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Changes in Nitrogen Loading to the Northeast Creek Estuary, Bar Harbor, Maine, 2000 to 2010

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Changes in Nitrogen Loading to the Northeast Creek Estuary, Bar Harbor, Maine, 2000 to 2010

By Martha G. Nielsen

Open-File Report 2013–1256

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U.S. Geological Survey

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U.S. Geological Survey
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SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	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)
	Volume	
liter (L)	0.2642	gallon (gal)
	Flow rate	
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)
milligram (mg)	0.0003527	ounce (oz)
kilogram per hectare per year (kg/ha/yr)	.05710	pound per square mile per year ($lb/mi^2/yr$)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)

Elevation, as used in this report, refers to distance above the vertical datum.

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

Abbreviations

ANP	Acadia National Park
DSS	decision support system
GIS	geographic information system
NEC	Northeast Creek
NPS	National Park Service
USGS	U.S. Geological Survey

Acknowledgments

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Changes in Nitrogen Loading to the Northeast Creek Estuary, Bar Harbor, Maine, 2000 to 2010

By Martha G. Nielsen

Abstract

Since 1999, the U.S. Geological Survey and the National Park Service have been monitoring land use and nitrogen loading in a 26.3-square-kilometer (10-square-mile) estuarine watershed at Acadia National Park, Mount Desert Island, Maine. The initial study linking land use and nitrogen loads entering the Northeast Creek estuary was completed in 2000, and findings were used to develop simulations of nitrogen loading to the estuary, thereby helping to inform local land-use planning decisions. At that time, the amount of nitrogen entering the Northeast Creek estuary was relatively small, and no evidence of nutrient-related degradation was observed in the *Ruppia*-dominated estuarine ecosystem. A new round of water-quality monitoring and streamflow measurements was conducted to determine nitrogen loading from 2008 to 2011 as a means to evaluate the effects of increased rural residential housing within the watershed since 2000. On the basis of a 2.6-percent increase in residential-housing land use in the watershed from 2000 to 2010, simulations of nitrogen export predicted a 7-percent increase in nitrogen loading to Northeast Creek. The measurement-based loads estimated for the Northeast Creek tributaries, however, increased much more than predicted, from 1.89 kilograms per hectare per year (kg/ha/yr) in 2000 to 3.12 kg/ha/yr in the time period centered on 2010—a 66-percent increase. This increase is likely primarily a result of the prevalence of much wetter conditions during the 2008–11 sampling period than during the earlier sampling period. In addition to increasing the physical transport of nitrogen in the watershed, wet climatic conditions have been shown in other studies to increase the rates of biotic and abiotic processes that control nitrogen export from northern-latitude forested watersheds. The new loading estimates, however, also support the possibility that some portion of the increase in nitrogen loading results from the observed land-use changes, and that the increase in residential housing has, in fact, contributed to the observed increase in nitrogen loading.

Introduction

Estuaries within and around Acadia National Park (ANP) provide nursery, breeding, and forage grounds for many species of fish and wildlife, as well as unique recreational opportunities for the park's visitors and local residents. These estuaries are threatened by potential contaminants from rapidly increasing residential development outside the park boundary. Nutrient loading to estuarine systems is one of the park's most important resource-management challenges. The Water Resources Management Plan for ANP (Kahl and others, 2000) lists the maintenance of water quality to maintain ecosystem integrity as the highest water-resources priority for Park managers. The second largest of these estuaries, the Northeast Creek (NEC) estuary, is surrounded by privately owned rural residential land, which makes up most of the watershed of the estuary. In NEC, as well as in other estuaries in the park, the projected ecological response to nutrient enrichment (primarily nitrogen) is habitat degradation caused by the increased growth of algae and subsequent decline of submerged aquatic vegetation in the estuary (Kinney and Roman, 1998; Neckles and others, 2003).

Studies of nitrogen loading to the NEC estuary began in 1998, when the U.S. Geological Survey (USGS) and the National Park Service (NPS) began a cooperative project to quantify the water budget for Northeast Creek and determine nitrogen loadings from precipitation and surface-water sources (Nielsen, 2002b). The surface-water nitrogen loads measured during that study (conducted in 1999–2000), hereafter referred to as the "2000 loads," were used in conjunction with a land-use analysis of the watershed and in situ mesocosm experiments in the estuary to develop simulations of nitrogen export to the NEC estuary (Guntenspergen and others, 2005; Guntenspergen and others, 2009). The mesocosm experiments were conducted to determine the amount of nitrogen loading the estuary potentially could absorb before detrimental ecosystem change likely would occur (Neckles and others, 2003; Guntenspergen and others, 2009), and the simulations that were developed included information on the relative ecosystem health that would be expected from changes in land use, following changes in nitrogen loading. Local land managers were able to conduct these simulations using a geographic information system- (GIS) based decision-support system (Guntenspergen and others, 2009, p. 519–520).

Land-use changes in the NEC watershed since 2000 have raised questions about how much change has occurred in the nitrogen loading to the NEC estuary; how well the simulations predicted nitrogen loading changes; and whether the land-use-based predictions of nitrogen loading changes are sufficient for understanding loading variability and provide enough information to make planning decisions to protect the health of the ecosystem. The current study, undertaken in cooperation with NPS and the Town of Bar Harbor from 2008 to 2011, attempts to answer these questions so that NPS and the Town of Bar Harbor can continue working together to make science-based management decisions that minimize the adverse effects of development on the ecological health of the estuary and watershed.

Northeast Creek Study Area

The NEC estuary is a small tidal estuary located on the north side of Mount Desert Island in the Town of Bar Harbor, Maine (fig. 1). Northeast Creek flows into Thomas Bay; its outlet is constricted by a bridge and the remains of an old rock dam. The dam remains are at an elevation slightly below mean high tide. Sea water enters the estuary for a short period of time at the peak of each tidal cycle on most days of the lunar cycle. During neap tides and lower high tides, no saltwater enters the estuary. Water in the estuary is often highly stratified—freshwater from inflowing tributaries stays above the saltwater because of density differences. During large runoff events, the freshwater completely flushes the saltwater out of the estuary, only to be partly displaced again by saltwater at the next tidal maximum (unpublished data available at the U.S. Geological Survey office in Augusta, Maine). Because the saltwater stays at the bottom of the creek, the submerged vegetation consists primarily of salt-tolerant *Ruppia maritima* (widgeon grass) along most of its length.

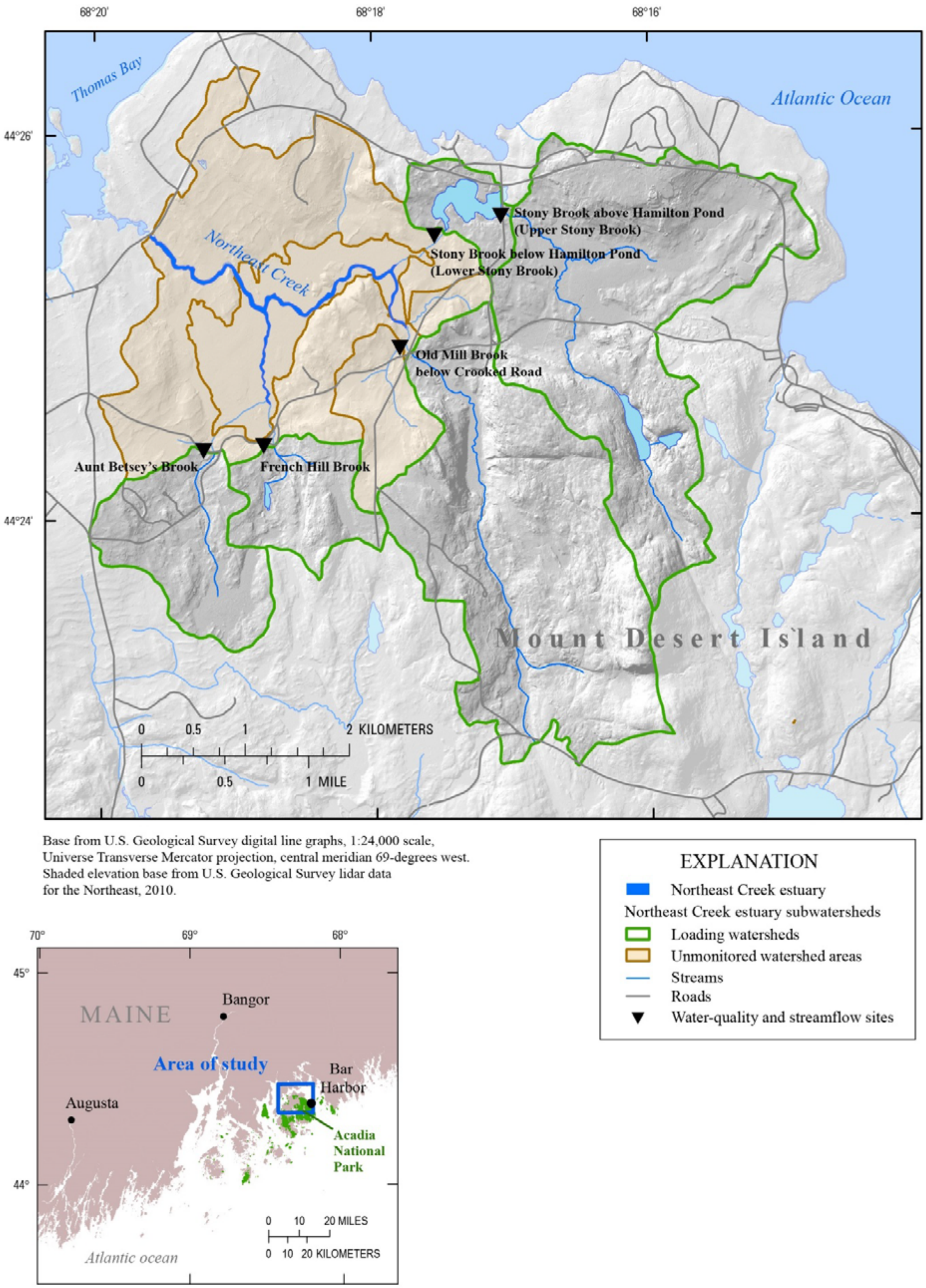


Figure 1. Map showing location of the Northeast Creek study area on Mount Desert Island, Bar Harbor, Maine.

The estuary receives freshwater input from four perennial tributaries (from east to west with their watershed areas, Stony Brook (7.41 square kilometers (km^2), Old Mill Brook (6.85 km^2), French Hill Brook (1.30 km^2), and Aunt Betsey's Brook (2.02 km^2)); from three unnamed intermittent tributaries; and from unchannelized flow from upland and wetland areas adjacent to the estuary (6.58 km^2) (fig. 1). The total watershed area is 26.25 km^2. The topography of the watershed is quite varied—runoff from the smaller tributaries tends to be sluggish because of large areas of wetlands and relatively small topographic gradients, but runoff from Old Mill Brook is very rapid, as much of its watershed is steep and very little soil covers the granitic bedrock of the area. Runoff from Stony Brook is slowed by a large wetland in the middle of the watershed and a pond (Hamilton Pond) a short distance upstream from where the tributary flows into Northeast Creek (fig. 1). Total topographic relief is 221 meters (m). Average annual precipitation for the area (1981–2010) is 144 centimeters per year (cm/yr) (56.7 inches per year) (National Oceanic and Atmospheric Association, 2013).

Previous Investigations in the Northeast Creek Study Area

The USGS has been conducting investigations in the NEC study area since 1998; these investigations include studies of water quality and nitrogen cycling (Nielsen, 2002b; Culbertson and others, 2007; Nielsen and others, 2002; Nielsen and Kahl, 2007; Huntington and others, 2011; Huntington and others, 2012); watershed hydrogeology (Nielsen, 2002b); and the estuarine ecosystem (Neckles and others, 2003). The relation between land use and water quality has been of particular interest, because of the increasing residential construction in the watershed and concerns that nitrogen input from that development could impair the relatively pristine condition of the estuary.

The first studies of nutrient export from the tributary watersheds to Northeast Creek during 1999–2000 showed significant differences in nitrogen loading rates among the tributary watersheds, and indicated that one factor that may be responsible is the variation in land use across the watersheds (Nielsen, 2002b; Nielsen and Kahl, 2007). The initial calculations of nitrogen loads to Northeast Creek were based on the results of sampling conducted from April 1999 to September 2000 (Nielsen, 2002b), and are referred to in this report as the "2000 loads." Samples from the mouths of the four perennial tributaries were collected monthly along with instantaneous-streamflow measurements. A short-term continuous-streamflow gage located at an upstream site on Old Mill Brook was used to establish a local baseline to estimate daily streamflows at the monitoring sites and thereby to help estimate annual nitrogen loads to Northeast Creek. Additional details of this study are discussed farther on in this report.

