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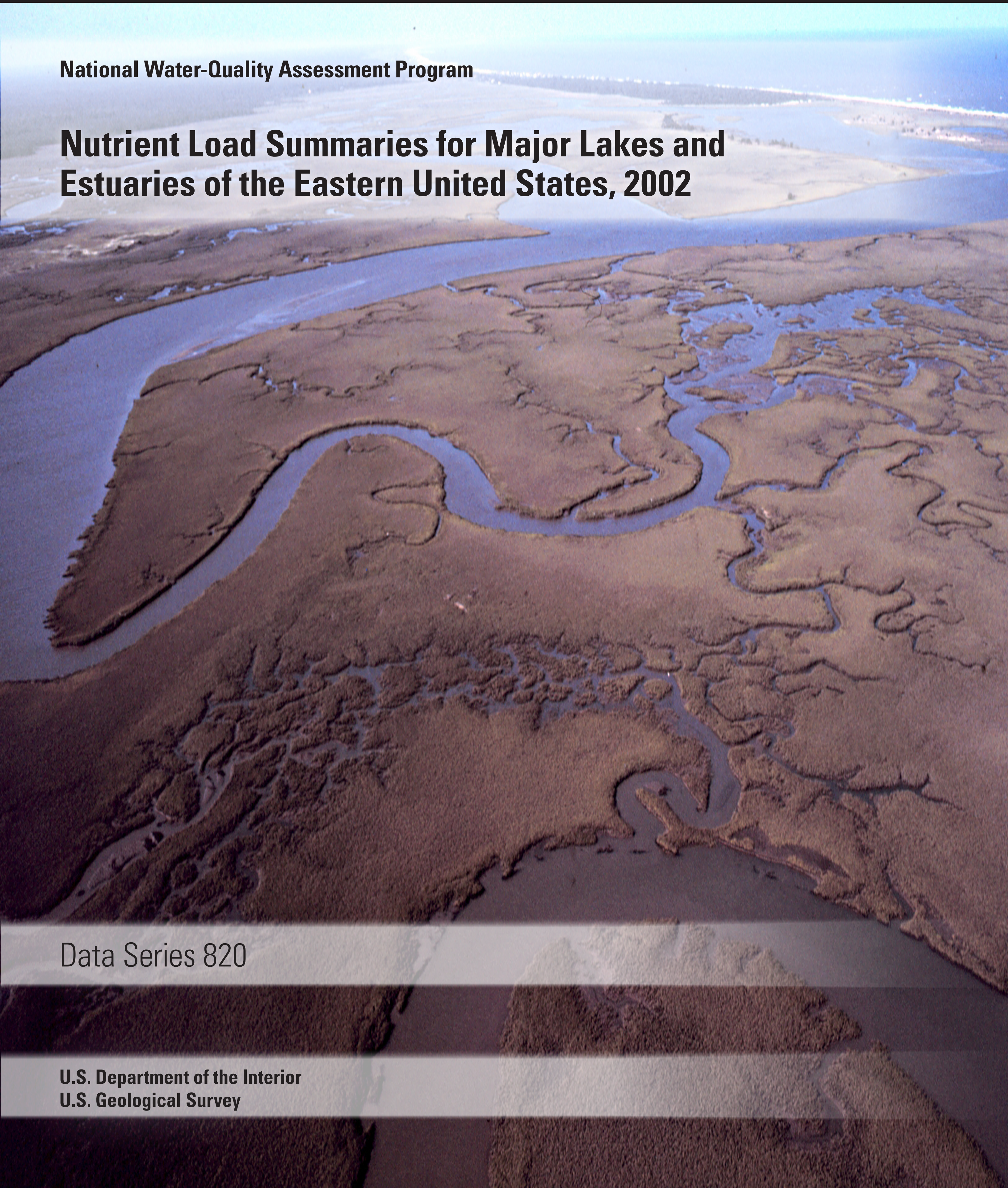
Nutrient Load Summaries for Major Lakes and Estuaries of the Eastern United States, 2002



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Cover photograph. Aerial view of meandering tidal creeks and extensive pristine marshes in North Inlet estuary, Winyah Bay National Estuarine Research Reserve, near Georgetown, South Carolina (NOAA Photo Library, National Oceanic and Atmospheric Administration/ Department of Commerce).

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

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Suggested citation:
Moorman, M.C., Hoos, A.B., Bricker, S.B., Moore, R.B., García, A.M., and Ator, S.W., 2014, Nutrient load summaries for major lakes and estuaries of the Eastern United States, 2002: U.S. Geological Survey Data Series 820, 94 p., *http://dx.doi.org/10.3133/ds820*.

