Water Budget for and Nitrogen Loads to Northeast Creek, Bar Harbor, Maine

Water-Resources Investigations Report 02-4000

Prepared in cooperation with the National Park Service

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

Cover: Aunt Betsey's Brook and Fresh Meadow during high water.
(Photograph by Charles W. Culbertson)

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By Martha G. Nielsen

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Augusta, Maine
2002

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CONVERSION FACTORS, VERTICAL DATUM, AND OTHER ABBREVIATIONS

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	.6214	mile
millimeter (mm)	.03937	inch
	Area	
square kilometer (km^2)	.3861	square mile
	Volume	
milliliter (mL)	.0338	fluid ounce
liter (L)	.2642	gallon
cubic meter (m^3)	8.110×10^{-4}	acre-foot
cubic meter (m^3)	35.31	cubic foot
	Mass	
milligram (mg)	3.527×10^{-8}	ounce
kilogram (kg)	2.205	pound
kilogram per square kilometer per year ($kg/km^2/yr$)	5.710	pound per square mile per year
	Flow Rate	
cubic foot per second (ft^3/s)	.02832	cubic meter per second

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

$$°F = (1.8 \times °C) + 32$$

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

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

Other abbreviations used in this report:

nm, nanometer

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by Martha G. Nielsen

ABSTRACT

The potential for nutrient enrichment to coastal estuaries on Mt. Desert Island, Maine, may affect the health of these important ecosystems at Acadia National Park. Inputs of water and nitrogen entering one of these coastal estuaries, Northeast Creek, and adjacent wetlands on Mt. Desert Island were quantified in a recent study conducted by the U.S. Geological Survey, in cooperation with the National Park Service. Streamflow and concentrations of nitrogen species in the four perennial streams entering the wetland/estuary system were measured monthly for 18 months to estimate loads and develop a water budget. Old Mill Brook was instrumented with a continuous-recording streamflow gage; the MOVE.1 record-extension technique was used with this and several other nearby continuous gages to estimate daily surface-water inflow to the wetland. Inflow from ungaged basins was estimated from the unit-area yield calculated from data obtained from the gaged basins. Precipitation data collected at the National Atmospheric Deposition Program (NADP) site at Acadia National Park Headquarters and the Acadia National Park weather station were used to calculate atmospheric inputs. Evapotranspiration from the wetland was calculated using Fennessey and Vogel's regionalized multivariate regression model of Penman-Montieth evapotranspiration. Geologic data collected in the field and taken from published geologic maps indicate that ground water probably does not contribute significantly to the water budget of this wetland system. Surface-water outflow from the wetland was not calculated because of the tidal nature of the outlet of the wetland and the difficulties associated with measuring flow in a tidal stream.

The water-budget equation used in the analysis was used to calculate a residual term (interpreted to equal surface-water outflow plus or minus changes in storage plus errors in the other calculations) from surface-water inputs plus precipitation minus evapotranspiration. This residual term was larger than the calculated surface-water inflows in the fall, winter, and spring months, and probably consists of changes in storage and surface-water outflows. During the dry summer months when evapotranspiration was high, the residual term was smaller than surface-water inflow. This may be explained by the reduction in storage in the wetland as a result of evapotranspiration.

In this study, nitrogen (nitrate and total nitrogen) input loads were calculated with respect to Northeast Creek, rather than to the wetland, because the creek is more susceptible to ecological effects from development. Nitrogen loads were estimated from surface-water sources using the daily streamflow estimates calculated for the water budget and the monthly water-quality sampling data. Nitrate (as N) concentrations ranged from below detection (< 0.01 mg/L (milligrams per liter)) to 0.20 mg/L. Total nitrogen concentrations ranged from 0.19 to 0.98 mg/L. The rating-curve regression method was used to calculate daily loads from inflow streams. Average unit-area yields were used to estimate loads for the ungaged areas. Atmospheric inputs were calculated from the NADP nitrogen data.

Nitrogen yields from the inflow streams generally were small compared to yields from

streams in urbanized areas and otherwise highly affected streams elsewhere in the northeastern United States, where the median yield of total nitrogen is 520 kg/km^2/yr (kilograms per square kilometer per year), and yields can exceed 1,000 kg/km^2/yr in the most urbanized watersheds. Nitrate yields from the Northeast Creek inflow streams ranged from 13 to 44 kg/km^2/yr. Total nitrogen yields ranged from 130 to 270 kg/km^2/yr. Over the 18-month study period, the estuary received an estimated 5,900 kg (kilograms) of total nitrogen and 780 kg of nitrate. Atmospheric inputs (totaling 85 kg of nitrogen) represented only 1 percent of the total nitrogen load and less than 10 percent of the inorganic nitrogen load.