The annual stream loads of a constituent can be divided by the watershed area of the stream to obtain an average annual load per unit area of watershed, also termed a "yield," or loading rate. Loading rates for total nitrogen (as N) ranged from 1.3 kilograms per hectare per year (kg/ha/yr) in Aunt Betsey's Brook to 2.7 kg/ha/yr in Stony Brook during 1999–2000 (Nielsen, 2002b). These yields were found to be much lower than yields from watersheds of eutrophic estuaries elsewhere on the East Coast. However, these estimates were calculated on the basis of only 18 months of samples (not all of which were suitable for use in the estimates), and during a time period when precipitation during many months of the study was approximately half the long-term average (Nielsen, 2002b).

Simulations Relating Loading Rates to Land Use

After the field study of surface-water loads to the estuary was completed, work began to relate the loading rates to different land uses (Guntenspergen and others, 2009) and to determine how much nitrogen input the estuary could assimilate before undergoing changes indicative of degradation (Neckles and others, 2003). Land use in the watershed of Northeast Creek and other watersheds on Mount Desert Island was mapped by using color-infrared aerial photos from 1996 (scale 1:15,840)

(Nielsen and Kahl, 2007). The land-use delineations were then field-checked and adjusted to conditions observed on the ground in 2000. Each polygon in the land-use dataset was coded as one of six land-use types: forest; agriculture (primarily pasture and hay production); urban/suburban (houses and yards, roads and driveways, commercial properties, and other urban development); wetlands; open water; and quarry/bare rock/gravel pits.

The nitrogen export coefficients, as described by Guntenspergen and others (2009), represent just the annual nitrogen yield from a unit area of a specific land use, whereas the total annual nitrogen yield, or loading rate, represents an average yield per unit area for an entire watershed or subwatershed encompassing multiple land uses. In reality, the land uses in the NEC watershed are not entirely homogeneous, and some of the land-use categories, particularly the urban/suburban category, consist of a mixture of land uses related to the development of land for human habitation. Watershed areas having substantial numbers of houses, for example, may have older or newer housing stock (and septic-system technology) depending on their location and the history of development within the watershed, but they are all categorized the same in the NEC studies.

Nitrogen export coefficients for the calculation of loadings to the NEC estuary were based on previously published values and the estimated export of nitrogen (the 2000 loads) from the Northeast Creek watersheds plus one adjacent similarly sized watershed, and land-use characteristics in those watersheds in late 2000 (Guntenspergen and others, 2009). Nitrogen export coefficients (in kilograms per hectare per year) were derived by using a minimum-least-squares approach to parameter estimation, conditioned with ranges of values for those land uses published in other studies. The simulation of nitrogen export from watersheds based on land-use export coefficients, described by Guntenspergen and others (2009), provides a rough prediction of both the total nitrogen loading to the estuary on the basis of the proportions of the watershed within different land-use categories for any given time period for which land use is known, and an average loading rate, using a weighted average calculation.

In order to place predictions of nitrogen yields into an ecosystem-health context, Neckles and others (2003) conducted an in situ mesocosm study within the NEC estuary. Mesocosms are experimental enclosures situated in the natural environment that are small enough to control for variables to be studied but large enough to allow the natural ecosystem processes of interest to occur and be measured. The NEC mesocosms (each measuring 1 square meter) were constructed to mimic conditions in the estuary under varying levels of nitrogen loading, with four levels of nitrogen inputs studied. Each level was replicated with four mesocosms, plus two different sets of controls. This study identified a set of nitrogen loading thresholds at which the estuary would undergo changes in estuarine structure and function, moving toward a more eutrophic condition. The threshold for the transition between "healthy" and "degrading" was determined to be 2.2 kg/ha/yr for the entire watershed, and the threshold between "degrading" and "degraded" was 4.4 kg/ha/yr (Neckles and others, 2003). The simulations of nitrogen export conducted using a GIS-based decision-support system include comparisons of predicted nitrogen loading in NEC to these thresholds (Guntenspergen and others, 2009, p. 519–520).

Application of Nutrient Export Simulation for Local Planning

The Bar Harbor comprehensive land-use plan, adopted in 2007 (Town of Bar Harbor, 2007), directs the town to use the simulations of nitrogen export to help guide land-use decisions in the Northeast Creek watershed. The Town of Bar Harbor's planning department is committed to considering the simulation results in planning decisions (Town of Bar Harbor, 2007). From 2000 to 2008, the number of houses in the NEC watershed increased by 40 percent, resulting in a likely increase in the nitrogen load to the estuary. Simulation of nitrogen export from watersheds with coefficients based on 2007 land-use data indicated that the recent land-use changes might already be resulting in yields that approach the lower threshold identified in the mesocosm study—in other words, levels that would cause an increase in nutrient enrichment and possible degradation of the estuary (Karen Anderson, Acadia National Park, written commun., 2008).

Use of these simulations has been successful in motivating the community to consider the effects of land-use change on water quality. However, the fact that the simulation of nitrogen loads to the estuary by use of export coefficients based on land use is a simplification of the processes operating on the landscape (it considers only the type of land use in each parcel within the watershed and no other factors, such as distance to streams or other water bodies, or variability in hydrologic conditions from year to year) contributes to uncertainty in the predictions relating land-use change for a specific time period to estuarine nitrogen input and potential ecosystem impacts. This uncertainty points to several critical areas of concern that require scientific inquiry to support the local land-use-planning community in making effective decisions for the health of the ecosystem: How has the nitrogen loading to the NEC estuary changed since the first round of sampling in 1999–2000? Is simulation of nitrogen export from watersheds based on land use and export coefficients a sufficient tool for understanding recent and future changes in loading? What other factors contribute to variability in loading?

These questions prompted the current collaboration among the USGS, the NPS, and the Town of Bar Harbor to address the following points: (1) What is the rate of nitrogen loading to the NEC estuary after 10 years of land-use change? (2) Has loading changed since the 2000 load study? (3) How do the updated loads compare to the predictions from the simulations using land use from 2010? (4) Are simulations based on export coefficients still useful for making planning decisions? (5) What factors other than land-use changes should be considered to improve understanding of potential future changes in loading?

Purpose and Scope

This report presents the results of a study that was undertaken to evaluate current nitrogen loads to the Northeast Creek estuary as of 2010; to evaluate the simulations, based on land-use coefficients of nitrogen export, used to help make decisions about land management in the estuary watershed; and to better understand variability in nitrogen input to the estuary. Results of sampling for nitrogen in tributary streams to the NEC estuary from 2008 to 2011 is described and summarized. The nitrogen concentrations are compared to concentrations measured during an earlier nutrient loading study (1999–2000) in NEC. Annual nitrogen loading estimates for the 2010 time period, based on the 2008–11 sampling, are presented. The report also documents land-use changes following almost 10 years of rural residential development in the tributary watershed after the initial nitrogen loading estimates were done in 2000. The simulation of nitrogen loading to NEC in 2010 using export coefficients, based on these land-use changes, is presented. The changes in nitrogen loading between two sampling periods (2000 and 2010) are presented and compared to the simulations based on land-use changes. Factors such as climatic variability are discussed as possible additional variables to take into consideration in future predictions of nitrogen inputs to NEC.

Field Study of Nitrogen Loading to Northeast Creek, 2010 Time Period

The 1999–2000 study of nutrient loading in tributaries of NEC (Nielsen, 2002b) established a baseline for the amount of nitrogen entering the NEC estuary (referred to as the “2000 loads” in this report) from its four tributaries. In the current study, a second round of nitrogen loading estimates was made for these tributaries, with water-quality sampling and streamflow measurements starting in two streams in July 2008, and in the remainder of the streams in April 2010. Sampling continued in all streams through November 2011. After sampling was completed, the annual nitrogen loads were estimated using the LOADEST program developed by the USGS. The load estimates include all sampled months from 2008 to 2011, representing a period roughly centered on 2010. These estimates are referred to as the “2010 loads” in this report, and represent an annual average for the whole sampling period. The 2010 loads are compared with the 2000 loads, which similarly represent an annual average for the period from April 1999 to September 2000 (Nielsen, 2002b).

Nitrogen Sampling and Streamflow Measurements, 2008–11

Water-quality samples were collected at the same sites for the 2008–11 study as for the 1999–2000 study, with one additional site on Stony Brook, upstream from a large pond (Hamilton Pond, fig. 1), for a total of five sampling sites (table 1). Instantaneous streamflow was measured during sample collection at all sites using standard USGS methods (Carter and Davidian, 1968; Rantz and others, 1982).

Table 1. Locations of water-quality sampling and streamflow measurements, 2008–11.
[km^2, square kilometers; USGS, U.S. Geological Survey]

Site name	USGS station number	Drainage area, in hectares	Drainage area, in km^2	Samples collected for:
Old Mill Brook	01022805	685	6.85	This study, 2008–11
Upper Stony Brook	01022809	669	6.69	This study, 2008–11
Lower Stony Brook	01022810	741	7.41	This study, 2008–11
Aunt Betsey’s Brook	01022815	202	2.02	Huntington and others (2011), 2008–09; this study, 2010–11
French Hill Brook	01022807	130	1.30	Huntington and others (2011), 2008–09; this study, 2010–11

Water-Quality Sampling Procedures

Following the methodology used in the 1999–2000 study (Nielsen, 2002b), water-quality samples were collected monthly at five sites on four tributary streams in the NEC watershed (table 1), in two phases. A filtered sample (.45-micron filter size) and an unfiltered (preserved) sample were collected and analyzed for total nitrogen (as N), nitrite plus nitrate (as N), ammonia (as N), and total phosphorus. Organic nitrogen concentration was calculated from measured values of other nitrogen constituents. Samples were kept on ice and analyzed at the USGS National Water Quality Laboratory in Lakewood, Colorado, within 5 days of sample collection. Additional sampling and analysis details can be found in Nielsen (2002b).

Samples were collected on a monthly schedule. The first phase of the sampling, from July 2008 to July 2009, included Old Mill Brook and the Upper and Lower Stony Brook sites. Wintertime samples were not collected during that sampling phase. The second phase of the sampling, from April 2010 to November 2011, added the Aunt Betsey's Brook and French Hill Brook sites. Samples were collected monthly year-round during the second sampling phase. A total of 28 samples were collected at the sites that were sampled during both phases, and 20 samples were collected at the two sites that were sampled only during the second phase (table 1). In a separate study, additional monthly samples were collected from Aunt Betsey's Brook and French Hill Brook in 2008–09 (Huntington and others, 2011), but streamflow was not measured. Water-quality data from those samples (11 per site; table 1) are included in the discussion below, but were not used for load estimation because of the lack of concurrent streamflow data.

Streamflow Measurements, 2008–11

The sampling events during the study period covered a wide range of streamflows. Low flows were generally observed during July and August of 2010 and 2011. High flows were measured during April 2009 and December 2010. An evaluation of the daily mean streamflows at the USGS gaging station at Otter Creek near Bar Harbor (station number 01022840), located 7 kilometers (km) southeast of the study area, during the study period and on days on which samples were collected at NEC tributaries (fig. 2) indicates that instantaneous streamflows measured during the sampling events were representative of the range of streamflows during the entire study period, and captured high, average, and low flows.

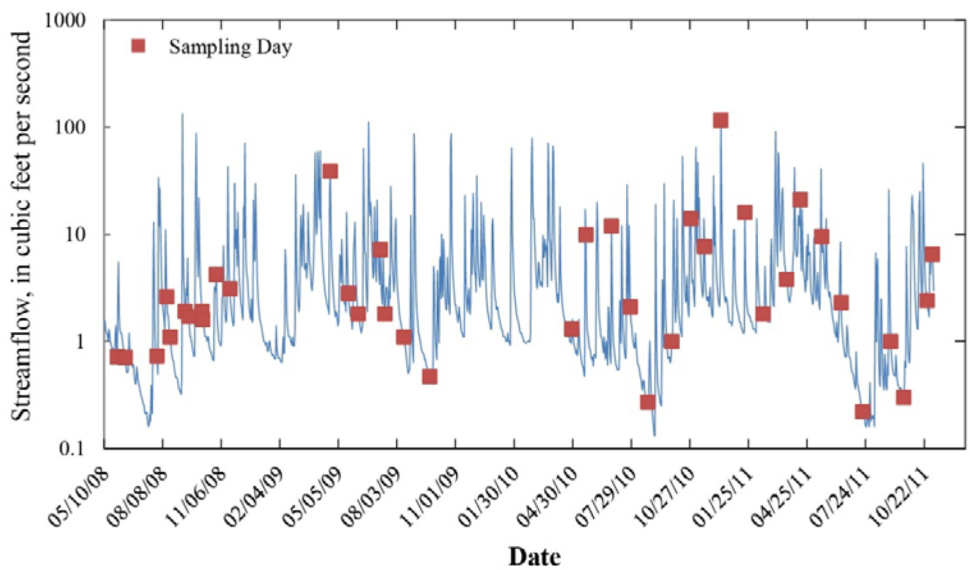


Figure 2. Hydrograph of daily mean streamflow at U.S. Geological Survey streamgage at Otter Creek, near Bar Harbor, Maine, May 2008 to September 2011, showing streamflow on days of sample collection for the Northeast Creek study.

