sites, the median TN concentration ranged from 0.17 to 0.41 mg/L, whereas at the Landscape II sites, the median TN concentration ranged from 0.39 to 1.2 mg/L. The median TN concentration (defined as the median of the median concentrations) among all water samples from Landscape II (developed) sites, 0.85 mg/L, was greater than the median TN concentration from Landscape I (undeveloped) sites, 0.26 mg/L.

High- and low-flow median TN concentrations were 0.23 and 0.28 mg/L, respectively, for Landscape I sites and 0.83 and 0.77 mg/L, respectively, for Landscape II sites (Table 1). The average yield of TN also was greater for Landscape II sites (378 $kg/km^2/yr$) than for Landscape I sites (188 $kg/km^2/yr$), with the highest yields in the Toms River, Metedeconk River, and Wrangel Brook basins (Table 4). The annual load of TN in surface-water discharge to the BB-LEH estuary was estimated to be 405,000 kg/yr (Table 3). The largest loads were from the Toms River basin (170,000 kg/yr, or 42 percent of the surface-water-discharge load to the estuary), the Metedeconk River basin (86,000 kg/yr, or 21 percent), and the Wrangel Brook basin (39,000 kg/yr, or 10 percent). Long Swamp Creek basin contributed the smallest TN load (1,700 kg/yr, or 0.4 percent) to the estuary.

The range of median concentrations of nitrate plus nitrite (NO_3^{2-}), like that of TN, was higher at Landscape II sites (0.09-0.64 mg/L) than at Landscape I sites (0.02-0.03 mg/L). Likewise, the median NO_3^{2-} concentrations during high and low flows were 0.02 and 0.03 mg/L, respectively, at Landscape I sites and 0.40 and 0.45 mg/L, respectively, at Landscape II sites (Table 1). The fact that concentrations were larger during low flow than high flow indicates that ground-water discharge to the streams is likely an important source of NO_3^{2-} to the estuary. The average yield also was greater for Landscape II sites (196 $kg/km^2/yr$) than for Landscape I sites (19 $kg/km^2/yr$) (Table 4). The annual load of NO_3^{2-} to the BB-LEH estuary from surface-water discharge was estimated to be 187,000 kg/yr (Table 3). The largest loads were from the Toms River (78,000 kg/yr), Metedeconk River (50,000 kg/yr), and Wrangel Brook (29,000 kg/yr) basins.

The median concentration of total ammonia plus organic nitrogen (TAON) ranged from 0.19 to 0.37 mg/L at Landscape I sites, and from 0.18 to 0.62 mg/L at Landscape II sites. The median TAON concentrations during high and low flows were 0.31 and 0.23 mg/L, respectively, at Landscape I sites and 0.35 and 0.24 mg/L, respectively, at Landscape II sites (Table 1). The fact that concentrations were larger during high flow than low flow indicates that storm runoff is likely an important source of TAON to the estuary (Hunchak-Kariouk and Nicholson, 2001). The average yield of TAON, unlike those of TN and NO_3^{2-}, was slightly greater for Landscape I sites (196 $kg/km^2/yr$) than for Landscape II sites (180 $kg/km^2/yr$) (Table 4). The annual load of TAON in surface-water discharge to the estuary was estimated to be 204,000 kg/yr (Table 3). The largest loads were from the Toms River (68,000 kg/yr), Metedeconk River (32,000 kg/yr), and Cedar Creek (28,000 kg/yr) basins, and the smallest load was from the Long Swamp Creek basin (960 kg/yr).

The median concentration of ammonia (NH_3) ranged from 0.05 to 0.08 mg/L at Landscape I sites and from 0.02 to 0.47 mg/L at Landscape II sites. The median NH_3 concentration for both high and low flows was 0.05 mg/L at Landscape I sites and 0.08 mg/L at Landscape II sites (Table 1). The average yield of NH_3 was 43 $kg/km^2/yr$ at Landscape I sites and 62 $kg/km^2/yr$ at Landscape II sites (Table 4). The annual load of NH_3 in surface-water discharge to the estuary was estimated to be 62,000 kg/yr (Table 3), with the largest loads contributed by the Toms River (27,000 kg/yr), Metedeconk River (7,600 kg/yr), and Mill Creek (7,900 kg/yr) basins. Particularly high concentrations and yields of NH_3 at the Mill Creek station (01409150) may be explained by the presence of a nearby landfill that operated until 1983 and remained uncapped for more than 15 years (Robert Schuster, New Jersey Department of Environmental Protection, written commun., 2009).

In summary, the annual load of nitrogen to the BB-LEH estuary from surface-water discharge is estimated to be 405,000 kg/yr (Table 3). For each of the nitrogen species examined, the Toms River and Metedeconk River basins contributed the largest loads. Concentrations and yields of TN and NO_3^{2-} appear to be higher in developed areas (greater than 10 percent urban land cover) than in undeveloped areas (less the 10 percent urban land cover).