INTRODUCTION

Eutrophication of coastal estuaries is an important environmental concern along the eastern coast of the United States. Loads of nutrients, particularly nitrogen, to these estuaries have caused rapid shifts in plant communities (Harlin, 1995; Short and Burdick, 1996; Valiela and others, 1978). As nitrogen loads increase, algae growth increases to the extent that rooted aquatic plants, such as seagrasses, cannot compete and die out, leaving an algae-dominated system. Experiments on estuaries and estuarine plants have shown that nitrogen is the limiting nutrient in these systems (Harlin, 1995; Harlin and Thorne-Miller, 1981). Increases in loads of nitrate and ammonia have caused extensive growths of floating, mat-forming algae in estuaries that crowd out and shade the native rooted plants. Furthermore, when these algae die, they decompose and consume the available oxygen, causing a condition known as hypoxia, which can contribute further to habitat loss. Estuaries affected by eutrophication have been well-documented in North America, Australia, Italy, and elsewhere, including on Mt. Desert Island (Harlin, 1995; Kinney and Roman, 1998). The primary factor identified in these studies as contributing to eutrophication is nutrient enrichment from upland residential development (McClelland and Valiela, 1998; Valiela and others, 1992).

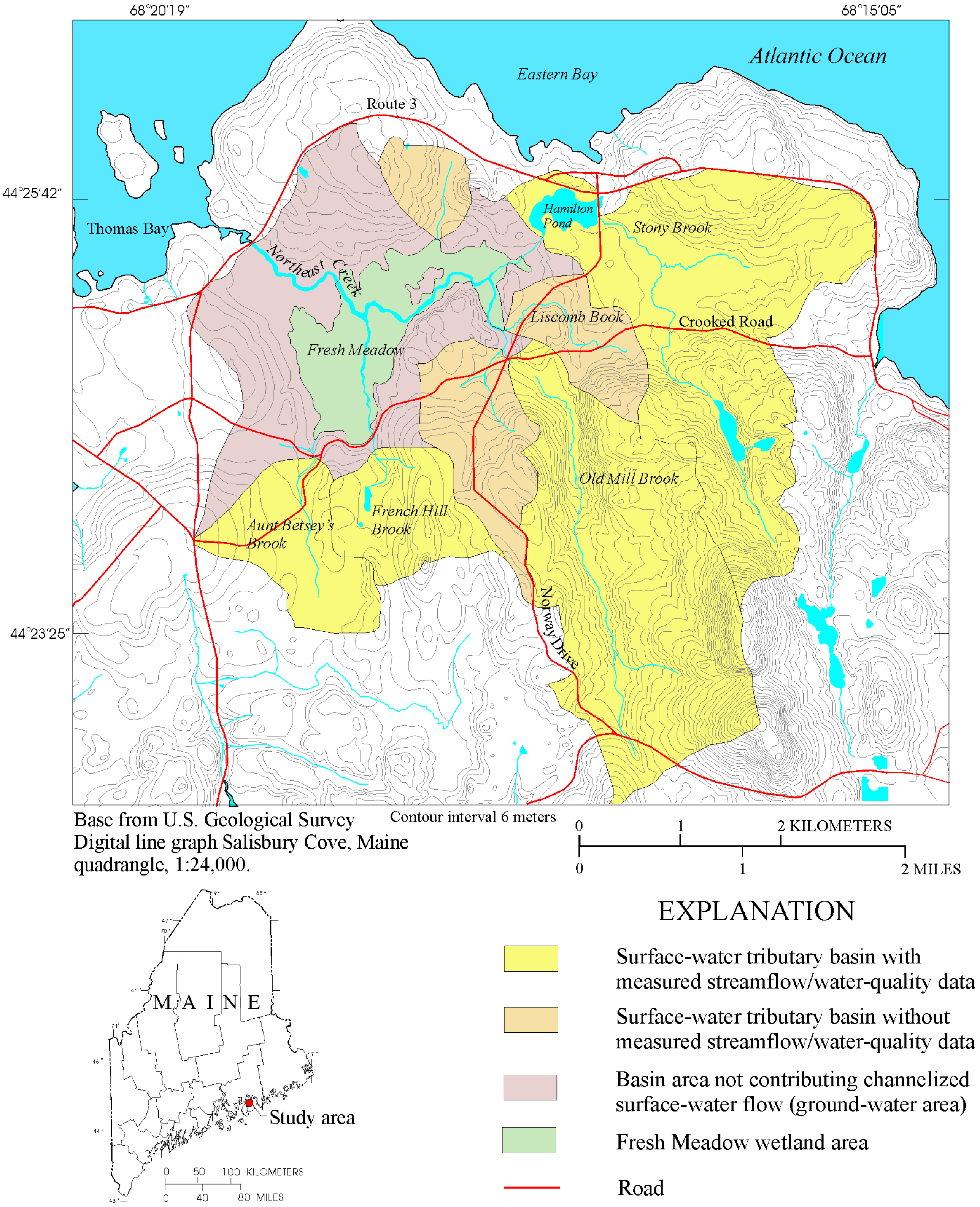
Eutrophication of one coastal estuary (Bass Harbor Marsh) has been documented at Acadia National Park, on Mt. Desert Island in coastal Maine (Doering and others, 1995). The conversion of widgeon grass habitat to algae took place there even when the overall loading rate was considered relatively low (Kinney and Roman, 1998). Concerns about the potential for the development of eutrophic conditions in other, currently unaffected estuaries on Mt. Desert Island have arisen because of the rapid growth in residential development across the island during the late 1990s. These residential developments are served by domestic septic systems, and nitrogen from the increasing number of these systems may affect the water resources of the island. In order to understand the possible effects of this development, the U.S. Geological Survey (USGS), in cooperation with the National Park Service, began a study of the largest estuarine wetland on Mt. Desert Island, the Northeast Creek/Fresh Meadow wetland, in 1999. The goals of the study were to develop a water budget for the area and to quantify hydrologic nutrient inputs to the system in order to evaluate the potential effect of increasing residential development in the uplands that drain into Northeast Creek.