Nitrogen Constituent Concentrations in Northeast Creek Tributaries, 2008–11

Nitrogen concentrations, both inorganic and total N, varied in both time and space, but were generally low, with most total N concentrations less than 1 milligram per liter (mg/L). Concentrations of inorganic N species (ammonia-N (NH_4-N) and nitrite plus nitrate-N (NO_2+NO_3-N)) in samples collected from 2008 to 2011 ranged from 0.0014 to 0.7 mg/L and from 0.003 to 0.17 mg/L, respectively (table 2). Total N concentrations ranged from 0.09 to 1.4 mg/L (filtered) and from 0.08 to 1.49 mg/L (unfiltered). Concentrations of organic N, which was not analyzed for but was determined as a calculated value, ranged from below detection (0.2 mg/L) to 1.3 mg/L. Concentrations of NH_4-N and NO_2+NO_3-N were frequently below the detection limit, which ranged from 0.0014 to 0.02 mg/L and from 0.0014 to 0.016 mg/L, respectively. In Old Mill Brook, which was anomalously low in inorganic N species, concentrations of NH_4-N and NO_2+NO_3-N were below detection in 79 and 71 percent of the samples, respectively. In other tributaries, the percentage of samples with concentrations of inorganic N species below detection ranged from 3 to 32 percent of all samples.

Table 2. Summary of streamflow and nitrogen-species concentrations for samples from Northeast Creek tributary monitoring sites, Bar Harbor, Maine, 2008–11.

[Available separately at http://pubs.usgs.gov/of/2013/1256/]

Nitrogen concentrations also varied by tributary (fig. 3). Overall, Old Mill Brook had the lowest concentrations of all the nitrogen species, with medians of 0.24 mg/L of total N (filtered), 0.008 mg/L of NO_2+NO_3-N, 0.01 mg/L of NH_4-N, and 0.24 mg/L of organic N. The Upper Stony Brook site had the highest concentrations of almost all the nitrogen species, with medians of 0.59 mg/L of total N (filtered), 0.013 mg/L of NO_2+NO_3-N, 0.014 mg/L of NH_4-N, and 0.56 mg/L of organic N. Concentrations of some constituents (except NO_2+NO_3-N and NH_4-N) were higher in samples from Upper Stony Brook than in those from Lower Stony Brook, indicating that processes in Hamilton Pond, such as nitrification and mineralization, may be converting organic N to inorganic forms, and denitrification may be reducing the total amount of N exiting the pond.

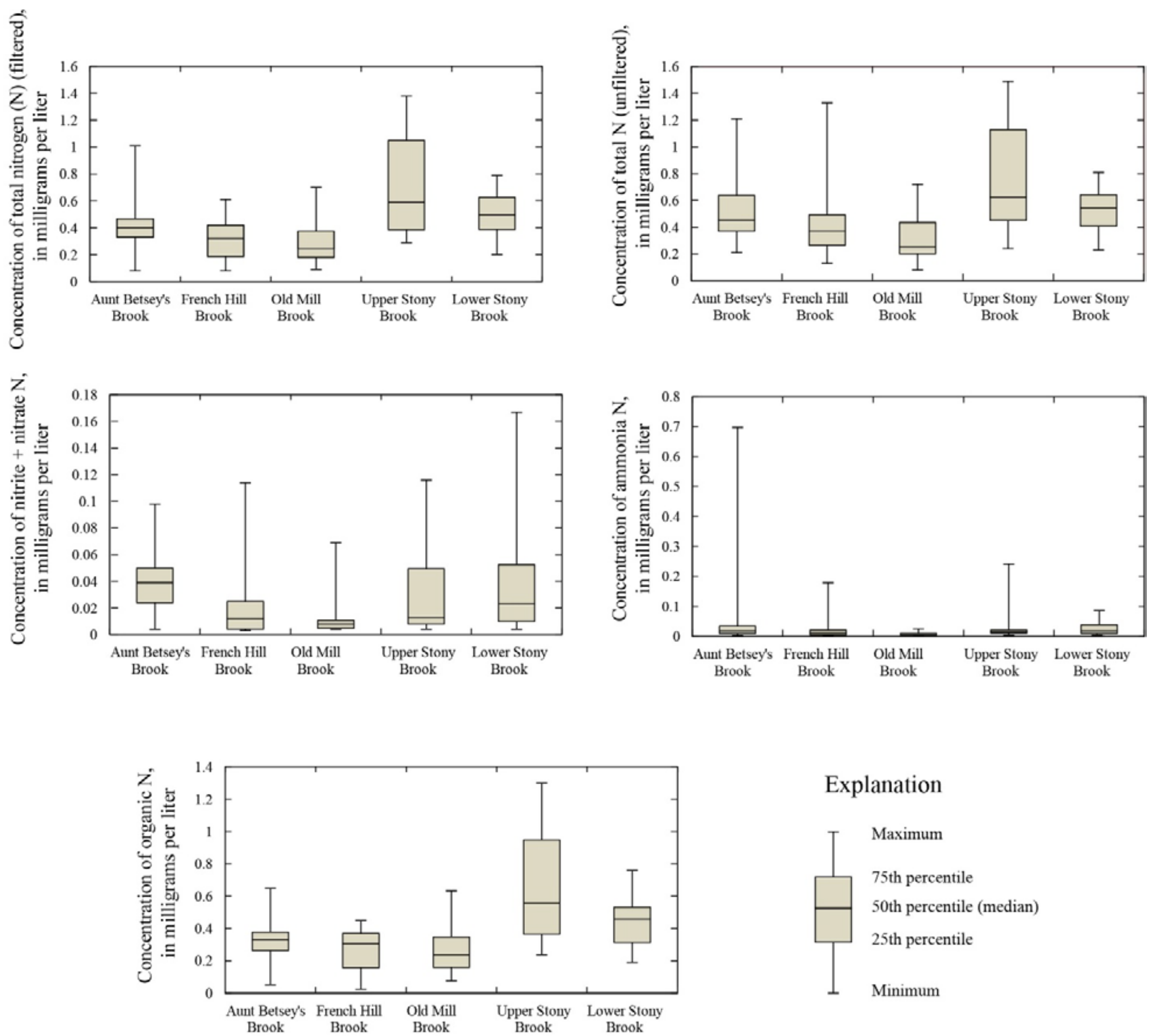


Figure 3. Boxplots summarizing distribution of nitrogen (N) constituent concentrations, Northeast Creek tributaries, 2008–11.

Other researchers investigating N export from relatively undisturbed watersheds in northern latitude forests also have found significant natural variability in concentrations over time and among adjacent watersheds (Creed and Beall, 2009; Creed and Band, 1998; Lovett and others, 2002; Willard and others, 1997; and Andersson and Lepistö, 2000). Factors known to affect the magnitude and variability of N concentrations include soil composition (Lovett and others, 2002), topography (Creed and Band, 1998), hydrogeology and its effects on stream generation (Schiff and others, 2002), and possibly forest disturbance history (Goodale and others, 2000), although the importance of forest disturbance has been disputed (Lovett and others, 2002).

Fractions of Organic and Inorganic Nitrogen in Tributary Streams

Organic and inorganic forms of nitrogen function differently in aquatic environments, and information on the relative amounts of these constituents is useful in evaluating possible sources and potential effects on ecosystem health. The ratio of organic N:inorganic N was estimated for each set of samples from three tributaries (fig. 4). Because concentrations of the inorganic species were frequently below the detection limit, a value of half the detection limit was used for each nondetected value in this estimation. The ratio of organic N:inorganic N ranged from a high of 95:5 to a low of 73:27. A seasonal pattern can be identified in the data, as seen in a graph of the ratio of organic N:inorganic N plotted over time for the three tributaries (fig. 4). The percentage of total N in the organic form is highest during the warmer months for most of the samples. This pattern is especially noticeable in the samples from Old Mill Brook and Upper Stony Brook. During the colder months, the amount of inorganic N increases substantially. Creed and Beall (2009) suggest that topographic depressions and flat areas in watersheds can transform inorganic N (particularly NO_3) to organic N, primarily through microbially mediated reactions.

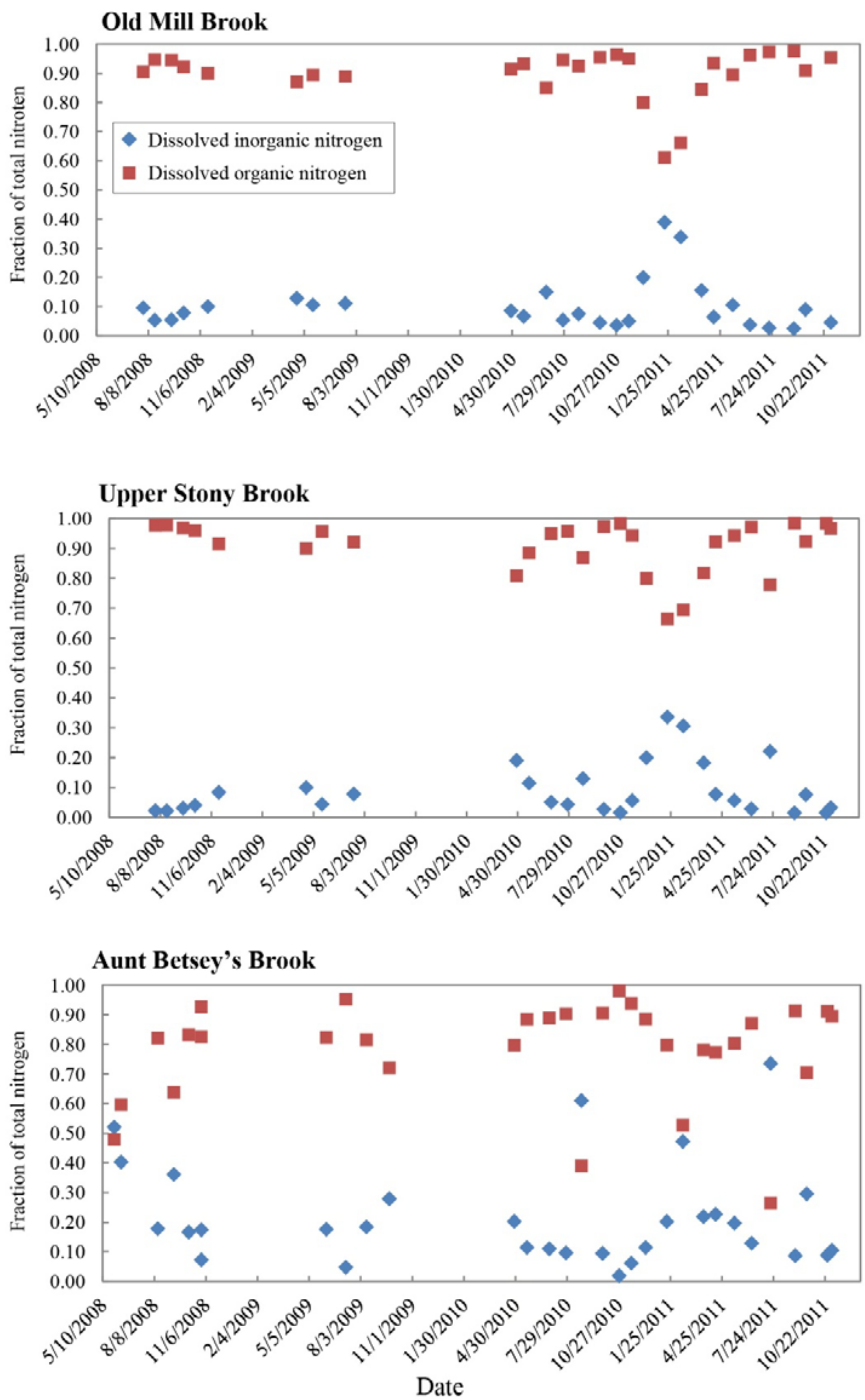


Figure 4. Graphs showing ratio of organic and inorganic nitrogen (N) to total N in samples from selected tributaries to Northeast Creek, Bar Harbor, Maine, 2008–11.