Direct storm runoff

The nitrogen load from storm runoff was estimated in the ground-water discharge area (Figure 1). The contribution of nitrogen from storm runoff that discharges directly to the estuary had not been previously calculated, but was calculated as part of this updated loading estimate, and is in addition to the nitrogen accounted for in the surface-water discharge estimate described earlier. In a previous investigation by Baker and Hunchak-Kariouk (2006), stormwater quality in four tributaries to Toms River was characterized through extensive sampling and base-flow separation, such that the entire stormflow contribution of each species of nitrogen (TN, NO_3^{2-}, ON, and NH_3) was computed for each of the four tributaries and related to land use. Linear regression was used to establish relations between percent urban development and stormflow loading of N for the Long Swamp Creek and Davenport Branch (a tributary to Wrangel Brook) basins (Table 5). The regression equation from the previous study was used along with the percentage of urban development in each of the basins in the ground-water discharge area of the BB-LEH watershed to calculate the direct stormwater nitrogen load to the BB-LEH estuary. The annual loads of TN, NO_3^{2-}, TAON, and NH_3 to the BB-LEH estuary from storm runoff that discharges directly to the estuary are 26,000, 7,800, 18,000, and 3,700 kg/yr, respectively (Table 3). The total surface-water contribution of N to the estuary is the sum of the load from surface-water discharge (405,000 kg/yr) and direct storm runoff (26,000 kg/yr); therefore, the total surface-water load is 431,000 kg/yr.

Direct ground-water discharge

Shallow ground water contributes nitrogen to the Barnegat Bay-Little Egg Harbor estuary both indirectly through ground-water discharge to streams that discharge into the estuary, and directly through ground-water discharge to the estuary and adjacent coastal wetlands (Hunchak-Kariouk and Nicholson, 2001). The surface-water nitrogen loads described previously account for most of the indirect ground-water discharge that enters the streams as base flow and is eventually delivered to the estuary. The nitrogen load from ground water that discharges directly to the estuary and adjacent coastal wetlands or to small unnamed tributaries near the coast was estimated using the following equation:

$L_g = Q \times C \times A$,

where

L_g = nitrogen loading from direct ground-water discharge to the estuary, in kg/yr ;

Q = simulated mean ground-water discharge to the estuary, in m^3/s ;

C = a representative nitrogen concentration in shallow ground water that discharges to the estuary, in mg/L ; and
A = a unit conversion factor derived from the following equation:
= (60 s/min)(60 min/hr)(24 hr/day) x (365 days/yr)(kg/10^6 mg) x (1,000 L/m^3)
= 31,536 (s·kg·L)/(yr·mg·m^3) .

The contributing ground-water discharge area is shown in Figure 3. Using a ground-water-flow model developed for the Barnegat Bay watershed area, a mean discharge of 3.37 m^3/s (119 ft^3/s) was computed for this area, based on a simulation of average hydrologic conditions during calendar years 2000-03 (Stephen Cauller, U.S. Geological Survey, written commun., 2009). This discharge value represents an estimate of ground-water discharge from the source area, and is nearly 10 percent higher than the previous estimate (3.06 m^3/s, or 108 ft^3/s) used by Hunchak-Kariouk and Nicholson (2001).