Purpose and Scope

The Northeast Creek/Fresh Meadow estuarine wetland (referred to in this report as “the Northeast Creek/Fresh Meadow system”) includes a brackish tidal creek (Northeast Creek) referred to as “the creek” in this report, and a freshwater wetland (Fresh Meadow). This report describes the results of an investigation to develop a preliminary hydrologic budget for the Northeast Creek/Fresh Meadow system and to determine the flux of external nitrogen entering Northeast Creek. The study focused on the most readily determined aspects of the hydrologic budget of the system—surface-water inflows, atmospheric precipitation, and evapotranspiration. Nitrogen fluxes from surface-water inflows and atmospheric precipitation also were determined. Ground-water inflows also were considered. Data are presented for the period of study, from April 1999 through September 2000.

Description of Study Area

The Northeast Creek/Fresh Meadow system is located on the northern side of Mt. Desert Island, Maine (fig. 1). The outlet of Northeast Creek flows into Thomas Bay, and is constricted by the remains of an old rock dam and a bridge, which are at an elevation just slightly below mean high tide. Northeast Creek



Base from U.S. Geological Survey
Digital line graph Salisbury Cove, Maine
quadrangle, 1:24,000.

EXPLANATION

- 🟨 Surface-water tributary basin with measured streamflow/water-quality data
- 🟧 Surface-water tributary basin without measured streamflow/water-quality data
- 🟪 Basin area not contributing channelized surface-water flow (ground-water area)
- 🟩 Fresh Meadow wetland area
- 🟥 Road

Figure 1. Location of the Northeast Creek/Fresh Meadow study area, Bar Harbor, Maine.

receives tidal input during most of the lunar cycle and often is highly stratified. Freshwater from the inflow-streams rides above the saltwater because of density differences. During large runoff events, the freshwater completely flushes the saltwater out of the estuary, only to be partially displaced again by saltwater at the next tidal maximum (unpublished data available at the U.S. Geological Survey office in Augusta, Maine). Because the tidal saltwater stays at the bottom of the creek, the submerged vegetation consists predominantly of salt-tolerant *Ruppia maritima* (widgeon grass) along most of its length.