The percentages of inorganic N are generally higher in samples from Aunt Betsey's Brook than in those from the other two tributaries (as is the magnitude of inorganic N) (fig. 3), and the seasonal pattern is less pronounced (fig. 4). The topographic setting of Aunt Betsey's Brook is not substantially different from the other watersheds, so natural topographic differences do not appear to account for the differences in proportions of nitrogen constituents in this watershed. The differences could be a reflection of the fact that the Aunt Betsey's Brook watershed has a larger percentage of urban or suburban land use (with residential construction and associated septic systems), and that the septic systems employ older technology than much of the newer construction in the Old Mill Brook watershed. NH_4-N concentrations are higher in Aunt Betsey's Brook than in the other tributaries, and NO_2+NO_3-N concentrations are substantially higher than in Old Mill Brook (fig. 3). Both NH_4 and NO_2+NO_3 are produced from septic systems.

Relations Between Constituent Concentrations and Streamflow

The relation between nitrogen concentrations and streamflow is slightly different for each of the tributaries. Old Mill Brook and Upper Stony Brook both exhibit a decrease in total N concentration with increasing streamflow (fig. 5). The lowest flows in Old Mill Brook (less than about 2 cubic feet per second (ft^3/s)) are associated with total N concentrations in the range of 0.3 to 0.8 mg/L (fig. 5), and those in higher flows (up to about 40 ft^3/s) range from less than 0.1 to about 0.6 mg/L. In Upper Stony Brook, the lowest flows (less than about 1 ft^3/s) are associated with concentrations of total N in the range of 1.0 to 1.5 mg/L, whereas those in higher flows (up to about 10 ft^3/s) range from 0.2 to 0.8 mg/L. The highest flows for both streams are associated with some of the lowest measured total N concentrations. This pattern of decreasing concentration with increasing streamflow also is observed, to a lesser degree, in French Hill Brook. Dilution of higher concentration base flow with lower concentration storm runoff could explain the observed relation. The relation between flow and total N concentration for Lower Stony Brook and Aunt Betsey's Brook is less clear, although the highest flows are associated with lower concentrations than the lower flows. Because the Lower Stony Brook site is just downstream from a surface-water body (Hamilton Pond), mixing within the pond would be expected to dampen any chemical signal in water entering the pond from upstream during high-flow events. The reason for the absence of a relation between flow and concentration in Aunt Betsey's Brook is not readily apparent. The number of sampling events is small for all the tributaries, however, and additional water-quality samples and streamflow measurements may be necessary to identify a concentration–streamflow relation that yields more information about processes in the tributary watersheds.

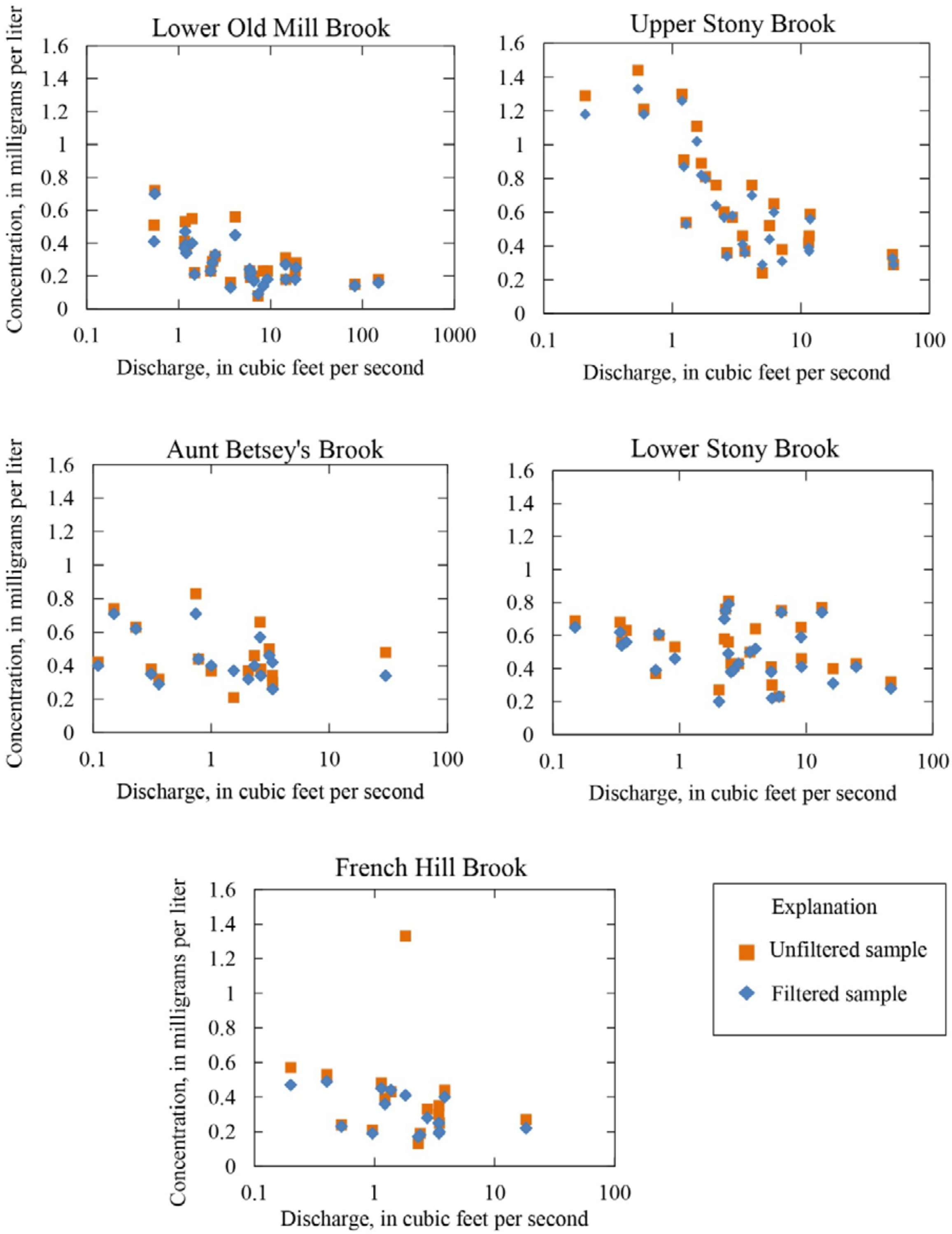


Figure 5. Graphs showing variation in total nitrogen concentration with stream discharge in tributaries to Northeast Creek, Bar Harbor, Maine, 2008–11.

Comparison of Total Nitrogen Concentrations in Northeast Creek Tributaries, 1999–2000 and 2008–11

The concentrations of total N (unfiltered) in water samples from the four tributaries sampled in the 1999–2000 study were compared to the concentrations in samples collected at the same sites during the 2008–11 study (fig. 6). Upper Stony Brook was not included in the comparison because it was not sampled in the first study. Overall, the concentrations of total N do not appear different between the two studies. Nonparametric two-sample t-tests showed no significant differences (at an α of 0.05) between the two datasets for any of the tributaries. The highest measured concentrations in Aunt Betsey's Brook and French Hill Brook were higher in the more recent study, indicating a possible long-term trend toward higher concentrations in those tributaries, but the opposite result was observed in Old Mill Brook and Lower Stony Brook, where the highest concentrations were measured in the earlier study. However, naturally high variability in total N concentrations over time is to be expected, regardless of whether there is any long-term trend in the data.

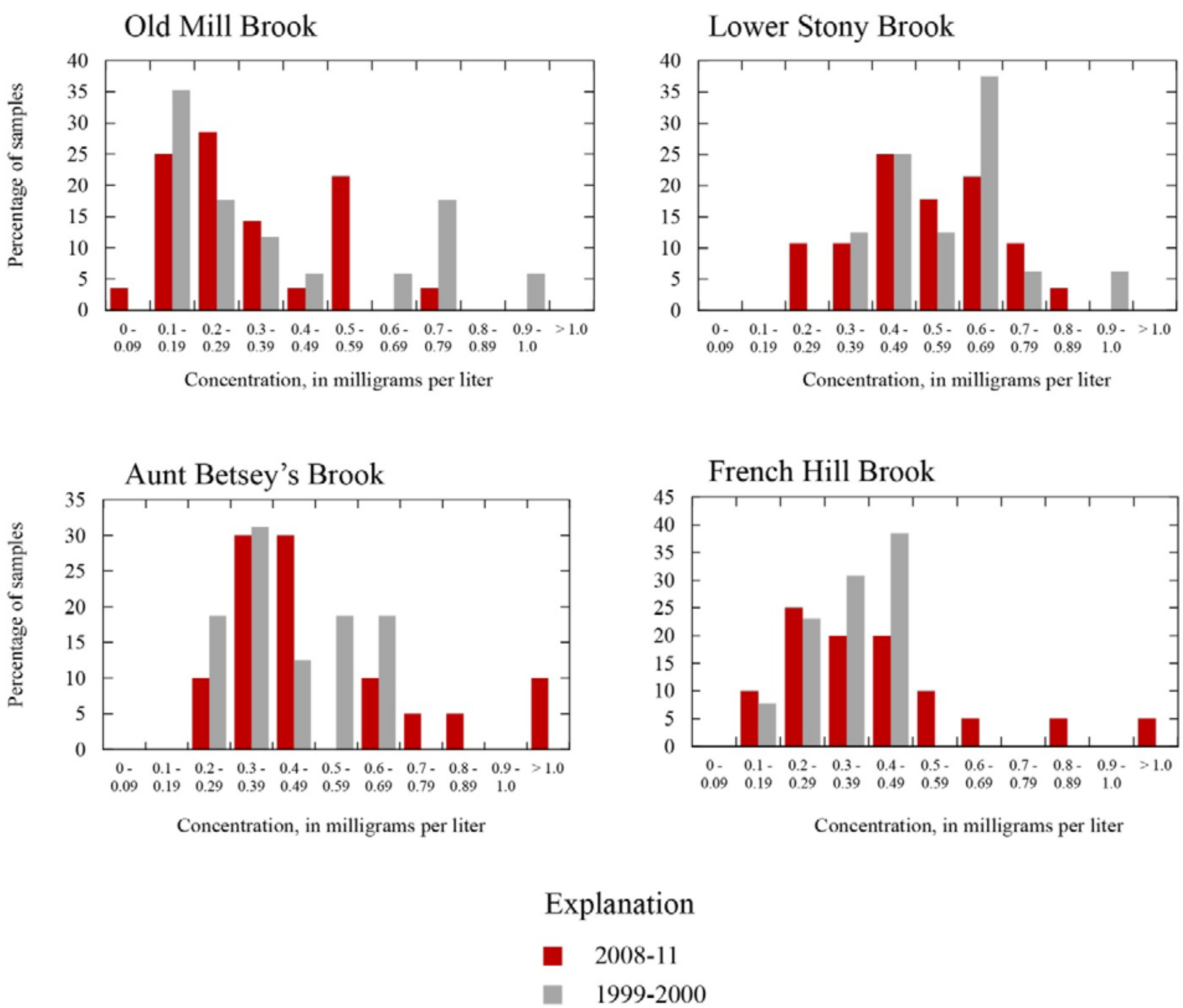


Figure 6. Bar graphs showing comparison of total nitrogen concentrations in samples from tributaries to Northeast Creek, Bar Harbor, Maine, 1999–2000 and 2008–11 (>, greater than).

Estimation of Nitrogen Loading to Northeast Creek, 2010 Time Period

Loads in the tributary streams to Northeast Creek were estimated in the same manner as those estimated for the 1999–2000 study (Nielsen, 2002b). The LOADEST program requires a continuous record of daily mean streamflow values for the estimation period, and a time series of paired constituent concentrations and instantaneous streamflows, with a minimum number of concentration values above the detection limit.

The loads estimated with the LOADEST software were based on a dataset of continuous daily mean streamflows derived from instantaneous streamflow measurements made during the field study, using techniques described in this report, and on analytical results for water-quality samples collected during the field study. These load estimates are hereafter referred to as "estimated loads" or "measured loads" to distinguish these field-based estimates from the estimates predicted from simulation of nitrogen export from watersheds based on land use and export coefficients, described by Guntenspergen and others (2009), and referred to as "predicted loads" in this report. Technically, constituent loads are not "measured" instream, but the estimates are based on instream field measurements and analyses of instream water quality.

Generation of Daily Mean Streamflow Values for Use in Load Estimation

The daily mean streamflow datasets required for load estimation were developed for each tributary stream by using the MOVE.1 technique (Hirsch, 1982) and the instantaneous streamflow measurements from 2008–11, similarly to those developed for the 1999–2000 study (Nielsen, 2002b). This technique uses log-transformed instantaneous-streamflow data from the tributary streams paired with continuous daily mean flows for an index stream to develop equations that predict continuous daily mean flows for the tributary streams, with statistical distributions similar to those expected if the daily streamflows actually had been measured (Helsel and Hirsch, 1992).