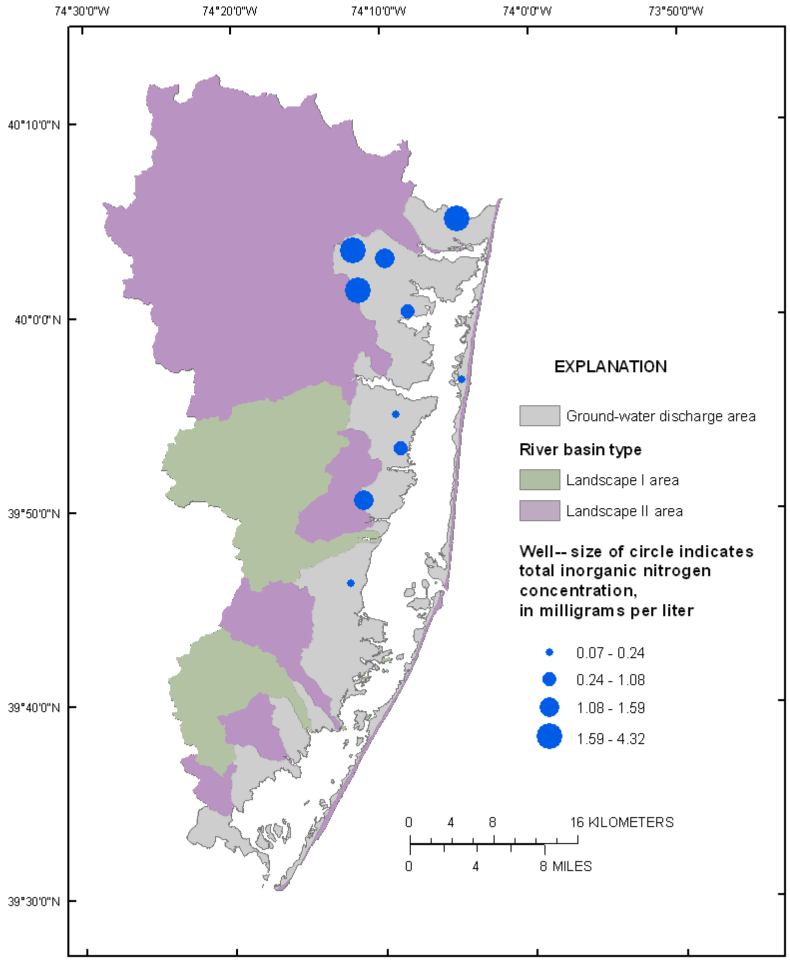

Figure 3. Concentrations of total inorganic nitrogen in samples from shallow wells in the ground-water discharge area in the Barnegat Bay-Little Egg Harbor watershed, water years 1997-2006.

Concentrations of total inorganic nitrogen (nitrate plus nitrite (NO_3^{2-}) and ammonia (NH_3)) were used to determine a representative concentration in the source area; organic species of N were not present at detectable concentrations in the ground-water samples considered here. The median concentration of inorganic nitrogen in water-quality samples from 10 wells less than 61 m (200 ft) deep (Figure 3) within the ground-water discharge area collected during water years 1997-2006 was 1.23 mg/L, more than 95 percent of which is in the form of nitrate. (In the previous investigation, a median NO_3^{2-} concentration of 1.5 mg/L was used.) Although data were available for a total of 17 wells, there were five clusters in which wells were located less than 1.6 km (1 mi) apart. To reduce spatial bias, the most recent value for each of these clusters was used to calculate the median. Using the above equation, the gross estimated N loading to the estuary from ground water is 130,700 kg/yr. This gross, or potential, loading estimate was reduced by 40 percent to account for nitrate losses from subsurface denitrification and in-stream processes (Kauffman and others, 2001; Hunchak-Kariouk and Nicholson, 2001), such that the net N loading to the estuary from ground water is 78,000 kg/yr.

Atmospheric deposition

A number of studies have indicated that atmospheric deposition of N may contribute a large fraction of the total nitrogen load to BB-LEH and other coastal water bodies (Castro and others, 2003; Castro and Driscoll, 2002; Valigura and others, 2001; Hunchak-Kariouk and Nicholson, 2001; Jaworski and others, 1997). Atmospherically deposited N is derived from a number of sources, including automobile emissions, industrial emissions, natural N-fixation processes, and emissions from agricultural sources, including fertilizer application and animal waste (Castro and others, 2003; Gao and others, 2007). Atmospheric deposition of N can occur as N dissolved in precipitation (wet deposition) or through the settling of N-containing gases and particulates in the absence of precipitation (dry deposition) (Gao and others, 2007; Paerl and others, 2002). Estimation of the N load from direct atmospheric deposition to the estuary surface is described below. N that is atmospherically deposited in the watershed and then transported to the BB-LEH estuary through surface-water discharge, direct storm runoff, or ground-water discharge is not included because it is accounted for in the surface-water and ground-water load calculations.

The contribution of wet and dry atmospheric deposition to the nitrogen load to BB-LEH estuary was estimated by using wet-deposition data from the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) and dry-deposition data from the U.S. Environmental Protection Agency's (USEPA) Clean Air Status and Trends Network (CASTNET). A total wet-deposition rate of 4.86 kg N/ha/yr for the Barnegat Bay watershed was estimated based on wet-deposition data collected at the NADP/NTN monitoring site located in the Edwin B. Forsythe Wildlife Refuge during 2000-06 (National Atmospheric Deposition Program, 2009), and following the calculation methods of Meyers and others (2001). The total wet-deposition rate represents the sum of the wet-deposition rates for ammonium, NH_4^+ (1.62 kg N/ha/yr); nitrate, NO_3^- (2.27 kg N/ha/yr); and organic N (0.97 kg N/ha/yr). Dry-deposition rates for the watershed were estimated based on a median wet-to-dry N deposition ratio of roughly 2:1