ISSN 2327-638X (online)

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
Length		
meter	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square kilometer (km^2)	0.3861	square mile (mi^2)
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
Flow rate		
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
Mass		
kilogram (kg)	2.205	pound avoirdupois (lb)
milligram (mg)	35.27	ounce, avoirdupois (oz)
megagram (Mg)	1.102	ton, short (2,000 lb)
Nitrogen or phosphorus yield		
kilograms per square kilometer per year ($kg/km^2/yr$)	82.64	pounds per acre per year (lb/ac/yr)
kilograms per square kilometer per year ($kg/km^2/yr$)	0.01	kilograms per hectare per year (kg/ha/yr)

Abbreviations

NAWQA	National Water-Quality Assessment Program
NHD	National Hydrography Dataset
NHDWaterbody	Geopatial data file of waterbody features (lakes, ponds, reservoirs, swamps, etc.) from the National Hydrography Dataset
SPARROW	Spatially Referenced Regression on Watershed attributes
TN	total nitrogen
TP	total phosphorus

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By Michelle C. Moorman,[1] Anne B. Hoos,[1] Suzanne B. Bricker,[2] Richard B. Moore,[1] Ana María García,[1] and Scott W. Ator[1]

Abstract

Nutrient enrichment of lakes and estuaries across the Nation is widespread. Nutrient enrichment can stimulate excessive plant and algal growth and cause a number of undesirable effects that impair aquatic life and recreational activities and can also result in economic effects. Understanding the amount of nutrients entering lakes and estuaries, the physical characteristics affecting the nutrient processing within these receiving waterbodies, and the natural and manmade sources of nutrients is fundamental to the development of effective nutrient reduction strategies. To improve this understanding, sources and stream transport of nutrients to 255 major lakes and 64 estuaries in the Eastern United States were estimated using Spatially Referenced Regression on Watershed attributes (SPARROW) nutrient models.

Introduction

Nutrient enrichment has been observed in surface waters across the Nation (Bricker and others, 2007, 2008; U.S. Environmental Protection Agency, 2009) and can lead to taste and odor issues in drinking-water supplies, increased treatment costs for drinking water, toxic algal blooms, oxygen depletion, fish kills, and decreases in the aesthetic value of the waterbody (table 1). Although elevated concentrations of either nitrogen or phosphorus can cause eutrophication, phosphorus levels usually have the greatest effect on lakes because phosphorus is less abundant in freshwater and is more likely to limit plant and algal growth (Smith and Schindler, 2009). In saline environments, nitrogen is typically the limiting nutrient (Paerl and others, 2002; Howarth and Marino, 2006), although in some estuaries changes in either nitrogen or phosphorus levels stimulate algal production (Malone and others, 1996; Prasad and others, 2010).

National assessments of eutrophication in U.S. lakes and estuaries have linked the eutrophic status to nutrient concentrations within the waterbody as well as to nutrient loading from tributary streams and rivers. Bricker and others (1999, 2003, 2007) reported that 29 of the 99 estuaries assessed had moderate to high eutrophic conditions and predicted that conditions would worsen in 48, stay the same in 11, and improve in 14 estuaries by 2020 (Bricker and others, 2007). The U.S. Environmental Protection Agency (EPA) (2008 and 2009) found that nitrogen and phosphorus concentrations were elevated in almost 20 percent of all lakes sampled and that more than 20 percent of lakes assessed with poor ecological condition would improve if nutrient loads were reduced.

Watershed model estimates of stream nutrient loads have been a critical component for these assessments. For example, the 1999 assessment (Bricker and others, 1999) of estuarine eutrophication in the United States was based on 1987 estimates of stream nitrogen loads from a national-scale Spatially Referenced Regression on Watershed attributes (SPARROW) model (Smith and others, 1997). The SPARROW watershed model provides a mechanism to assess nutrient sources and transport to lakes, reservoirs, and estuaries and evaluate a variety of nutrient reduction management scenarios.

The U.S. Geological Survey (USGS) National Water Quality Assessment Program (NAWQA) recently completed assessments of nitrogen and phosphorus transport in streams in six major regions extending over much of the United States, using the SPARROW model (Preston and others, 2011). Hoos and others (2013) used previously published SPARROW models for nitrogen and phosphorus (Hoos and McMahon, 2009; Garcia and others, 2011; Moore and others, 2011) in streams in the northeastern and southeastern regions of the United States and extended the model structure to investigate specific questions about the effects of wetlands and atmospheric deposition on nutrient transport to lakes, reservoirs, and estuaries along the Atlantic and eastern Gulf of Mexico coasts. The atmospheric deposition source in the nitrogen model has been improved to account for individual components of atmospheric input derived from emissions from agricultural manure, agricultural livestock, vehicles, powerplants, other

[1]U.S. Geological Survey.

[2]National Oceanic and Atmospheric Administration.

Table 1. Description of eutrophic symptoms in lakes and estuaries (modified from Bricker and others 2007).