The USGS streamflow gage at Otter Creek in Bar Harbor (station 01022840) was used as the index gage for all of the daily mean streamflow estimations for the 2008–11 study. Very low flows and zero-flow values in the measured tributary streams present problems with this method, as all the calculations are done in log space, so the days with zero or near-zero flow were omitted from the development of the streamflow estimation equations. Each site had either 18, 26, or 28 pairs of flows with which to develop the equations (table 3). The R^2 values describing the correlation between the instantaneous discharges at the Northeast Creek tributary sites and the daily mean flows at the Otter Creek index site (in log space) ranged from 0.67 (at the Lower Stony Brook site) to 0.88 (at the Aunt Betsey's Brook site) (table 3). Values at the Lower Stony Brook site were lagged 1 day compared to those at the Otter Creek site because of storage in Hamilton Pond upstream. Daily mean flows were estimated for each site between the start and end dates of streamflow data collection (table 3).

Table 3. Summary of data used in the MOVE.1 estimation of daily mean streamflows at the Northeast Creek tributary sites, 2008–11.

[R^2, correlation coefficient squared; USGS, U.S. Geological Survey]

Site name (USGS station number)	Start date	End date	Number of non-zero stream-flow measure-ments	R^2 relating instanta-neous measure-ments to index site daily mean flows	Tributary site stream-flow mean (log)	Tributary site streamflow standard deviation (log)	Index site streamflow mean (log)	Index site streamflow standard deviation (log)
Old Mill Brook (01022805)	7/30/2008	11/3/2011	26	0.82	0.66549	0.60901	0.52120	0.61693
Upper Stony Brook (01022809)	7/30/2008	11/3/2011	28	0.77	0.26524	0.76561	0.43750	0.58435
Lower Stony Brook (01022810)	7/30/2008	11/3/2011	28	0.67	0.38344	0.69074	0.40547	0.58442
Aunt Betsey's Brook (01022815)	4/28/2010	11/3/2011	18	0.88	-0.01000	0.76802	0.72241	0.67445
French Hill Brook (01022817)	4/28/2010	11/3/2011	18	0.79	0.03687	0.71000	0.67847	0.64363

Methods for Estimating Nitrogen Constituent Loads

The LOADEST program (Runkel and others, 2004) was utilized to develop regression equations relating constituent concentration to daily mean streamflow for NO_2+NO_3-N and total N for each tributary stream. LOADEST can evaluate up to nine potential models for the estimation of loads to determine which model best fits the data for each dataset. The models include various combinations of explanatory variables, including the natural log of streamflow, the square of the natural log of streamflow, decimal time, and sine and cosine terms to address seasonal variability.

The program utilized the adjusted maximum likelihood estimation (AMLE) method to select and test model coefficients, using the Akaike Information Criterion (AIC) and the Schwartz Posterior Probability Criterion (SPCC) to evaluate the various possible models (Runkle and others, 2004). The AMLE method reduces bias when censored data (concentrations below the detection limit) are present. Once the "best" model was selected by the LOADEST program, it was applied to the daily streamflow dataset for each stream to determine total, seasonal, and annual loads.

A new version of the load estimation software (LOADEST) became available between the two studies, which primarily affected the calculation of the 95-percent confidence intervals on the load estimates. The LOADEST output from the 2000 loading estimates provided a measure of the standard error of the prediction, which was used to calculate 95-percent confidence intervals on the estimates for the earlier time period. The LOADEST output from the 2010 loading estimates provided the 95-percent confidence intervals on the estimates directly.

Nitrogen Constituent Load Estimates for Northeast Creek Tributaries, 2010 Time Period

Loads of total N and NO_2+NO_3-N were estimated for the Northeast Creek tributaries by using all available data for each site. Consequently, loads for Aunt Betsey's Brook and French Hill Brook were estimated by using data for 2010–11, whereas load estimates for the other sites were estimated by using data for 2008–11 (table 2). The number of censored values in the NH_4-N data exceeded the threshold for load estimation in LOADEST. Consequently, NH_4-N loads and organic nitrogen loads could not be estimated. The LOADEST program produced estimates of mean daily loads in kilograms per day on an annual basis, with upper and lower 95-percent confidence intervals. Multiplying the mean annual daily load by 365 gave estimates of average annual loads for each of the sites. The annual loads represent averages for the years used in the estimation, rather than annual loads for specific years. Seasonal estimates were also produced, but were not the focus of this study, as the decision support system (DSS) uses the annual loading rate in its output.

Either 20 or 28 uncensored concentration values were used in the load estimation models for total N for the five sites (table 4), and from 8 to 24 uncensored values were used for NO_2+NO_3-N. Old Mill Brook had only eight uncensored values for NO_2+NO_3-N, resulting in a high level of uncertainty for this estimate, with an R^2 of zero and very high residual variance (table 4). The sites with a greater number of uncensored values had higher R^2 values and lower residual variances but, in general, the regression results for the NO_2+NO_3-N load estimates were much more uncertain than those for the total N load estimates, which had R^2 values as high as 0.92 and very low residual variances.

Table 4. Load estimation model characteristics and estimated average annual loads and loading rates for Northeast Creek tributary sites, determined from sampling results, 2008–11.

[CI, confidence interval; kg, kilograms; kg/d, kilograms per day; kg/ha/yr, kilograms per hectare per year; R^2, correlation coefficient squared; N, nitrogen]

Monitoring watershed and constituent	Concentration regression results: Number of observations	Number of uncensored observations	R^2	Residual variance	Estimated daily mean load, in kg/d: Mean daily load	95-percent lower CI	95-percent upper CI	Standard error	Annual load, kg	Annual loading rate, kg/ha/yr
Total N										
Old Mill Brook	28	28	0.69	0.0928	4.33	3.69	5.06	0.34	1,580	2.3
Aunt Betsey's Brook	20	20	0.73	0.0645	1.06	0.88	1.27	0.09	387	1.9
Upper Stony Brook	28	28	0.92	0.0285	6.76	5.67	8.00	0.59	2,470	3.7
Lower Stony Brook	28	28	0.60	0.0496	8.56	7.16	10.2	0.74	3,120	4.2
French Hill Brook	20	20	0.65	0.1184	1.03	0.82	1.28	0.11	376	2.9
Nitrite + Nitrate as N										
Old Mill Brook	28	8	0.00	2.227	0.26	0.06	0.73	0.17	95	0.14
Aunt Betsey's Brook	20	19	0.49	0.2288	0.090	0.070	0.130	0.010	33	0.16
Upper Stony Brook	28	20	0.70	0.5085	0.52	0.22	1.07	0.22	190	0.28
Lower Stony Brook	28	24	0.72	0.3141	0.41	0.2	0.74	0.14	150	0.2
French Hill Brook	20	12	0.43	0.6768	0.036	0.020	0.058	0.009	13	0.1

Mean daily loads for total N ranged from 1.03 kilograms per day (kg/d) in French Hill Brook to 8.56 kg/d in Stony Brook (at the lower site) (table 4). Average annual loads for total N ranged from 376 kilograms per year (kg/yr) in French Hill Brook to 3,210 kg/yr in Stony Brook (lower site). Annual estimated loads for NO_2+NO_3-N ranged from 13 kg/yr in French Hill Brook to 190 kg/yr at the Upper Stony Brook site. Chemical transformations in Hamilton Pond may be responsible for the lower estimated NO_2+NO_3-N load downstream (150 kg/yr) at the Lower Stony Brook site; however, because the confidence intervals for the upstream and downstream load estimates for Stony Brook overlap, additional data would be necessary to confirm the effects of Hamilton Pond. When annual loads are divided by drainage area to adjust for tributary size, the annual loading rates for total N, in kilograms per hectare per year, for the sites vary considerably (fig. 7, table 4), from 1.9 kilograms per hectare per year (kg/ha/yr) in Aunt Betsey's Brook to 4.2 kg/ha/yr in Lower Stony Brook. For all tributaries combined, the average annual loading rate was 3.1 kg/ha/yr.

The 95-percent confidence intervals for the total N estimates range from ± 15 to 24 percent of the estimated load. Because concentrations of NO_2+NO_3-N nitrogen generally have greater variability than those of total N, with a larger number of censored values, the 95-percent confidence intervals for the NO_2+NO_3-N load estimates represent a much greater percentage of the estimated loads, ranging from ± 22 to 180 percent.

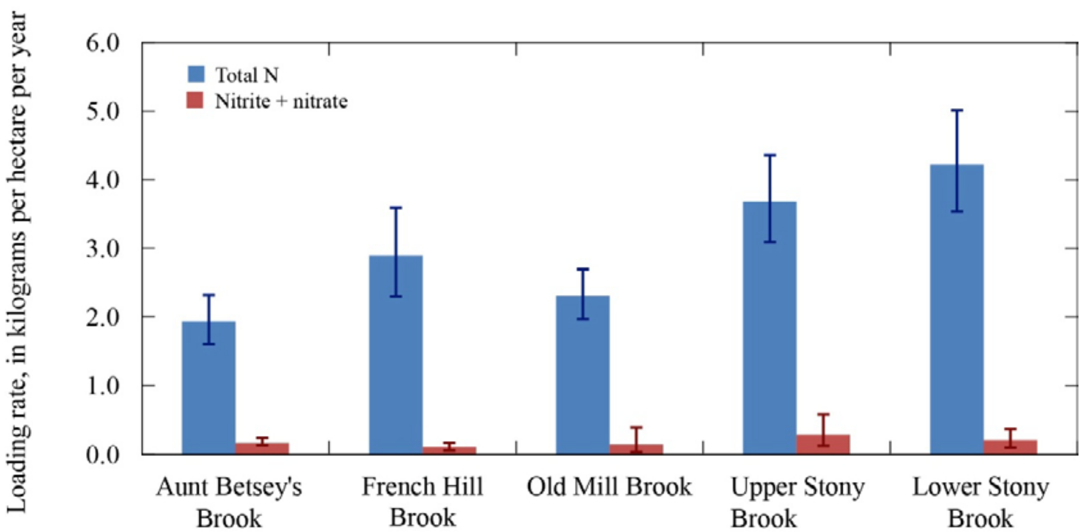


Figure 7. Boxplot showing estimated average loading rates (yields) of total nitrogen (N) and nitrite+nitrate (N) for tributaries to Northeast Creek, Bar Harbor, Maine, with 95-percent confidence intervals, for the 2010 time period. (The 2010 time period includes samples from 2008–11.)

Loading rates for total N in the Northeast Creek tributary watersheds are similar to those in other small, northern latitude forested watersheds. Total N export rates from small undeveloped watersheds in the Algoma Highlands of southern Ontario, at the eastern end of Lake Superior, ranged from 3.65 to 6.79 kg/ha/yr (Creed and Beall, 2009). Nitrate-N export from nine watersheds in the mid-Appalachians of the U.S. (West Virginia, Maryland, and Pennsylvania) ranged from 0.04 to 7.88 kg/ha/yr (Willard and others, 1997). In Finland, export of nitrate-N plus organic N from six small forested watersheds ranged from 1.29 to 2.2 kg/ha/yr (Andersson and Lepistö, 2000).

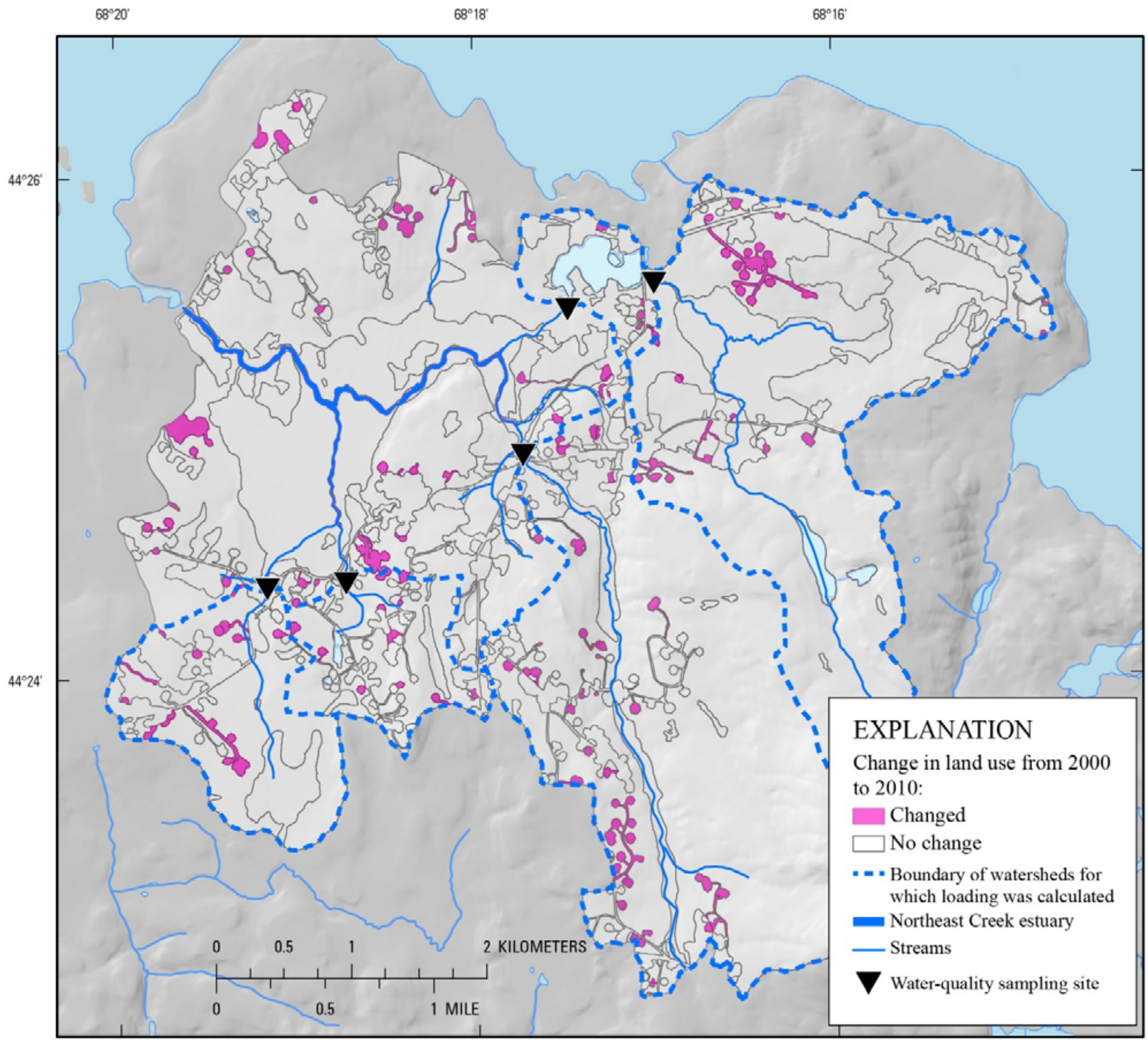
Northeast Creek Watershed Land-Use Change, 2000 to 2010, and Predicted Effect on Nitrogen Loading