calculated for a suite of N-deposition monitoring sites along the Eastern Seaboard (U.S. Environmental Protection Agency, 2009). Dry-deposition rates for the watershed are 1.46 kg N/ha/yr for NO_3^- and 0.86 kg N/ha/yr for $NH_4^+ + NH_3$, for a total dry-deposition rate of 2.32 kg N/ha/yr. The total wet-plus-dry deposition rate of 7.18 kg N/ha/yr represents the deposition rate to the land-mass portion of the watershed; however, the rate of deposition to open estuarine and coastal water surfaces is lower than the rate of deposition to land surfaces (Paerl and others, 2001). To account for the lower delivery efficiency over water surfaces, the total wet-plus-dry deposition rate of 7.18 kg N/ha/yr was reduced by approximately 30 percent (Meyers and others, 2001) to 5.06 kg N/ha/yr. This deposition rate, applied over the 27,900-ha water surface of Barnegat Bay and Little Egg Harbor, equals approximately 141,000 kg N/yr, which represents the N load from direct atmospheric deposition to the estuary.

Total Load

Based on all data evaluated in this investigation, the combined total nitrogen load to the BB-LEH estuary is estimated to be 650,000 kg N/yr. Of this amount, surface water contributes 66 percent (431,000 kg N/yr) of the total N load, direct ground-water discharge accounts for 12 percent (78,000 kg N/yr), and atmospheric deposition accounts for 22 percent (141,000 kg N/yr) (Figure 4). This updated total N load is 10 percent lower than the previous estimate of 720,000 kg N/yr (Hunchak-Kariouk and Nicholson, 2001).

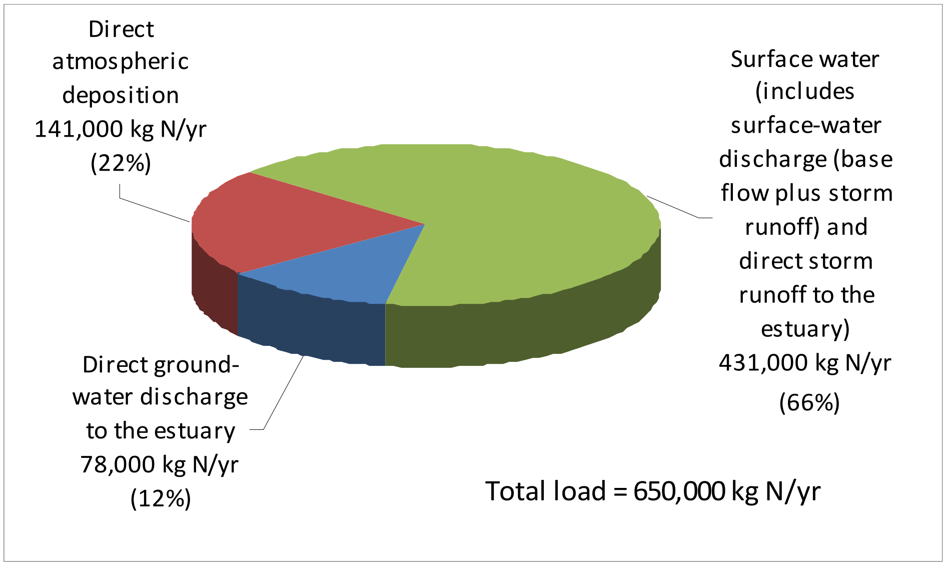

Figure 4. Relative contributions of nitrogen loads to the Barnegat Bay-Little Egg Harbor estuary from surface water, ground water, and atmospheric deposition. (kg N/yr, kilograms of nitrogen per year.)

Comparison of Current and Previously Published Nitrogen Loads

Surface water

The load of 405,000 kg N/yr from surface-water discharge (excluding direct storm runoff) to the estuary is 4 percent higher than the previous estimate of 390,000 kg/yr (Hunchak-Kariouk and Nicholson, 2001). In some cases, the updated estimate of TN load was higher for particular river basins (for example, the Toms River, Metedeconk River, and Westecunk Creek basins) and in other cases, the updated estimate of TN load was lower (Oyster Creek, Cedar Creek, and Tuckerton Creek basins) than the previous estimate. One reason for the differences is that more recent data affected the median concentration used in the loading calculation. Another factor may be variability in the methods used to calculate certain parameters; for example, decisions about stations to include in the correlation analysis used to obtain flow-duration values are subjective. Also, a slightly different approach for assessing Landscape Type was used—in this study, only the downstream-most stations were used to determine the median concentration for each landscape type; in the previous study, water-quality data from multiple stations in many basins were used to compute median concentrations.