Four perennial streams and three intermittent streams feed the Northeast Creek/Fresh Meadow system. An area adjacent to the wetland does not contribute substantial channelized surface-water flow to the wetland or creek, but probably contributes shallow ground-water flow to the wetland. The four perennial streams and their drainage areas (fig. 1) are, from largest to smallest, Stony Brook (6.73 km^2), Old Mill Brook (6.13 km^2), Aunt Betsey's Brook (1.62 km^2), and French Hill Brook (1.40 km^2). The drainage basins of the three intermittent streams, including Liscomb Brook, have a total area of 3.40 km^2. Uplands immediately surrounding the wetland that are not drained by channelized surface runoff total 4.74 km^2 in area. The Fresh Meadow wetland covers an area of 1.85 km^2. The surface area covered by Northeast Creek itself (upstream from Route 3) is estimated to be 0.14 km^2.

One potentially important factor in the contribution of nitrogen to the system is the density of population in the basin. The population of the study area in 1981and 1996 (the only two years before the study when population data could be estimated in each basin) was estimated to be 246 and 365, respectively (table 1). Since 1996, residential growth in the study area accelerated further (unpublished records, Town of Bar Harbor, Maine). The 1981 estimate is based on the number of houses visible on the Salisbury Cove, Maine, 1:24,000-scale topographic map and occupancy data (1.55 persons per household) for Hancock County, Maine (U.S. Bureau of the Census, 1992). During the 1990s, this area was one of the last undeveloped non-park areas on Mt. Desert Island and was a desirable location for new houses. The 1996 estimate is based on the number of houses visible on 1996 digital orthophoto quadrangles. Some of these houses are occupied only seasonally, so the year-round population probably is somewhat lower. Most of the population growth in the study area has been in the western and southern parts—French Hill Brook, Old Mill Brook, and the southern unnamed tributary to Northeast Creek. The population of Stony Brook Basin has remained fairly stable. Because many houses there were built before the 1980s, they utilize older septic technology than that used when the newer houses in other parts of the study area were built.

Table 1. Estimated 1981 and 1996 population in the Northeast Creek drainage basin, Bar Harbor, Maine

[Data from 1981 U.S. Geological Survey topographic map, 1996 U.S. Geological Survey digital orthophoto quadrangle, and U.S. Bureau of the Census, 1992]

Drainage basin	1981		1996	
	Estimated number of houses	Estimated number of people	Estimated number of houses	Estimated number of people
Aunt Betsey's Brook	7	11	12	19
French Hill Brook	5	8	24	37
Stony Brook	55	86	59	92
Old Mill Brook	16	25	35	55
Unnamed tributary south	20	31	33	51
Unnamed tributary north	3	5	2	3
Liscomb Brook	15	23	24	37
Ground-water area	37	57	47	71
Total area, Northeast Creek basin	158	246	236	365

Most of the study-area drainage basin is forested. Portions of Old Mill Brook, Stony Brook, and French Hill Brook were burned in a severe forest fire in 1947. A few fields are scattered throughout the drainage area. Some of these are grazed by cattle and horses, but most are in hay production.

CONCEPTUAL MODEL OF THE WATER BUDGET AND NITROGEN INPUTS TO THE NORTHEAST CREEK/FRESH MEADOW ESTUARY SYSTEM

Water Budget

A conceptual model of the water budget for the Northeast Creek/Fresh Meadow system (fig. 2) includes inputs from surface-water runoff ($Q_{S\text{-}in}$), precipitation (P), ground water (Q_{GW}), and tidal inflows ($Q_{T\text{-}in}$). The ground-water inputs can be divided into deep ground-water flow from the fractured-bedrock aquifer recharged in the upland parts of the basin (Q_{GWdeep}) and shallow ground-water flow ($Q_{GWshallow}$) from the nearby lowlands that are not drained by channelized surface-water flows. This division is required because the deep and shallow ground-water systems are separated by a marine clay layer, the Presumpscot Formation, which is widespread in lowland areas in coastal Maine (Bloom, 1960; Thompson and Borns, 1985), including the study area (Hansen, 1980). Outputs from the wetland system include surface-water outflows ($Q_{S\text{-}out}$), ground-water outflows ($Q_{GW\text{-}out}$), tidal outflows ($Q_{T\text{-}out}$) and evapotranspiration (ET), plus or minus changes in storage in the wetland system. The water-budget equation for the wetland system is written as follows:

$$\Delta Storage + Q_{(S\text{-}out)} + Q_{(T\text{-}out)} + ET + Q_{(GW\text{-}out)} = Q_{(S\text{-}in)} + Q_{(T\text{-}in)} + Q_{(GWdeep)} + Q_{(GWshallow)} + P \quad . (1)$$