Symptom	Description
High concentrations of chlorophyll *a* (phytoplankton)	Chlorophyll *a* is a measure of pigment used to estimate the amount of microscopic algae (phytoplankton) growing in a waterbody. High concentrations of algae can lead to large daily fluctuations in dissolved-oxygen levels, with low levels occurring at night near the lake or estuary bottom as a result of decomposition.
Macroalgal blooms	Macroalgal blooms are large algae, commonly referred to as “seaweed” in estuaries. Blooms can cause loss of submerged aquatic vegetation by blocking sunlight. Additionally, blooms can degrade habitat for fish and smother immobile shellfish and corals. The unsightly nature of some blooms may affect tourism because their presence can reduce an estuary’s appeal for swimming, fishing, and boating.
Low dissolved oxygen	Low dissolved oxygen occurs as a result of decomposing organic matter from algal blooms, which sinks to the bottom and uses oxygen during the decay process. Low dissolved oxygen can cause fish kills, habitat loss, and degraded aesthetic values, resulting in loss of recreational use and property values.
Loss of submerged aquatic vegetation	Loss of submerged aquatic vegetation (SAV) occurs when algal blooms caused by excess nutrient additions decrease water clarity and light penetration. The loss of SAV can have negative effects on a waterbody’s functionality, particularly for estuaries, and may affect some fisheries, owing to the loss of nursery habitat and waterfowl.
Nuisance/toxic algal blooms	Nuisance/toxic algal blooms occur when there are too many phytoplankton in the water column. Blooms are thought to be caused by a change in the natural mixture of nutrients caused by increasing nutrient inputs over a long period of time, but the exact role of nutrient enrichment is unclear. Algal blooms may release toxins that kill fish and shellfish. Human health problems may also occur due to the consumption of contaminated shellfish, from drinking or coming in contact with contaminated water, or from the inhalation of airborne toxins.

industry, and background sources. This accounting makes it possible to simulate the effects of altering an individual component of atmospheric deposition, such as nitrate emissions from vehicles or powerplants. The recalibrated nitrogen and phosphorus models account explicitly for the influence of wetlands on regional-scale land-phase and aqueous-phase transport of nutrients and, therefore, allow comparison of the water-quality functions of different wetland systems over large spatial scales.

Purpose and Scope

The purpose of this report is to provide estimates of nutrient loads and source shares, nutrient yield from the contributing watersheds, and nutrient concentrations in inflows to the major lakes and estuaries draining into the Atlantic Ocean; estimates are based on SPARROW model estimates by Hoos and others (2013). Basic principles of the SPARROW modeling approach are explained to provide background for the assessment approach. Maps and tables of nutrient sources and stream delivery of nutrients to 255 major lakes (surface area greater than 5 square kilometers (km^2) or 1,250 acres) and 64 estuaries are presented in appendix 1.

Understanding the Assessment Approach (SPARROW Model)

The SPARROW model is used to predict mean annual nutrient loads in streams and rivers on the basis of watershed characteristics. The SPARROW model links watershed inputs from nutrient sources with transport characteristics of nutrients across the land surface and in stream channels in order to estimate annual delivery of nutrients to downstream lakes and estuaries (Smith and others, 1997; Schwarz and others, 2006). The SPARROW model uses statistical regression, with stream load as the response variable, to estimate source-specific and overall instream loads for each stream and receiving waterbody in the model area. The SPARROW modeling approach is designed to

1. identify watershed characteristics representative of nutrient source inputs and the overland and instream transport mechanisms that are statistically significant predictors of the spatial pattern of observed stream annual load;
2. estimate a coefficient for each watershed characteristic that minimizes the overall error in the model; and
3. estimate source-specific and overall instream load for each stream reach in the model area.

Output from the SPARROW model described in Hoos and others (2013) is summarized in this report as estimates of nutrient loads to estuaries documented in the National Oceanic and Atmospheric Administration (NOAA) National Estuarine Eutrophication Assessment (figs. 1A and 1B; Bricker and others, 2007) and to lakes greater than 5 km^2 in the Eastern United States. These estimates reflect long-term mean annual nutrient loads. A statistical procedure was used to ensure that the model predictions reflect long-term hydrologic and water-quality variability during a consistent time period in order to produce robust model predictions. These estimates were standardized to a base year of 2002 to give an estimate of the nutrient loads that would have occurred in streams that year if mean annual flow conditions had prevailed. The base year was chosen to ensure consistency with ancillary information on nutrient source information.

The estimates in this report of nutrient load, yield, and source shares are based on model predictions and are not adjusted to match observed loads at monitoring stations. The use of unadjusted versus adjusted predictions depends upon the objective. Adjusted predictions are modified so that load predictions in monitored reaches exactly match the observed loads at monitoring stations used to calibrate the model. Such predictions do not preserve mass balance and, thus, do not provide the ability to trace predicted load in a given stream reach to the individual sources in each of the upstream reach watersheds (U.S. Geological Survey, 2013). Estimation of source shares can only be obtained through the use of unadjusted predictions.