The Toms River basin is by far the most comprehensively monitored basin in the BB-LEH watershed. It is also the largest basin in the watershed and contributes the largest TN load (though not necessarily the highest yield) to the estuary. For this reason, it is particularly important to examine changes in load for the Toms River basin. Based on the previous study, the TN load from the Toms River basin was estimated to be 150,000 kg/yr, whereas the updated estimate is 170,000 kg/yr. The fact that both long-term streamflow and water-quality data from the Toms River station were available for both studies suggests that the load has increased in recent years, and that the difference is not attributable to differences in calculation methods. Furthermore, no significant trends were detected in streamflow at the Toms River near Toms River gaging station from 1966 to 2001 (Watson and others, 2005), indicating that increased TN loads in this basin are due to increases in nitrogen concentrations, not streamflow. The recent increase in urban development in the basin is a likely factor in the increase in TN.

The updated load for the Metedeconk River basin incorporated streamflow and water-quality data collected at stations on both the North Branch and South Branch Metedeconk stems. These data were not available at the time of the previous investigation, resulting in an entirely estimated load for the basin. The TN load for the Metedeconk River basin from the previous loading estimate was 77,000 kg/yr (19.7 percent of the surface-water-discharge load); the updated estimate is 86,000 kg/yr (21.2 percent). This increase may be a reflection of more complete water-quality data, increased urban development in the basin, or both. The estimated NO_3^{2-} load increased from 28,000 to 50,000 kg/yr—the largest change in load of all constituents for all basins, most likely a reflection of improved data contributing to a more accurate estimate.

The median concentrations of some constituents under certain flow conditions varied from the estimate of Hunchak-Kariouk and Nicholson (2001) (Table 1). For Landscape Type I sites, the median concentration varied little from the previous estimate with the exception of the TN concentration during high flow conditions. For Landscape Type II sites, the median TN and NO_3^{2-} concentrations were consistently higher in the updated estimate (with the exception of the TN concentration during low flow, which was lower). The median NH_3 concentration was higher during high and low flows. However, when sites that were included in the previous estimate but not in the updated estimate are excluded from the previous estimate as well, the updated median concentration is lower. The median TAON concentration was lower in the updated estimate under all flow conditions. Much of the change in estimated median concentrations in the Landscape II sites can be attributed to the inclusion of data from the North Branch and South Branch Metedeconk stations in the analysis, as well as more recent data for Toms River.

Although the N load from surface-water discharge increased by 4 percent, the overall contribution of surface water to the total N load increased from 54 percent to 66 percent. Much of this increase can be explained by the inclusion of direct storm runoff in the updated surface-water load, and a substantial decrease in the loads contributed by direct ground-water discharge and atmospheric deposition.

Direct ground-water discharge

The updated N load of 78,000 kg/yr from direct ground-water discharge to the estuary is 12 percent lower than the previous estimate of 89,000 kg/yr (Hunchak-Kariouk and Nicholson, 2001). Although the estimated rate of direct ground-water discharge to the estuary was nearly 10 percent higher than that used in the previous study, the median concentration of inorganic nitrogen in wells sampled in the ground-water discharge area was lower by an even greater percentage. However, because the sample size (represented by the number of wells included in the analysis) is so small, a statistically meaningful assessment of trends is not possible and a lower median concentration does not necessarily reflect a downward trend in concentrations. The overall contribution of direct ground-water discharge to the total N load to the estuary remained constant at approximately 12 percent.

Atmospheric deposition

In this study, the N load to the estuary from atmospheric deposition is estimated to be 141,000 kg/yr—roughly 42 percent lower than the previous estimate of 242,000 kg/yr (Hunchak-Kariouk and Nicholson, 2001). Much of the difference can be attributed to lower deposition rates at the Edwin B. Forsythe Wildlife Refuge (EWR) station than at the Washington Crossing station, which was used in the previous estimate. For example, from 2000-06, the average wet-deposition rate for NO_3^- at the EWR station was 2.27 kg N/yr, which is 34 percent lower than the rate at Washington Crossing (3.42 kg N/yr). For the same years, the average wet-deposition rate for NH_4^+ was lower at EWR by 38 percent. A similar comparison was not made for dry-deposition rates because these data were not available for both stations. The atmospheric-data-collection station at EWR was installed after the previous loading estimate was made; data from this station are likely to be more representative of conditions affecting the estuary both because of its proximity to the estuary and its location (near the coast rather than inland).

Another factor contributing to the lower atmospheric-deposition estimate is a regional downward trend in the deposition rate of certain atmospheric contaminants, including NO_3^-. For example, over the period 1982-96 (used for the previous estimate), the average wet-deposition rate for NO_3^- at Washington Crossing was 3.78 kg N/yr, whereas for the more recent period (1997-2006), it was 3.36 kg N/yr, which is 11 percent lower. Analyses of both wet-deposition data collected through the NADP/NTN network and dry-deposition data from CASTNET have revealed a downward trend in NO_3^- deposition in the northeastern United States over the past 20 to 25 years (Lehmann and others, 2005; U.S. Environmental Protection Agency, 2007). Similarly, a recent report on national air-quality status and trends cites a regional downward trend in NO_3^- deposition, marked by a 30-percent decrease in the mid-Atlantic and Northeast, from 1989-91 to 2005-07 (U.S. Environmental Protection Agency, 2008).