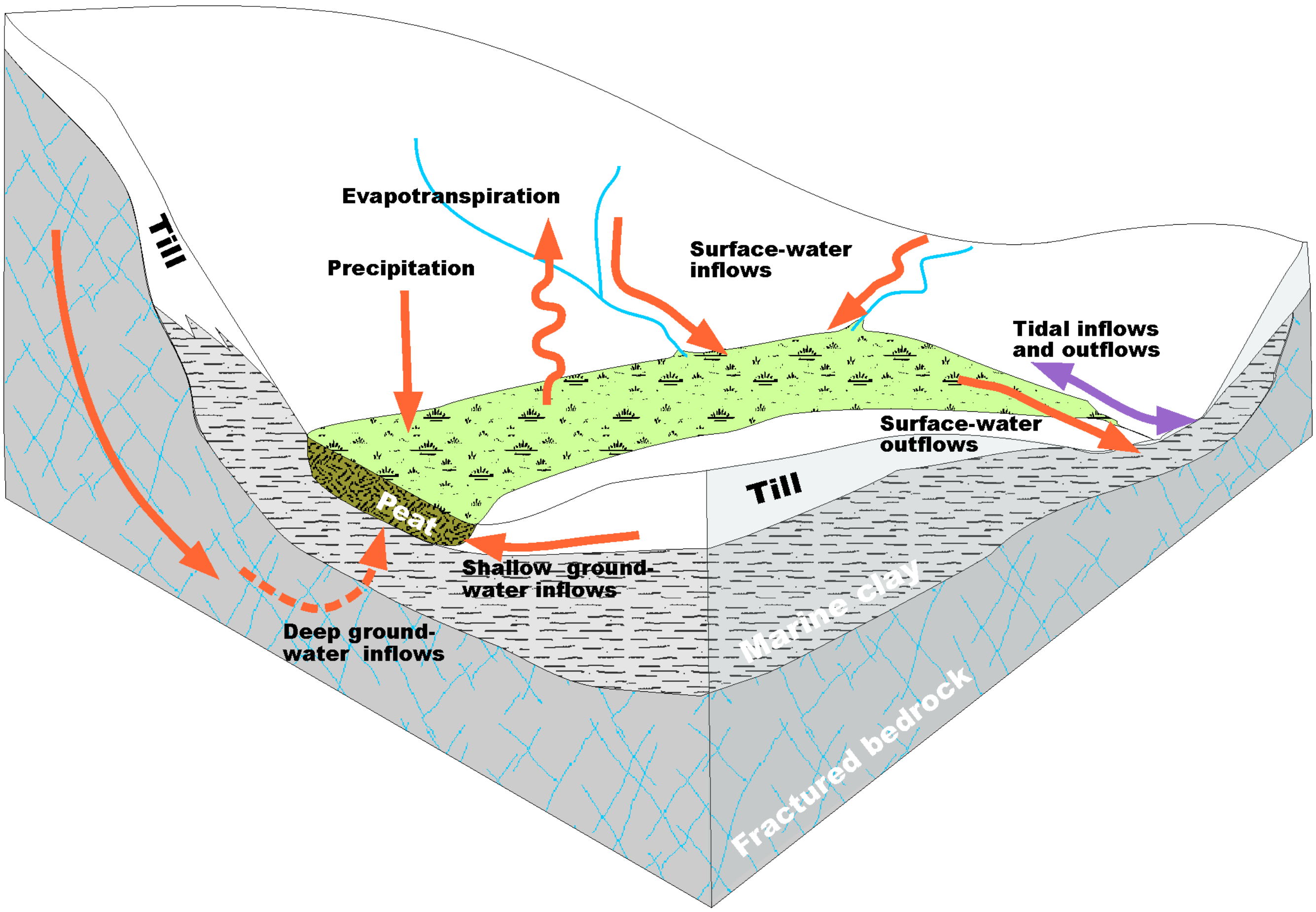


Figure 2. Conceptual hydrologic budget for the Fresh Meadow/Northeast Creek system.