The GIS-based simulation tool or decision support system (DSS) used by the National Park Service and the Town of Bar Harbor to predict nitrogen loading applies nitrogen export coefficients to each land-use polygon in the spatial land-use data (Guntenspergen and others, 2009). This method can best be considered as a way to evaluate potential changes in average conditions over time. Data from the Town of Bar Harbor's Assessing Department (unpublished data on file at the office of the Town of Bar Harbor, Bar Harbor, Maine) showed an increase in the number of rural houses in the watersheds of more than 40 percent from 2000 to 2008, when the first part of this study began. By using updated aerial photos available from online databases, comparisons can be made between the land use at the time that the DSS was developed (2000) and 2010. A new land-use GIS data layer was developed from 2010 aerial imagery, by using the same mapping techniques as those used in the 2000 land-use delineation that formed the basis of the DSS. The same land-use categories (forest, wetlands, urban/suburban (residential), agriculture, open water, and quarry/open rock/gravel pits) were used to ensure compatibility with the earlier mapping. The 2000 land-use data layer was used as a starting point for delineating changes.

Comparing the new (2010) land-use distribution with the old (2000) shows that although there was a fairly large increase in the number of residential units in the watershed, only 2.6 percent of the watershed (68 hectares) changed land-use categories (fig. 8). The land-use change was fairly evenly distributed throughout the NEC watershed, and none of the tributary watersheds monitored for the loading study had a substantially different percentage of land-use change (table 5). Almost all of the changes were from the forest or agriculture category to urban/suburban.

Table 5. Land-use changes in the Northeast Creek tributary watersheds, 2000 to 2010.

Subwatershed	Total area, in hectares	Number of hectares of land-use change	Percent change
Aunt Betsey's Brook	202	7.6	3.7
French Hill Brook	130	3.8	2.9
Old Mill Brook	685	18.2	2.7
Stony Brook	741	15.4	2.1
Unmonitored uplands	559	23.1	3.4



Base fom U.S. Geological Survey digital line graphs, 1:24,000 scale,
Universe Transverse Mercator projection, centrial meridian -69 degrees west.
Shaded elevation base from U.S. Geological Survey National Elevation Dataset
10-meter digital elevation model.

Figure 8. Map showing changes in land use in the Northeast Creek watershed from 2000 to 2010, Bar Harbor, Maine.

Decision Support System Predictions of Changes in Nitrogen Loading to Northeast Creek

Simulations were run with the 2000 land-use distribution and the updated 2010 land-use distribution to determine the changes in nitrogen export that would be predicted from the 2.6-percent land-use change that occurred during that 10-year time period. The export coefficients for land-use categories used in the DSS simulations were determined by using previously published ranges of values and a minimum least squares best-fit optimization approach based on land use and nitrogen loading calculations for five watersheds on Mount Desert Island in 1999–2000 (Guntenspergen and others, 2009). Total N export coefficients for agriculture, forest, urban/suburban (residential), and wetlands land-use types were derived to be 4.7, 1.5, 6.9, and -0.1 kg/ha/yr, respectively. Two land-use types had export coefficients of zero: open water and quarry/open rock/gravel pits. More detailed descriptions of the land-use types and determination of the export coefficients can be found in Guntenspergen and others (2009) and Rohweder and others (2004).

For the entire NEC watershed, predicted load for total N increased from 5,210 kg/yr in the 2000 time period (1.98 kg/ha/hr) to 5,560 kg/yr in the 2010 time period (2.12 kg/ha/yr), a 7-percent increase. The spatially averaged predicted total N yields for 2010 for all tributary watersheds (monitored or unmonitored) in the NEC watershed, including all land-use types, ranged from 2.03 to 3.76 kg/ha/yr. The highest yield was for a tributary with a very small watershed (28 ha) near Stony Brook and Old Mill Brook (not sampled during the loading study; see fig. 1) that is mostly residential (urban/suburban) land use mixed with agriculture and forest. The lowest total N yields were for the larger tributary watersheds, such as Old Mill Brook, that are largely forested and wetland areas. Predicted increases in total N load for the tributary watersheds that were monitored for nitrogen loading are illustrated in figure 9. Individually, the predicted increases in total N load in the tributary watersheds ranged from 5.6 percent in Stony Brook to 8.6 percent in Aunt Betsey's Brook.

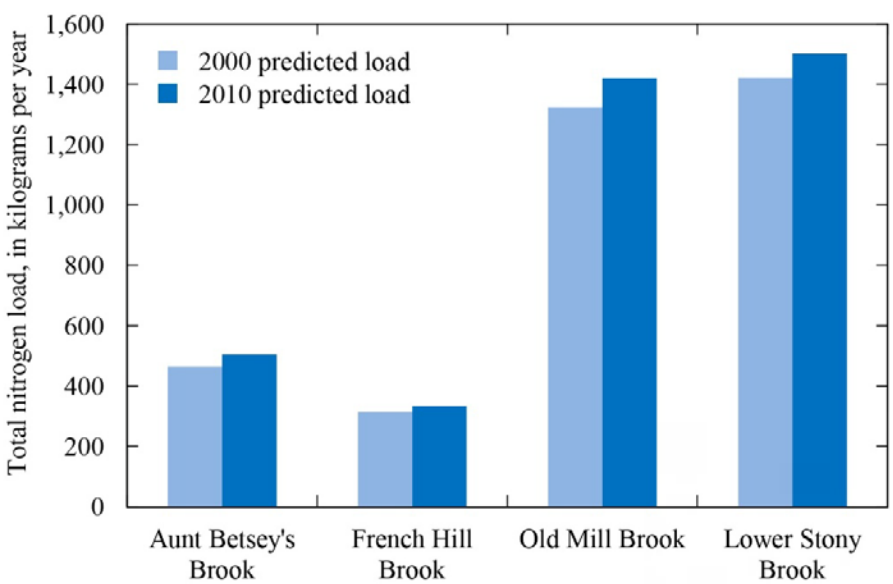


Figure 9. Bar graph showing predicted annual loads of total nitrogen to Northeast Creek from selected tributaries for 2000 and 2010, from the decision-support system, determined from changes in land use, Bar Harbor, Maine.

The DSS tool not only provides the predicted total N loading rates from the various watersheds in the study area, but also compares them to thresholds that can be used to put the loads in an ecological context. The threshold for the transition between “healthy” and “degrading” is 2.2 kg/ha/yr for the entire watershed, and the threshold between “degrading” and “degraded” is 4.4 kg/ha/yr (Neckles and others, 2003). In 2000, the loading rate predicted by use of the DSS was 1.98 kg/ha/yr, and in 2010, the prediction was 2.12 kg/ha/yr. It should be noted that these thresholds were determined specifically for the NEC estuary, based on in-estuary experiments (Neckles and others, 2003). In the process for deriving the thresholds, it is also assumed that the loading rate during the growing season, when the experiments were conducted, is the same as the year-round average loading rate.

Changes in Estimated Total Nitrogen Loading to Northeast Creek, 2000 to 2010

The main focus of this study was to evaluate the loading results from the 2010 time period, based on a field study of streamflow measurements and water-quality sampling, and compare the results to both those for the 2000 time period and the predictions from the DSS. Because the same methodology was used for the 2010 time period (sampling during 2008–11) as in the original study (2000 time period, with sampling during 1999–2000), it was possible to make a direct comparison of nitrogen loading between the two time periods. One small change from the original study (Nielsen, 2002b) was the redelineation of the drainage basins used for the calculation of the loading rate. The original watershed delineations were based on the topographic map contours, but the watersheds were redelineated on the basis of stereo orthophotograph pairs in 2001. Before comparing the two loading estimates, the 2000 loads were recomputed to reflect the adjusted watershed areas.

Changes in Total Nitrogen Loading Based on Sampling Data, 2000 to 2010

The average loading rates and total average annual load increased for all the tributaries sampled in both the 2000 and 2010 studies (table 6). Although the measured concentrations of nitrogen in samples collected during the two time periods were not significantly different statistically, the total loads estimated for the 2010 study were much higher than those estimated for the 2000 study (fig. 10). In all but the French Hill Brook tributary, where loads increased 16 percent, the 2010 loads were from 68 to 84 percent higher than the earlier loads. For the four tributaries combined, the load was 66 percent higher during the 2010 study. The average loading rates for three of the four tributaries for the 2010 time period are above the threshold that would move the Northeast Creek estuary from a “healthy” condition to a “degrading” condition, as is the 2010 loading rate for all tributaries combined (table 6).

Table 6. Total nitrogen loads and yields estimated from streamflow and water-quality datasets for tributaries to Northeast Creek, 2000 and 2010 time periods.

[kg/ha/yr, kilograms per hectare per year; kg/yr, kilograms per year; --, no data]

Watershed	Average loading rate, in kg/ha/yr		Average annual load, in kg/yr	
	2000	2010	2000	2010
Aunt Betsey’s Brook	1.1	1.9	210	387
French Hill Brook	2.5	2.9	324	376
Old Mill Brook	1.4	2.3	938	1,580
Upper Stony Brook	--	3.7	--	2,470
Lower Stony Brook	2.5	4.2	1,830	3,120
All tributaries combined	1.9	3.1	3,300	5,460

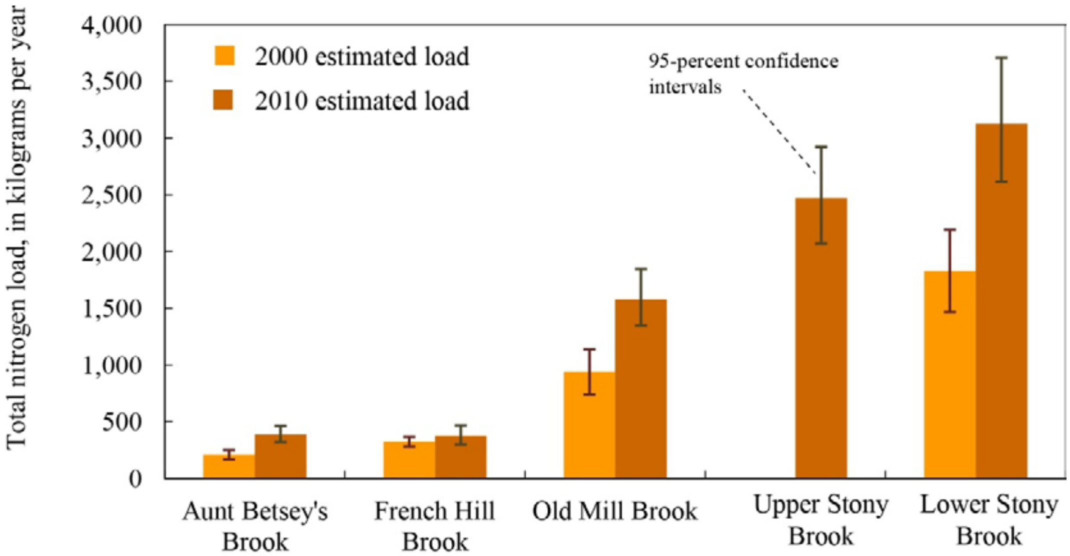


Figure 10. Boxplot showing estimated annual loads of total nitrogen from tributaries to Northeast Creek, determined from streamflow measurements and water-quality sampling, 2000 and 2010 time periods, Bar Harbor, Maine.