Estimates of nitrogen and phosphorus source shares and the load that reaches the estuaries (termed “delivered load”) are calculated as the summed load from all stream and

SPARROW Model Calculations of Nutrient Assimilation Rates in Lakes

For the purpose of this report, natural and manmade lakes are seen as both receiving waterbodies affected by nutrients and as nodes in the stream flow path to the estuary that alter nutrient transport rates as a result of nutrient processing and removal from the water column. The SPARROW model simulates removal of nutrients in lakes or reservoirs as the first-order mass transfer rate expression (Schwarz and others, 2006):

$$\text{Load out} = \text{Load in} * 1/(1 + \text{residence time surrogate} * \text{theta})$$

where

Load out = nutrient load at the downstream node of the lake or reservoir reach;

Load in = nutrient load entering the lake reach, either from the catchment adjacent to the lake, or from upstream reaches;

Residence time surrogate = a surrogate for lake residence time, calculated as the ratio of lake discharge to lake surface area (units of time per distance) from data in the National Hydrography Dataset (NHD), specifically from the data file NHDWaterbody (U.S. Environmental Protection Agency and U.S. Geological Survey, 2010). Early SPARROW models used residence time, the ratio of lake discharge to lake volume, in units of time, for estimating nutrient removal by lakes and reservoirs. However, the surrogate, typically referred to as the inverse of areal hydraulic loading, was used for this analysis due to absence of information about lake depth. Additionally, the surrogate has been determined to be a better predictor within SPARROW models (Schwarz and others, 2006, part 1, p. 57); and

theta = the lake loss coefficient, in units of distance per time, estimated by the model. The model-estimated coefficient for nitrogen is 5.8 meters per year (m/yr) and for phosphorus is 6.9 m/yr for lakes in the Northeast and 30 m/yr for lakes in the Southeast (Hoos and others, 2013). These coefficients are used as part of the model simulations of nutrient transport through the stream network to calculate removal of nutrients in the lakes and reservoirs along the stream flow path.