Information Gaps

The lack of hydrologic, surface-water-quality, or ground-water-quality data for substantial areas of the watershed and estuary is considered to be a data gap. As shown in Figure 3, ground-water-quality data are greatly limited, particularly in the southern portion of the watershed. New Jersey’s Private Well Testing Act (PWTA) (Public Law 2001, chapter 40 (C. 58:12A-26), approved on March 23, 2001) requires that water from certain private drinking-water wells be analyzed for constituents (including nitrate) in association with certain real-estate transactions. The resulting database is a potential source of ground-water-quality data throughout the study area, including the ground-water discharge area. At the time of this study, however, PWTA data were not readily available. Analyzing water samples from a large set of shallow domestic wells randomly distributed throughout the ground-water discharge area would likely improve the accuracy of the direct ground-water discharge portion of the loading estimate.

In terms of surface-water data, the southern portion of the watershed lacks recent water-quality samples. By the criteria used for this analysis (at least 3 years of N data for water years 1987-2008), Tuckerton Creek and Cedar Run are considered completely unmonitored, and the most recent water-quality data used to compute loading estimates for Westecunk Creek, Mill Creek, Oyster Creek, Forked River, Cedar Creek, and Jakes Branch basins are from a water-quality sampling effort that ended in 1996. More recent surface- and ground-water-quality data are needed to update loading estimates in the southern portion of the BB-LEH watershed for future studies, particularly in areas such as the Mill Creek basin that have experienced a substantial increase in urban development in recent years.

Because streamflow data at many of the water-quality stations are limited, this study relied on a coarse separation of high- and low-flow concentrations based on flow conditions at Toms River. However, comprehensive studies of the largest streams within the study area during all seasons and at all discharge levels (base flow and stormflow) would be useful to more accurately determine base-flow and stormflow loads at water-quality stations that are infrequently monitored.

Dry-atmospheric-deposition data represent another information gap. As indicated by this study, the difference in wet-deposition rates between the stations at Washington Crossing and EWR is large; however, the nearest dry-deposition station currently is at Washington Crossing. Long-term collection of dry-deposition data within, or in close proximity to, the watershed is needed to more accurately assess dry-deposition rates along the coast, and to assess temporal trends. Additionally, data from an air-deposition monitoring site in the northern part of the watershed would be useful to evaluate local differences in deposition rates between the northern and southern parts of the watershed.

Another potential source of N to the BB-LEH estuary for which only limited information is available is the ocean water that enters the estuary through ocean circulation and tidal influx. Monitoring the amount of N that enters the estuary through Barnegat Inlet, Little Egg Inlet, and the Point Pleasant Canal would help to assess the contribution of ocean water to the total N load to the estuary.

Additionally, analysis of nitrogen and oxygen isotope ratios, in conjunction with other information such as current and historical land use, can improve understanding of sources of nitrogen in environmental samples. For example, results of a study in the Coastal Plain of New Jersey that examined ratios of stable isotopes of nitrogen in 12 water samples indicate that the source of nitrate in ground water from wells in agricultural areas was predominantly chemical fertilizers rather than livestock waste or septic-system effluent (Vowinkel and Tapper, 1995). Future ground-water-monitoring efforts within the BB-LEH watershed could include nitrogen and oxygen isotope analyses to help identify the sources of nitrogen--humans, animals, the atmosphere, or inorganic fertilizers (Kendall, 1998).

Links to Other Information Sources

Streamflow, ground-water-quality, and surface-water-quality data collected throughout the nation by the U.S. Geological Survey (USGS) are available through the USGS's National Water Information Service Web interface (NWISWeb) at http://waterdata.usgs.gov/nwis/qw.

The National Atmospheric Deposition Program/National Trends Network (NADP/NTN) is a long-term, nationwide network of precipitation-chemistry monitoring sites and is a primary source for wet-deposition data; these data are available at http://nadp.sws.uiuc.edu/.

The USEPA's Clean Air Status and Trends Network (CASTNET) is a long-term monitoring network for measuring concentrations of contaminants involved in acid deposition, and is a primary source for dry-deposition data; these data are available at http://www.epa.gov/castnet/.

Table 1. Median concentrations of nutrients during all, high, and low flows at selected downstream-most stations in the Barnegat Bay-Little Egg Harbor watershed, water years 1987-2008.