Factors Affecting Total Nitrogen Loads and Loading Rates

A number of different factors may be responsible for the observed increases in total N loading from 2000 to 2010. As is indicated by the land-use-based simulations, changes in land use can cause changes in loading, particularly if, over time, land uses that export less nitrogen are converted to uses that export more nitrogen. Changes in point sources (as separate from distributed land-use export from nonpoint sources) may increase or reduce loads if population increases or if improved technologies are implemented.

Other factors that can cause changes in loading include changes in climate and streamflow patterns. As calculated in the LOADEST program, load is a product of concentration and flow, and the LOADEST program estimates loads by using the observed flows for the period of the estimation (flow is typically the first term in the load estimation equation, and derivatives of flow may appear in other terms in the equation for a given stream). If the climatic conditions during the two different, relatively short-term study periods were significantly different, the loading estimates would also differ. independent of other potential causes.

One way to evaluate the climatic conditions during the two study periods is to examine long-term streamflow records for a nearby streamflow gage, and determine where the streamflow during the two study periods falls with respect to long-term regional averages. The record of annual mean streamflow, encompassing both data-collection periods (1999–2000 and 2008–11), was evaluated for two long-term USGS gages in eastern Maine, the Narraguagus River at Cherryfield and the Penobscot River at West Enfield (fig. 11). The annual mean streamflow in both rivers was about average during the earlier study (about 450 ft^3/s for the Narraguagus River and 12,500 ft^3/s for the Penobscot River), but appears from the graph to have been slightly above average during the second study (about 550–600 ft^3/s for the Narraguagus River and 15,000 ft^3/s for the Penobscot River). A graph of cumulative flow distribution for annual mean streamflow at the Narraguagus River at Cherryfield, with annual records dating back to 1949, illustrates where the years of data collection for the two studies fall within that long-term context (fig. 12). The annual mean streamflow at the Narraguagus River in 1999 and 2000 fell at approximately the 35th and 55th percentiles, respectively, of the total distribution. In other words, flow during these years was near the median flow. The annual mean streamflow for the second data-collection period (2008–11) was more varied, with flows falling at the 45th, 83rd, 87th, and 97th percentiles (fig. 12). Regional streamflow conditions during the second data-collection period were, for 3 of the 4 years, much above normal.

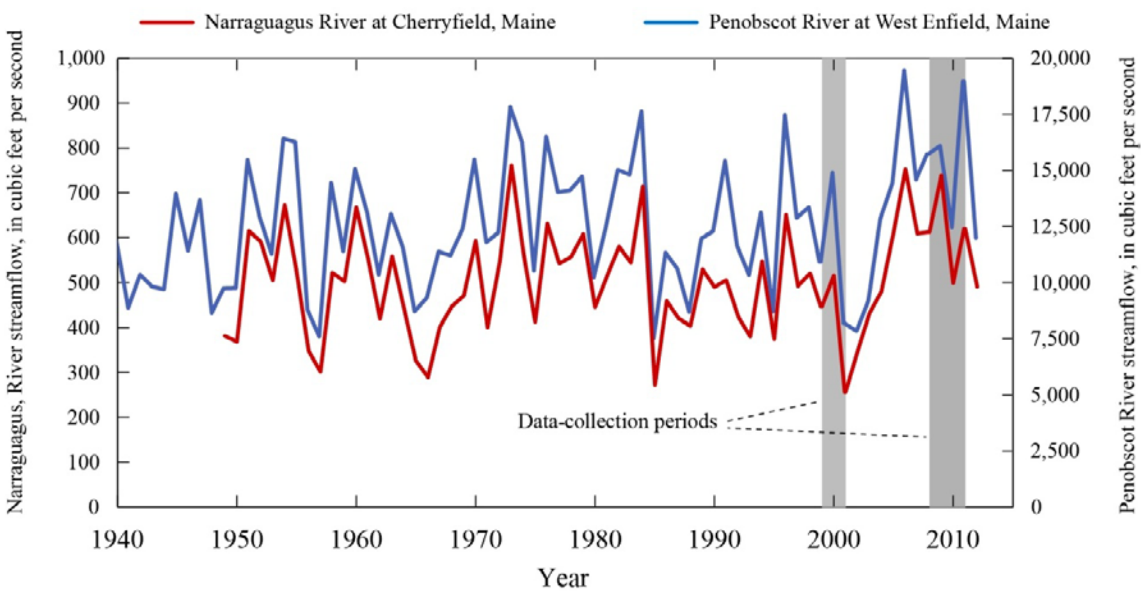


Figure 11. Hydrograph showing annual mean streamflow for period of record at U.S. Geological Survey streamflow gages on the Narraguagus River at Cherryfield and the Penobscot River at West Enfield, Maine, and the 2000 and 2010 data-collection time periods.

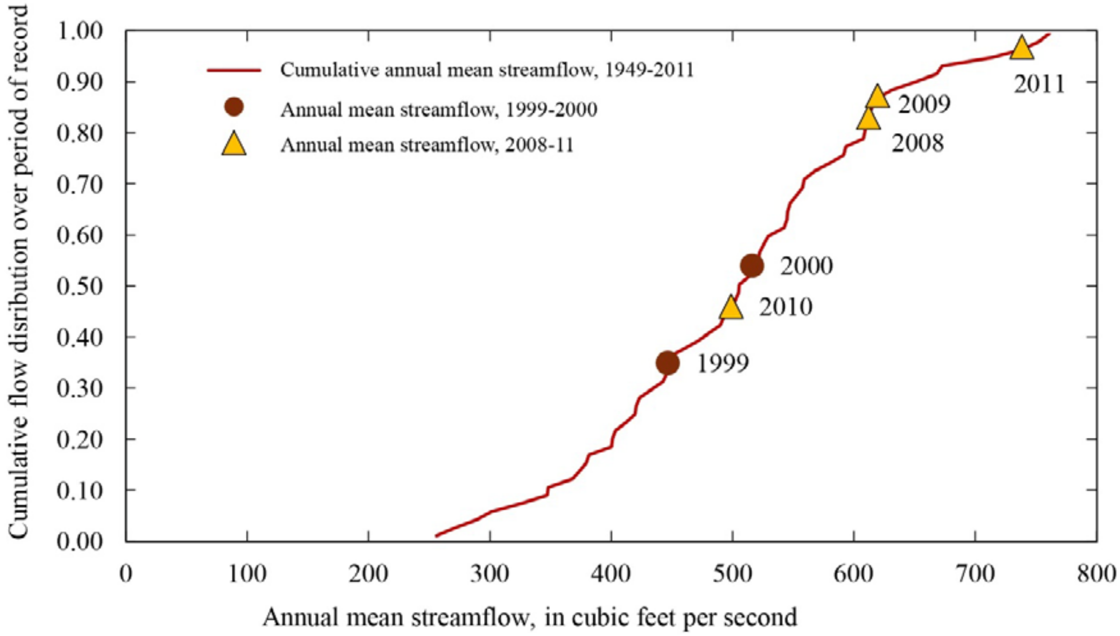


Figure 12. Graph showing cumulative distribution of annual mean streamflow at the U.S. Geological Survey streamflow gage at the Narraguagus River at Cherryfield, Maine, 1949–2010, and annual mean streamflow during the 1999–2000 and 2008–11 data-collection periods.

If the supply of N in the watersheds of NEC was finite, the amount of runoff would not produce a large change in loading, as the additional water would dilute the source and the total load would remain constant. Therefore, if N loading does increase with increasing runoff, there must be some factor or factors that could cause variation in N supply with climatic variability.

Researchers investigating temporal variability in N export from forested watersheds have found that N loading rates do, indeed, correlate with streamflow conditions. Andersson and Lepistö (2000) found that annual runoff was the single most significant factor in explaining variability in N yields. Other recent long-term studies of natural variability in loading rates have identified several hydrologically mediated processes that affect loading. Dry conditions and low soil-moisture levels are known to suppress microbial activity, and therefore also nitrogen transformations and export (Willard and others, 1997). Temperature-related effects on microbial activity were also cited as a factor in the variability of N export (Andersson and Lepistö, 2000). Topographically modulated hydrologic flushing—in other words, residence time of water in the soil column, which is in turn a function of both topography and rainfall patterns—has been identified as a major explanatory variable in N export (Creed and Beall, 2009). It is likely, therefore, that much of the observed increase in load in the NEC study area is linked to increased streamflow during the second data-collection time period.

The effect of atmospheric deposition on N loading may relate to spatial variation in atmospheric deposition over large distances, but the effect has not been observed everywhere. A USGS study of small undeveloped watersheds across the United States found that wet deposition of nitrate correlated well to nitrate yields in the eastern part of the country (Clark and others, 2000), but other studies have not found a strong link between atmospheric deposition and nitrogen yields (Andersson and Lepistö, 2000; Willard and others, 1997; Lovett and others, 2002). Other factors that have been linked to the spatial variability of N export include the ratio of carbon to nitrogen in soils and possibly forest type or disturbance history (Lovett and others, 2002; Andersson and Lepistö, 2000).

Changes in Nitrogen Load Predicted from Land-Use Data Compared to Estimated Changes Based on Field Studies in the Northeast Creek Watershed

The results of the two field-based N loading studies and the predictions for the 2000 and 2010 time periods from the DSS were compared in order to evaluate the effectiveness of the DSS (fig. 13). Overall, the magnitude of predicted change from the DSS from 2000 to 2010 is well exceeded by the magnitude of the estimated change in load based on the field study. This result indicates that the DSS may not be well suited to predicting N loading for a very specific time period, especially for one (such as 2010) that deviated substantially from "average" climatic conditions. The DSS uses land use as the only explanatory variable and, consequently, other factors that affect transport from the landscape are not incorporated in the predictions.

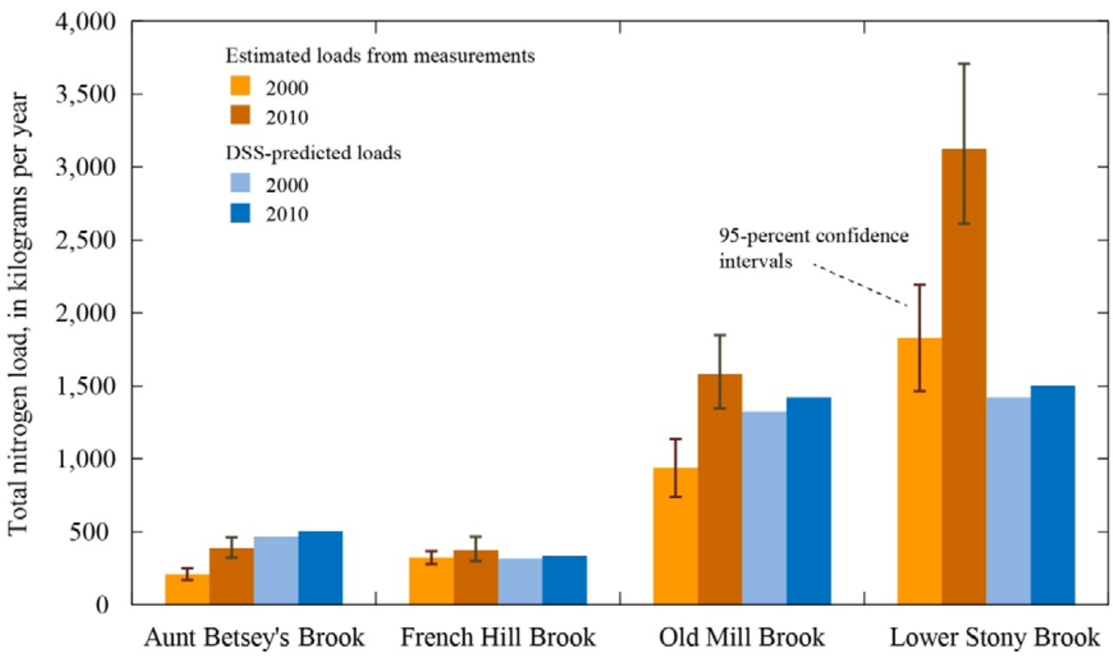


Figure 13. Boxplot showing estimated annual loads of total nitrogen from selected tributaries to Northeast Creek, determined from streamflow measurements and water-quality samples for the 2000 and 2010 time periods, and loads predicted by using the decision support system (DSS), 2000 and 2010, Bar Harbor, Maine.