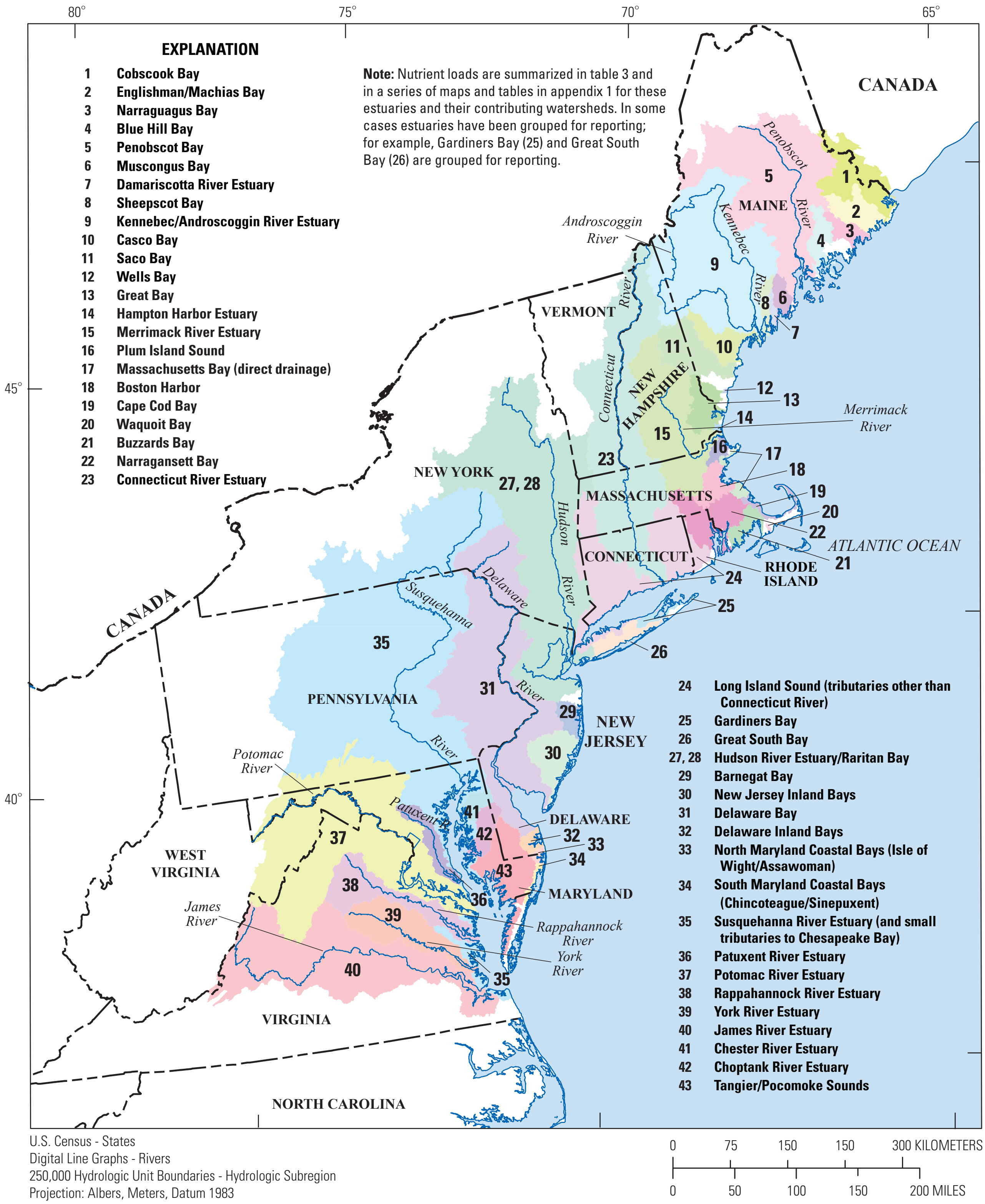
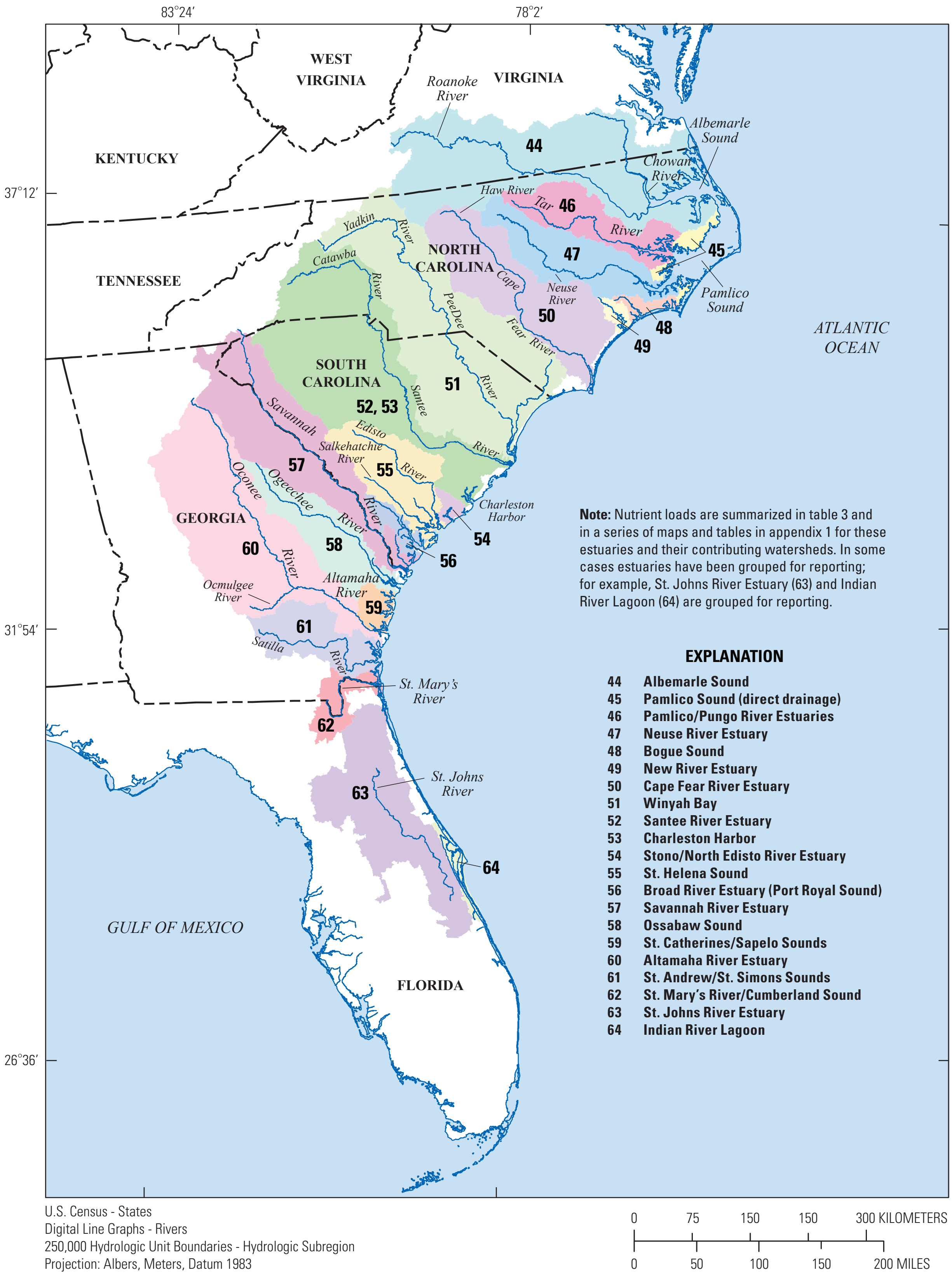


Figure 1A. Location of the estuaries and their contributing watersheds in the North and Middle Atlantic Region for which nutrient loads are summarized.