[USGS, U.S. Geological Survey; --, not available; TN, total nitrogen; NO_3^{2-}, nitrate plus nitrite; TAON, total ammonia plus organic nitrogen; NH_3, ammonia; locations of monitoring stations are shown in Figure 2]

Site number	USGS station number	Pinelands Commission station number	River	Median concentration during all flows (milligrams per liter)				C_H, median concentration during high flows (milligrams per liter)				C_L, median concentration during low flows (milligrams per liter)			
				TN	NO_3^{2-}	TAON	NH_3	TN	NO_3^{2-}	TAON	NH_3	TN	NO_3^{2-}	TAON	NH_3
Landscape I, sites with less than 10 percent urban land cover															
5	01408710	OCN032	Jakes Branch[1]	0.29	0.02	0.28	0.05	0.32	0.02	0.31	0.07	0.28	0.03	0.26	0.05
7	--	OCN044	Cedar Creek[1]	0.26	0.02	0.25	0.05	0.23	0.02	0.37	0.05	0.29	0.02	0.23	0.08
8	--	PFR4A	North Branch Forked River[1]	0.22	0.02	0.23	0.05	0.22	0.03	0.20	0.05	0.22	0.02	0.23	0.05
9	01409095	OCN051	Oyster Creek[1]	0.18	0.03	0.21	0.05	0.19	0.03	0.24	0.05	0.17	0.03	0.19	0.06
12	01409280	OCN059	Westecunk Creek[1]	0.39	0.02	0.25	0.05	0.41	0.02	0.37	0.07	0.29	0.03	0.20	0.05
Median concentration at all Landscape I sites[2]				0.26	0.02	0.25	0.05	0.23	0.02	0.31	0.05	0.28	0.03	0.23	0.05
Median concentration at all Landscape I sites (previous estimate)[2,3]				0.27	0.02	0.25	0.05	0.30	0.02	0.30	0.05	0.29	0.03	0.23	0.05
Landscape II, sites with greater than 10 percent urban land cover															
1	01408100	--	North Branch Metedeconk River	0.87	0.49	0.29	0.04	0.86	0.44	0.31	0.04	0.91	0.54	0.22	0.04
2	01408152	--	South Branch Metedeconk River	0.86	0.50	0.24	0.05	0.94	0.64	0.35	0.08	0.76	0.45	0.24	0.04
3	01408500	--	Toms River	1.00	0.51	0.40	0.17	0.83	0.34	0.36	0.13	1.20	0.63	0.42	0.20
4	01408640	--	Wrangel Brook	0.75	0.56	0.23	0.02	0.72	0.53	0.28	0.02	0.77	0.57	0.23	0.02
6	01408728	--	Long Swamp Creek	0.85	0.39	0.45	0.13	0.89	0.40	0.52	0.14	0.82	0.38	0.42	0.10
10	01409150	OCN054	Mill Creek[1]	0.62	0.09	0.55	0.39	0.6	0.09	0.62	0.31	0.62	0.09	0.55	0.47
11	--	PM16	Fourmile Branch[1]	0.45	0.25	0.32	0.05	0.54	0.27	0.33	0.05	0.39	0.25	0.18	0.08
Median concentration at all Landscape II sites[2]				0.85	0.49	0.32	0.05	0.83	0.40	0.35	0.08	0.77	0.45	0.24	0.08
Median concentration at all Landscape II sites (previous estimate)[2,3]				0.80	0.36	0.40	0.05	0.71	0.27	0.40	0.05	0.79	0.42	0.31	0.05

[1] Values from previous study (Hunchak-Kariouk and Nicholson, 2001) are shown here; no new data (1998-2008) are available for these sites.

[2] Median here is defined as the median of the median concentrations.

[3] The median concentrations from the previous estimate (Hunchak-Kariouk and Nicholson, 2001) include data from multiple stations within many basins.

Table 2. Low and high streamflow for selected downstream-most stations in the Barnegat Bay-Little Egg Harbor watershed.

[USGS, U.S. Geological Survey; --, not available; C, continuous-record; P, partial-record; U, ungaged; F_L, low streamflow; F_H, high streamflow]

Site number	USGS Station number	Pinelands Commission station number	Landscape type	River	Drainage area (square kilometers)	Discharge station type	F_L (cubic meters per second)	F_H (cubic meters per second
1	01408100	--	II	North Branch Metedeconk River	50.2	P	0.43	1.15
2	01408152	--	II	South Branch Metedeconk River	79.6	P	1.01	2.05
3	01408500	--	II	Toms River	319.4	C	3.66	7.31
4	01408640	--	II	Wrangel Brook	87.8	U	1.18	2.14
5	01408710	OCN032	I	Jakes Branch	22.5	U	0.29	0.60
6	01408728	--	II	Long Swamp Creek	17.4	P	0.02	0.11
7	--	OCN044	I	Cedar Creek	106.7	U	1.62	2.72
8	--	PFR4A	I	North Branch Forked River	34.1	U	0.30	0.63
9	01409095	OCN051	I	Oyster Creek	19.4	P	0.59	0.92
10	01409150	OCN054	II	Mill Creek	26.8	P	0.43	0.62
11	--	PM16	II	Fourmile Branch	10.5	U	0.10	0.23
12	01409280	OCN059	I	Westecunk Creek	41.0	P	0.69	1.21

Table 3. Loads of selected nutrients in major river basins of the Barnegat Bay-Little Egg Harbor watershed, water years 1987-2008.