Nitrogen Inputs

A complete nitrogen budget for the Fresh Meadow/Northeast Creek system would include all hydrologic inputs, biological inputs, and biologically mediated chemical transformations. Because of budget and time constraints, the scope of this investigation was limited to external hydrologic inputs of nitrogen to Northeast Creek (fig. 3). These nitrogen sources include precipitation on the creek surface ($N_{Precip.}$), surface-water inputs (N_{SW}), and ground-water inputs (N_{GW}). As in the water budget, the ground-water inputs are classified into deep ground-water infiltration through the streambed ($N_{GW\text{-}deep}$) and shallow infiltration of ground water from the peat soils of the Fresh Meadow wetland into the creek ($N_{GW\text{-}marsh}$). The determination of tidal inputs (N_T) was beyond the scope of this study, although they are recognized as potentially important to the nitrogen budget of the creek as a whole.

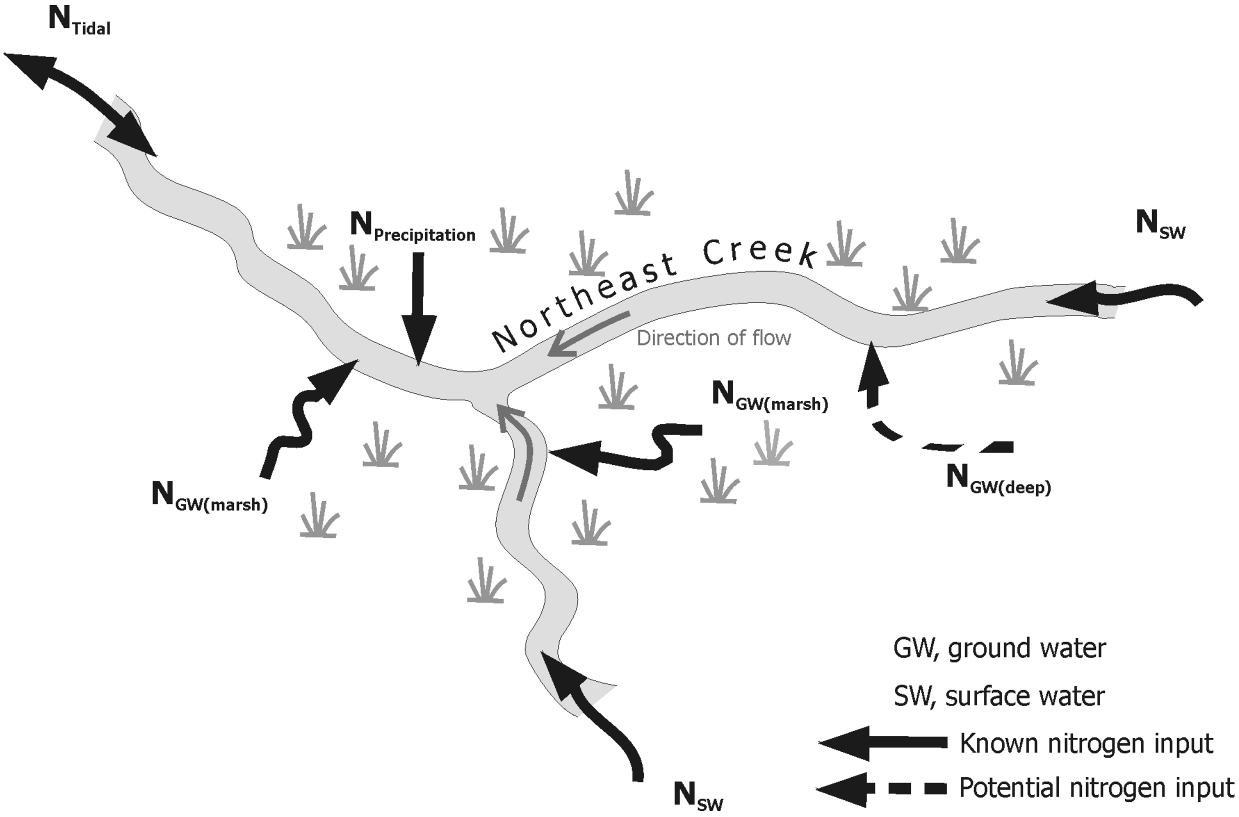


Figure 3. Conceptual model of nitrogen inputs to Northeast Creek.