Note: Nutrient loads are summarized in table 3 and in a series of maps and tables in appendix 1 for these estuaries and their contributing watersheds. In some cases estuaries have been grouped for reporting; for example, St. Johns River Estuary (63) and Indian River Lagoon (64) are grouped for reporting.

EXPLANATION

44	Albemarle Sound
45	Pamlico Sound (direct drainage)
46	Pamlico/Pungo River Estuaries
47	Neuse River Estuary
48	Bogue Sound
49	New River Estuary
50	Cape Fear River Estuary
51	Winyah Bay
52	Santee River Estuary
53	Charleston Harbor
54	Stono/North Edisto River Estuary
55	St. Helena Sound
56	Broad River Estuary (Port Royal Sound)
57	Savannah River Estuary
58	Ossabaw Sound
59	St. Catherines/Sapelo Sounds
60	Altamaha River Estuary
61	St. Andrew/St. Simons Sounds
62	St. Mary's River/Cumberland Sound
63	St. Johns River Estuary
64	Indian River Lagoon

Figure 1B. Location of the estuaries and their contributing watersheds in the South Atlantic Region for which nutrient loads are summarized.

shoreline reaches draining to the estuary. Estimates of nitrogen and phosphorus delivered loads to each lake are calculated as the sum of the load at the lake outlet and the load removed by lake processes (See sidebar, SPARROW Model Calculations of Nutrient Assimilation Rates in Lakes). The load from a source category for an estuary is summed across multiple reaches for streams discharging to the estuary, including watershed inputs, and is divided by total load to obtain the percentage source shares for the estuary. Percentage source shares for a lake are calculated by dividing the individual source shares at the outlet of the lake by the total load at the outlet. The source categories included in the SPARROW models for the Eastern United States are summarized in table 2 and are described in greater detail in Hoos and others, 2013.

Nutrient Load Summaries for Major Lakes and Estuaries

SPARROW model estimates of nutrient loads to major lakes and estuaries along the Atlantic coast (figs. 1A and B) are summarized in tables 3A and B. The summaries include nutrient load and source shares delivered to the waterbody (lake or estuary), nutrient yield from the contributing watershed, and nutrient concentrations in inflows to the waterbody. Information in table 3 is also presented in appendix 1 in a series of tables for each estuary or group of estuaries.

The series of tables in appendix 1 are accompanied by a series of maps showing the spatial variation in nutrient yield

Table 2. Nutrient source categories for the Spatially Referenced Regression on Watershed attributes (SPARROW) nitrogen and phosphorus models documented in Hoos and others (2013).

Category	Definition
Wastewater (nitrogen and phosphorus)	Permitted discharges of wastewater to streams, rivers, lakes, and estuaries.
Urban land (nitrogen and phosphorus)	Urban lands such as lawns, streets, and industrial sites. This category may also account for contributions from septic systems in areas without public sewer systems and from industrial wastewater in urban areas. For nitrogen, atmospheric deposition and subsequent runoff from industrial and vehicle emissions in urban areas are accounted for in separate categories (see below) but may also be represented in part by this category.
Fertilizer (nitrogen and phosphorus)	Fertilizer applied to agricultural lands within the watershed. For nitrogen, this category also includes atmospheric depositiona of nitrogen that originated as emissions from fertilizer application both within and outside the watershed.
Manure (nitrogen and phosphorus)	Manure from animal operations within the watershed. For nitrogen, this category includes atmospheric deposition[a] of nitrogen that originated as emissions from animal operations both within and outside the watershed.
Powerplant emissions (nitrogen)[a]	Atmospheric deposition and the subsequent transport to the stream of nitrogen from fossil-fuel powerplant emissions both within and outside the watershed.
Industrial emissions (nitrogen)[a]	Atmospheric deposition and the subsequent transport to the stream of nitrogen from industrial emissions other than powerplants both within and outside the watershed.
Vehicle emissions (nitrogen)[a]	Atmospheric deposition and the subsequent transport to the stream of nitrogen from vehicle emissions both within and outside the watershed.
Background (nitrogen)[a]	Atmospheric deposition and the subsequent transport to the stream of emission sources not related to human activities (lightning, fire, and biogenic emissions) as well as emissions from all international sources.
Background (phosphorus)	Weathering and erosion of minerals containing phosphorus naturally present in the parent rock material for the watershed; the only phosphorus share that is not directly related to human activities.
Mines (phosphorus)	Phosphate-mined land (does not include permitted discharge from active phosphate mine operations).