[USGS, U.S. Geological Survey; TN, total nitrogen; NO_3^{2-}, nitrate plus nitrite; TAON, total ammonia plus organic nitrogen; NH_3, ammonia]

		Load (kilograms per year (percentage of surface-water discharge load))				
Major river basin	Area (square kilometers)	TN		NO_3^{2-}	TAON	NH_3
Metedeconk River[1]	185.6	86,000	(21.2)	50,000	32,000	7,600
Toms River	332.5	170,000	(42.0)	78,000	68,000	27,000
Wrangel Brook	89.3	39,000	(9.6)	29,000	14,000	1,200
Long Swamp Creek	17.4	1,700	(0.4)	760	960	260
Jakes Branch	24.8	5,200	(1.3)	780	4,500	1,000
Cedar Creek	137.3	26,000	(6.4)	5,100	28,000	5,900
Forked River	62.6	14,000	(3.5)	6,000	8,200	2,500
Oyster Creek	33.3	7,000	(1.7)	980	8,000	1,900
Mill Creek[2]	59.2	21,000	(5.2)	7,200	15,000	7,900
Cedar Run[3]	21.4	4,000	(1.0)	400	4,200	910
Westecunk Creek	64.3	20,000	(4.9)	5,300	13,000	3,300
Tuckerton Creek[3]	41.2	11,000	(2.7)	3,500	7,800	2,100
All major river basins	1,069	405,000		187,000	204,000	62,000
Direct storm runoff from ground-water-discharge area	355	26,000		7,800	18,000	3,700
Entire watershed	1,424	431,000		194,800	222,000	65,700

[1] Values for the Metedeconk River basin include data for both North and South branches of the Metedeconk River, as shown in Tables 1 and 4.

[2] Values for the Mill Creek basin include data for both Mill Creek and Fourmile Branch, as shown in Tables 1 and 4.

[3] Water-quality data were not available for these subwatersheds; concentrations used in the load calculation were estimated from land-use patterns.

Table 4. Yields of nutrients for the drainage area of selected downstream-most stations in the Barnegat Bay-Little Egg Harbor watershed, water years 1987-2008.

[USGS, U.S. Geological Survey; TN, total nitrogen; NO_3^{2-}, nitrate plus nitrite; TAON, total ammonia plus organic nitrogen; NH_3, ammonia]

Site number	USGS station number	Pinelands Commission station number	River	Yield (kilograms per square kilometer per year)			
				TN	NO_3^{2-}	TAON	NH_3
Landscape I, sites with less than 10 percent urban land cover							
5	01408710	OCN032	Jakes Branch	191.2	14.5	183.2	39.6
7	--	OCN044	Cedar Creek	162.6	12.9	204.9	39.4
8	--	PFR4A	North Branch Forked River	94.8	11.6	90.4	21.5
9	01409095	OCN051	Oyster Creek	224.5	37.0	272.2	66.4
12	01409280	OCN059	Westecunk Creek	268.3	17.3	225.9	46
Average yield at all Landscape I sites				188.3	18.7	195.3	42.6
Landscape II, sites with greater than 10 percent urban land cover							
1	01408100	--	North Branch Metedeconk River	434.8	232.5	142.2	19.9
2	01408152	--	South Branch Metedeconk River	535.5	348.1	189	39.9
3	01408500	--	Toms River	518.0	237.3	205.9	83.3
4	01408640	--	Wrangel Brook	441.3	328.2	157.1	12.8
6	01408728	--	Long Swamp Creek	96.1	43.5	55.3	15.1
10	01409150	OCN054	Mill Creek	378.0	55.9	368.1	233.5
11	--	PM16	Fourmile Branch	243.0	129.5	140.2	28.9
Average yield at all Landscape II sites				378.1	196.4	179.7	61.9

Table 5. Yields of selected nutrients in stormwater for two tributaries to the Toms River, New Jersey.

[USGS, U.S. Geological Survey; TN, total nitrogen; NO_3^{2-}, nitrate plus nitrite; ON, organic nitrogen; NH_3, ammonia]

USGS station number	Stream	Drainage area (square kilometers)	Percent urban land use	Yield (kilograms per square kilometer per year)			
				TN	NO_3^{2-}	ON	NH_3
01408728	Long Swamp Creek	16.91	67	111.88	35.45	66.19	20.08
01408620	Davenport Branch	19.19	22	32.16	12.08	21.26	2.73

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