METHODS OF DATA COLLECTION

Surface Water

Five streamflow-gaging/water-quality stations (fig. 4) were established in the Northeast Creek drainage basin to determine the volume of water and mass of nitrogen entering the Fresh Meadow wetland system, including Northeast Creek (table 2). One station (Old Mill Brook at Old Norway Drive) was established to continuously record streamflow data. Partial-record stations, established at the mouths of the four perennial streams entering the Fresh Meadow system, were measured for streamflow and sampled for water quality monthly. All streamflow data were collected using USGS methods described in Carter and Davidian (1968) and in Rantz and others (1982).

Stage at the continuous-record station 01022800 was recorded at 15-minute intervals using an electronic data logger connected to a pressure transducer. Streamflow measurements were used to develop a rating curve, which gives the streamflow associated with a particular stage. The daily mean streamflow was computed as the arithmetic mean of the streamflows associated with the recorded stages for each day. The data for periods of ice (30 days) and 56 days of missing record were estimated using standard USGS methods (Stewart and others, 2001). Data collected at the partial-record sites consisted of periodic (monthly) measurements of stage and streamflow. A complete tabulation of the daily and monthly discharge data are published separately in Nielsen and others (in press).

Field parameters (dissolved oxygen, pH, temperature, and specific conductance) were measured at the time of sample collection using either a Yellow Springs Instruments 600XL or a Hydrolab minisonde multiparamter probe. Measurements were made by immersing the probe directly in the stream. All probes were calibrated at least twice a day.

Water-quality samples were collected monthly from April 1999 through September 2000 at each of the stations in table 2. (A complete listing of all the water quality data collected can be found in Nielsen and others (in press)). Unfiltered grab samples were collected by rinsing the sample bottles three times in the stream water, then filling each directly from the stream. Two 500-mL nalgene bottles were used to collect water for nitrogen analysis, and each was filled to the top and put on ice. Samples were kept on ice until delivered to the laboratory within 48 hours of collection.

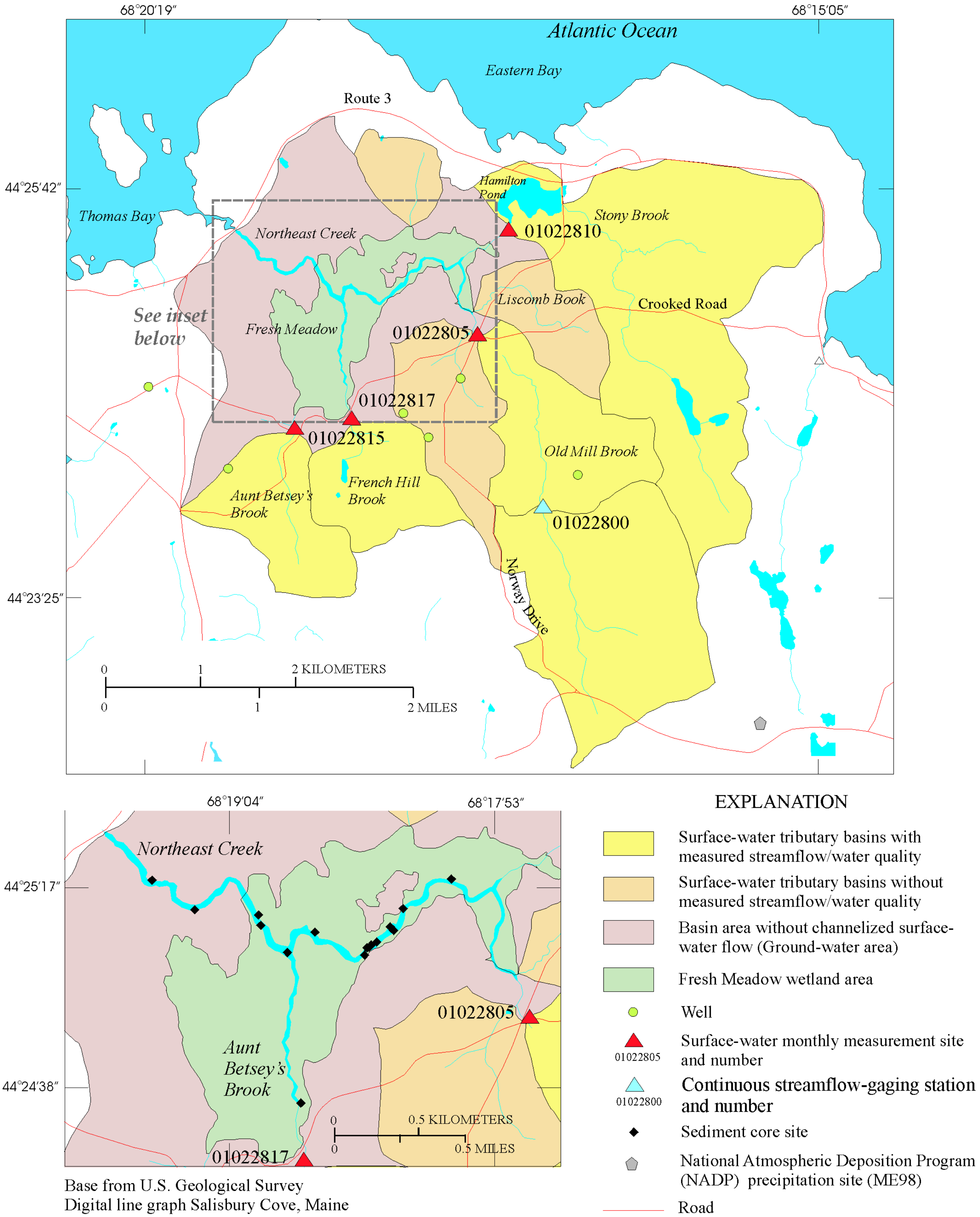
In the laboratory, the contents of one sample bottle were filtered through a 0.4-micron filter and split for analyses for nitrate and ammonium. The ammonium samples were acidified, stored in the dark at 4°C, and analyzed using a colorimetric method at 660 nm on an autoanalyzer within 28 days. Nitrate samples were stored in the dark at 4°C and analyzed by means of ion chromatography using a method based on U.S. Environmental Protection Agency (USEPA) method 300.0 within 7 days (Morrison, 1989). The other bottle was stored unfiltered in the dark at 4°C and analyzed within 28 days for total nitrogen using an alkaline persulfate digestion followed by colorimetric determination at 540 nm on an autoanalyzer using a method based on USEPA method 600/4-87/026, 1987, section 18 (Morrison, 1989). Samples also were analyzed for other constituents, including chloride (see Nielsen and others (in press)).