[a]Atmospheric deposition over land, lakes, and reservoirs and for certain riverine estuaries to the tidal reaches of the estuary itself are included in the load estimates. For the majority of the estuaries, however, direct deposition to the coastal waterbody is not included in the estimates.

within the contributing watershed for each estuary. These yield maps can be used to identify areas within a watershed that contribute the highest and lowest yields of nitrogen or phosphorus to a lake or estuary. The yield maps were prepared with a standard set of map intervals for nitrogen yield and a standard set for phosphorus yield, allowing direct comparison of nutrient yield among all watersheds in the Eastern United States. Maps of nutrient yield, load, and source shares for smaller areas, for example the specific stream reaches or subwatersheds, can be requested online (*http://cida.usgs.gov/sparrow/)* through the SPARROW Decision Support System (Booth and others, 2011; U.S. Geological Survey, 2011), using user-specified areal extent and map intervals.

The location and surface area of each of the 255 lakes for which loads are reported in table 3 are shown in the maps in appendix 1. The criterion for reporting in table 3 is lake size; lakes with surface area greater than 5 km^2 (1,250 acres) are included. This threshold corresponds with the distinction between intermediate and large lakes (U.S. Environmental Protection Agency, 2009). The 31,000 small and intermediate size lakes in the NHDWaterbody data file (U.S. Environmental Protection Agency and U.S. Geological Survey, 2010) for the Eastern United States are too numerous to include in table 3. Many of these lakes are of interest in nutrient assessments because of their role in removing nutrients from the stream network and because of beneficial uses of the lakes that may be threatened by eutrophication. The locations of intermediate size lakes (about 1,500 in the Eastern United States) are shown in the appendix 1 maps to indicate their spatial distribution within the watersheds.

The first 21 columns in tables 3A and 3B and the series of tables "Nutrient source shares and loads delivered from the watershed to …" in appendix 1, present annual estimates of nutrient source shares, loads, and yields delivered to major lakes and estuaries. This information can be used to compare loads and yields for lakes and estuaries of interest. The source-share information can identify contributing sources of nitrogen and phosphorus and help target nutrient-reduction strategies that can improve water quality for specific lakes and estuaries.

The last 11 columns in tables 3A and 3B and the series of tables "Estuary and lake characteristics …" in appendix 1, provide waterbody characteristics important to nutrient processing in the lakes and estuaries. The attribute *Contributing watershed area* is the total drainage area for the lake or estuary. *Surface area* is an estimate of the size of the lake or estuary and is used to estimate the residence time reported for lakes. *Residence time,* reported in days (or, for lakes, the *Residence time* surrogate*,* in days per meter), is a measure of hydraulic flushing in the lake or estuary. Generally, lakes and estuaries with long residence times and high nutrient inputs are more likely to experience symptoms of eutrophication than lakes and estuaries with shorter residences times and high nutrient inputs. Algal biomass is more likely to increase and cause nuisance blooms in slower moving water because algae are able to reproduce more rapidly than they are dispersed (Vollenweider, 1968, 1976; Lee and others, 1978; Newton and Jarrell, 1999; Ferreira and others, 2005; Bricker and others, 2008). Yet, lakes with long residence times generally have a higher assimilative capacity and retain a larger portion of the nutrient load delivered to the lake, resulting in the transport of a smaller portion of nutrients downstream (Schwarz and others, 2006).

The last eight attributes reported in tables 3A and 3B and in the series of tables "Estuary and lake characteristics …" in appendix 1 are calculated by combining the SPARROW model estimates of load with waterbody characteristics. *Load from watershed per hydraulic flushing rate of receiving waterbody* may be useful as an indicator of the vulnerability of lakes and estuaries to nutrient enrichment (Vollenweider 1968, 1976; Lee and others, 1978; Bricker and others, 2008). Large values of this attribute are associated with waterbodies with high nutrient loads as well as slow hydraulic flushing; therefore, large values of this attribute are associated with waterbodies that may accumulate nutrients during certain periods of the year. The attribute is calculated as the ratio of delivered load to hydraulic flushing rate or equivalently as the product of delivered load and residence time. For estuaries for which the residence time estimate from Bricker and others (2007) is a range (for example, 80–100 days), the calculation is made using the midpoint of the range (90 days).

Concentration of tributary inflow to receiving waterbody reports mean annual and flow-weighted concentrations of total nitrogen and phosphorus and is calculated from mean annual load and mean annual streamflow entering the estuary or lake. For estuaries, tributary inflow concentration is calculated as the ratio of total load (summed from all contributing rivers and shoreline reaches and expressed as mass per time) to total streamflow (summed from all contributing rivers and shoreline reaches and expressed as volume per time) multiplied by a conversion factor to obtain units of concentration in milligrams per liter. For lakes, tributary inflow concentration is calculated as the ratio of delivered load to streamflow at the lake outlet multiplied by the conversion factor.