Despite the magnitude of the differences between predicted and measured loads (the estimates based on field data), the DSS predictions fell within the 95-percent confidence intervals of the measured 2010 loads in two of the four tributaries, and represent to some degree the average measured loads for the two time periods in those two watersheds. The use of land-use-based export coefficients, although imperfect, is reasonable in some of the watersheds. The measured loads in Aunt Betsey's Brook were slightly lower than those predicted from the DSS. In Lower Stony Brook, however, the 2010 measured loads exceeded predicted loads by about a factor of two. Several possible explanations for this exist. The six land-use categories represented in the DSS may not sufficiently represent the actual variability in the landscape; some categories may be more heterogeneous than homogeneous, and categories may be too generalized, with respect to the magnitude of nitrogen sources. The climate-based variability seen in the other watersheds may, because of soil types or slope characteristics, be enhanced in Stony Brook, or the increased rainfall may have increased export from the urban/suburban land-use category more in that watershed than in others. Differences in the proximity of development to streams and monitoring locations may also be a factor; equal percentages of a given land use in two watersheds do not necessarily result in equal transport rates of nitrogen to streams. The measurement data, although providing the most realistic assessment of instream conditions determining nitrogen loads, could be improved by the addition of continuous streamflow monitoring at one or more locations in the watershed, year-round water-quality sampling in the tributaries, and monitoring of the water quality in the estuary itself.

Based on the sampling from the 2010 time period, it would be unwise to ignore the predictions of the DSS that increases in total nitrogen loads are likely to occur as land use shifts from undeveloped, primarily forested land to more urbanized land, and that some change in long-term nitrogen loading may already have occurred. However, the increases in annual loading of total nitrogen may result in large part from variability in streamflow—that is, above-average streamflow during much of the 2010 sampling period. The differences in streamflow conditions between the two time periods make interpretation and comparison of the specific loading values (as predicted by the DSS) difficult. The DSS may be performing as intended in predicting the change in loading resulting from land-use change.

Similarly, it would be difficult to firmly conclude that the current loads, on a long-term basis, are now exceeding the ecosystem-health threshold established for Northeast Creek, pushing the estuary into the "degrading" category, even though the combined loading rate for the monitored tributary watersheds was 3.1 kg/ha/yr (the threshold value is 2.2 kg/ha/yr). The length of time needed for the estuary to begin to degrade once conditions have in fact crossed that threshold also is unknown. However, it cannot be ruled out that conditions are, in fact, degrading as land is converted from forested and agricultural uses to rural homes and house lots. The lack of any monitoring within the estuary itself reduces the ability to draw definite conclusions about the ecological condition of the estuary at the present time (2012).

Summary and Conclusions

This study of nitrogen (N) loading in the tributaries of the Northeast Creek (NEC) estuary was begun in 2008 and continued until 2011, and was conducted by the U.S. Geological Survey (USGS) in cooperation with the National Park Service and Acadia National Park (ANP) and the Town of Bar Harbor, Maine. The study builds on an earlier USGS study of nitrogen loads conducted from 1999 to 2000.

The objectives of this report are to (1) present recent (2010) nitrogen concentrations and loads, and to document changes in nitrogen loading to Northeast Creek from 2000 to 2010; (2) evaluate the effects of increased amounts of rural residential housing within the watershed since 2000, by using load estimates based on the streamflow measurements and water-quality analyses (referred to here as “measured loads”), as well as predictions from the land-use-based simulations by use of export coefficients (referred to here as “predicted loads”); (3) evaluate the effectiveness of the decision support system (DSS) in predicting nitrogen loads; and (4) improve understanding of the variability in nitrogen loading, and the factors that contribute to that variability.

Stream samples for nitrogen species were collected approximately monthly and concurrent instantaneous streamflow measurements were made in four tributaries to the NEC estuary. Samples were analyzed for total nitrogen, ammonia-nitrogen (NH_4-N), and nitrite-plus-nitrate-N (NO_2+NO_3-N), and organic nitrogen was calculated from measured values of other nitrogen constituents. Loads were estimated using the LOADEST software developed by the USGS, and total annual loads and loading rates were calculated, with 95-percent confidence intervals on the estimates, for the period generally centered around 2010, which are referred to as “the 2010 loads.” The 2010 load estimates represent an annual average for the sampling period 2008 to 2011. The 2010 loads were compared to those determined in the earlier USGS study by using the same methods used to estimate loads on the basis of sampling in 1999–2000, which are referred to as “the 2000 loads.”

The concentrations of inorganic N species (NH_4-N and NO_2+NO_3-N) in samples from 2008 to 2011 ranged from 0.0014 to 0.7 milligrams per liter (mg/L) of NH_4-N and from 0.003 to 0.17 mg/L of NO_2+NO_3-N. Total N concentrations ranged from 0.09 to 1.4 mg/L (filtered) and from 0.08 to 1.49 mg/L (unfiltered). Old Mill Brook had the lowest concentrations for all the nitrogen species and the Upper Stony Brook site had the highest concentrations of almost all the nitrogen species. Samples from Upper Stony Brook had higher concentrations than those from the Lower Stony Brook site for some constituents (except NO_2+NO_3-N and NH_4-N), indicating that processes in Hamilton Pond, such as nitrification and mineralization, may be converting organic N to inorganic forms, and denitrification may be reducing the total amount of N exiting the pond.

The concentrations of total N (unfiltered) in water samples from the four tributaries sampled in the 1999–2000 study were compared to the concentrations at those same sites during the 2008–11 study. Overall, the concentrations of total N do not appear different between the two studies. Nonparametric two-sample t-tests found no significant differences (at an α of 0.05) between the two datasets for each tributary.

LOADEST was used to develop regression equations relating constituent concentration to daily mean streamflow for NO_2+NO_3-N and total N for each tributary stream (NH_4-N loads and organic nitrogen loads could not be estimated because of the large number of censored values in the NH_4-N dataset). The daily mean streamflow datasets required for load estimation were developed by using the MOVE.1 technique for each tributary stream, and using the USGS streamflow gage at Otter Creek as the index gage for all of the daily mean streamflow estimations for the 2008–11 study.

Average annual loads for total N ranged from 376 kg/yr in French Hill Brook to 3,120 kg/yr at the Lower Stony Brook site. Annual estimated loads for NO_2+NO_3-N ranged from 13 kg/yr in French Hill Brook to 190 kg/yr at the Upper Stony Brook site. Chemical transformations in Hamilton Pond may be responsible for the lower estimated NO_2+NO_3-N load downstream at the Lower Stony Brook site, 150 kg/yr. Adjusting for watershed size, the annual loading rates from the different sites vary considerably, from 1.9 kilograms per hectare per year (kg/ha/yr) in Aunt Betsey’s Brook to 4.2 kg/ha/yr at the Lower Stony Brook site. For the NEC tributary watersheds combined, the loading rate for the 2010 time period was 3.1 kg/ha/yr.

The 95-percent confidence intervals for the total N estimates range from ± 15 to 24 percent of the estimated load. Because concentrations of NO_2+NO_3-N generally have greater variability than those of total nitrogen, with a larger number of censored values, the 95-percent confidence intervals for the NO_2+NO_3-N load estimates represent a much greater percentage of the estimated loads, ranging from

± 22 to 180 percent. A simulation tool or DSS has been used for several years by Acadia National Park and the Town of Bar Harbor and to conduct simulations of total nitrogen loads in the Northeast Creek watershed. The DSS uses land use and nitrogen export coefficients to predict how increases in rural housing developments and other land-use changes could be affecting the ecological health of the Northeast Creek estuary. On the basis of a 2.6-percent change in the land-use distribution from 2000 to 2010, the DSS predicted that the nitrogen loading to the estuary would increase by 7 percent. The predicted loading rate for 2010, averaged over the tributary watersheds, was 2.12 kg/ha/yr. This loading rate is just below the threshold of 2.2 kg/ha/yr identified as the level at which local estuaries may undergo a transition from a “healthy” to a “degrading” condition.

The changes in nitrogen loading to the estuary based on sampling, however, show a much greater increase than predicted by the DSS. The 2010 loading rates based on the sampling showed an overall increase from 1.9 (in 2000) to 3.1 (in 2010) kg/ha/yr for the NEC tributaries (a 66-percent increase over the 2000 loads). This value is well above the 2.2-kg/ha/yr threshold for continued estuary health. The average loading rates and total average annual load increased for all the tributaries sampled in both the 2000 and 2010 studies. Although the measured concentrations of nitrogen sampled during the two time periods were not significantly different statistically, the total loads estimated for the 2010 study were much higher than those estimated for the 2000 study. In all but the French Hill Brook tributary, where loads increased 16 percent, the 2010 loads were between 68 and 84 percent higher than the earlier loads.

The final goal of the study was to determine what factors, other than land use, that contribute to changes in nitrogen loading. Previous research by other investigators on natural variability in nitrogen export from northern-latitude forested watersheds has identified a number of factors that relate to the natural interannual variability in N export, the primary ones being variations in climate—specifically rainfall, streamflow (sometimes evaluated as runoff in other studies), and temperature. These climatic variables have been shown to relate to biotic and abiotic processes in soils that control N export, such as microbial activity, mineralization, and nitrification, as well as direct transport. The climatic conditions in the study area during the 2008–11 time period, when most of the sampling for this loading study was conducted, were overall much wetter than normal. Streamflow in one gaged river in the same part of the state was in the upper 83rd, 87th, and 97th percentiles of the long-term record of flow (going back to 1949) during 3 of the 4 sampling years. In contrast, climatic conditions during the 2000 loading study were very close to average for this part of Maine, indicating that a part of the increase in measured total N loading could be a result of the wetter climatic conditions during the second study and may not be related to a long-term trend caused by changes in land use. The measurement data, although providing the most realistic assessment of instream conditions determining nitrogen loads, could be improved by the addition of continuous streamflow monitoring at one or more locations in the watershed, and year-round water-quality sampling.

Although climatic conditions could be responsible for much of the increase in measured total N loading to the NEC estuary beyond the DSS-predicted loads, the available data do not allow for partitioning the increase into specific amounts from different causes. A conservative approach would be to assume that the DSS is correct in predicting that the change in land use that occurred between 2000 and 2010 likely contributed to some of the observed increase in total N loading from the NEC tributaries.

As long as forested areas in the NEC watershed continue to be converted to roads, driveways, and house lots, a shift toward higher N loading to the estuary will likely continue. If land uses that contribute a greater amount of total N are converted to land uses that contribute less, the loading from those parcels could decrease. The urban/suburban land-use category is itself quite heterogeneous, as it is comprised of lawns, houses with septic systems (of various ages), roads, driveways, and commercial areas (which may or may not also have septic systems). If any of those specific uses within the urban/suburban category were to reduce their N export, that could also act to mitigate the effect of converting additional forested land use to residential land use.

Future efforts to enhance the DSS could include a more in-depth analysis of the urban/suburban land-use category, including the possibility of dividing it into two categories based on the age of and (or) the septic technology used for rural residential housing. Any upgrades to the DSS tool will need to be undertaken with consideration of the power of the available data to support the calibration of additional variables or to recalibrate the land-use coefficients with the same or redefined land-use categories.

The DSS tool in use by Acadia National Park and the Town of Bar Harbor likely will continue to be useful in testing alternative development patterns, up to and including build-out scenarios, or in testing any community-wide targeted actions to reduce N export from specific land-use categories. However, results of this study indicate that the tool has limitations in predicting loading from a specific time period, at least in part because interannual hydrologic variability is not incorporated. Although the DSS was originally designed as a software tool using ArcView™, which is no longer a supported GIS software package, the calculations it performs can be recreated with modern GIS software for continued future use, or for refinement of its functions.

Because no current monitoring program provides any information about trends in actual estuarine ecological condition, the increase in N loading from 2000 to 2010 cannot be compared to any changes in the observed health of the estuary.

The 2008–11 field investigation of nitrogen loading has contributed to the understanding of variability of total N loading to NEC, and to the evaluation of the possibilities and limitations of land-use-based computer predictions of loads. Evaluations of spatial and temporal variability in measured nitrogen concentrations and loads indicate that long-term monitoring of this important ecological habitat is essential for understanding natural variability in nitrogen loads, temporal trends in concentrations and loads, the effects of streamflow variability, and the effects of changing land use and other factors that affect estuarine health. Ongoing monitoring needs that will support local managers in their efforts include continuous streamflow measurements and water-quality monitoring in freshwater tributaries to support load estimation and trend analysis, and coordinated monitoring of conditions in the estuary that determine estuarine health. Reliable and timely data and related interpretations will continue to provide the kind of information that can lead to effective collaboration among local governments, ANP, and other interested organizations to protect the NEC ecosystem.

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Nielsen—**Changes in Nitrogen Loading to the Northeast Creek Estuary, Bar Harbor, Maine, 2000 to 2010**—Open-File Report 2013–1256

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