The ratio of total nitrogen to total phosphorus concentration in tributary inflow to the receiving waterbody *(Ratio of TN:TP)* provides an evaluation of whether nitrogen or phosphorus controls primary production in the receiving waterbody, especially in lakes. Smith (1982) proposed that lakes with TN:TP ratios greater than 17 can be considered to be limited by phosphorus, lakes with TN:TP ratios less than 10 are often limited by nitrogen, and lakes with TN:TP ratios between 10 and 17 are considered to be nutrient balanced.

Load assimilated in receiving waterbody is estimated from the SPARROW model predictions of nitrogen or phosphorus mass removed within a lake or reservoir. Large values of this attribute are associated with lakes with long residence time and (or) with large nutrient inflows. The effect that such lakes have on delivery of nutrients to downstream coastal areas is evident from inspection of the maps in appendix 1, especially the maps for phosphorus delivery in the watersheds draining to the South Atlantic for which estimated rates of assimilation are highest. For example, a distinct difference between values of phosphorus yield delivered to the Cape Fear River Estuary from catchments upstream from B. Everett Jordan Lake compared to the values from nearby catchments for which downstream transport is not intercepted by the lake is evident in map 48–50 “Contributing watersheds and nutrient yield for Bogue Sound and New River and Cape Fear River Estuaries (New and Cape Fear River Basins).” The map illustrates retention of phosphorus (69,901 kilograms per year (kg/yr) of total phosphorus removed as reported in table 3 and appendix 1) by B. Everett Jordan Lake. Comparison of the pattern of yield delivered to the estuary and the placement of reservoirs and lakes illustrates the importance of lakes and reservoirs as nutrient sinks. However, high values of nutrient loads trapped by a waterbody may indicate that the waterbody is susceptible to eutrophication. For example, B. Everett Jordan Lake periodically experiences algal blooms and fish kills. The lake is classified as impaired due to nutrient overenrichment, and local water suppliers are considering various best management practices that can be implemented to reduce eutrophication in the lake (Mary Giorgino, U.S. Geological Survey, oral commun., August 2013).

Overall Eutrophic Condition, reported for estuaries, represents the eutrophic condition assessed by Bricker and others (2007) based on estuarine monitoring data collected in the early 2000s. Estuaries ranked as high generally have periodic or persistent symptoms of eutrophication over an extensive area. In estuaries ranked as moderate high, the symptoms of eutrophication generally occur less regularly and (or) over a medium to extensive area. In estuaries ranked as moderate, the symptoms of eutrophication generally occur less regularly and (or) over a medium area. Estuaries ranked as moderate low generally have symptoms of eutrophication that occur episodically over a small to medium area. In estuaries ranked as low, few symptoms of eutrophication occur at more than minimal levels. Estuaries ranked as unknown had insufficient data for analysis. Of the 64 estuaries along the Atlantic coast included in this study, 12 were ranked as high, 24 were ranked as moderate high or moderate, 14 were ranked as moderate low or low, and 14 had insufficient data for ranking.

Acknowledgments

Preparation of this report was supported by the USGS National Water-Quality Assessment Program (NAWQA). The authors thank many USGS scientists and staff for assistance with verification and review of the data presented: Katherine Weaver, Mazie Ashe, and Alex Cordaro for assistance in the compilation and preparation of the data tables; Betzy Reyes for geographic information system (GIS) compilations and preparation; Jeff Corbett for assistance with data and figure compilation; Douglas Harned, Celeste Journey, Dan Wise, and Robin Dennis (U.S. Environmental Protection Agency) for technical reviews of the manuscript; and Kay Naugle for editorial review of the manuscript.

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Appendix 1. Contributing Watersheds and Nutrient Load Summaries for Major Lakes and Estuaries in the Eastern United States

[The number(s) at the beginning of each map or table title in appendix 1, for example "1–4. Cobscook, Englishman, Machias…" refers to the map index number(s) (figs. 1A and 1B) for the estuaries and their contributing watersheds. Abbreviations used in appendix 1 maps and tables: kg/km^2/yr, kilogram per square kilometer per year; km^2, square kilometer; kg/yr, kilogram per year; kg/ha/yr, kilogram per hectare per year; lbs/acre, pounds per acre; d, days; d/m, days per meter; Mg, megagram; kg, kilogram; mg/L, milligram per liter; TN, total nitrogen; TP, total phosphorus; TN:TP, ratio of total nitrogen to total phosphorus; NA, not assessed or data not available]

Approved for publication on January 15, 2014.

Prepared by:
USGS Science Publishing Network
Raleigh Publishing Service Center
3916 Sunset Ridge Road
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