Table 2. Surface-water monitoring locations, Northeast Creek/Fresh Meadow study area, April 1999 to September 2000

[km^2, square kilometer]

Station number	Station name	Drainage area (km^2)	Type of data collected for this study[1]
01022800	Old Mill Brook at Old Norway Drive	3.91	Continuous stage and periodic streamflow
01022805	Old Mill Brook at Crooked Road	6.13	Monthly streamflow and water quality
01022810	Stony Brook at Hamilton Pond	6.73	Monthly streamflow and water quality
01022815	Aunt Betsey's Brook	1.62	Monthly streamflow and water quality
01022817	French Hill Brook	1.40	Monthly streamflow and water quality

[1] Additional data may have been collected as part of other studies at these sites.



Base from U.S. Geological Survey
Digital line graph Salisbury Cove, Maine
quadrangle, 1:24,000.

Figure 4. Locations of data-collection sites in the Northeast Creek/Fresh Meadow study area.

Ground Water

Ground water in the bedrock aquifer surrounding the Northeast Creek/Fresh Meadow system discharges to a surface-water body near the study area. Evaluating whether or not the aquifer discharges to Northeast Creek and the Fresh Meadow wetland is crucial to understanding the potential contribution of nitrogen from ground water to the Northeast Creek/Fresh Meadow system. The creek and wetland would be a natural discharge point for the aquifer if the surficial materials beneath the wetland and creek bottom are hydrologically connected to the aquifer. If the surficial materials act as a barrier to ground-water flow, discharge from this aquifer must occur elsewhere, perhaps directly into Thomas Bay or Eastern Bay, which are the water bodies of lowest hydraulic head in the area. Available maps of surficial geology (Hansen, 1980; Gilman and others, 1988) indicate that a marine clay layer (the Presumpscot Formation) that would inhibit the discharge of deep ground water to the system likely is present beneath it.

In order to confirm the presence of the Presumpscot Formation along the bottom of Northeast Creek, a coring survey was completed in July 2000. Fifteen cores were collected to determine the composition of the bottom material. A 5-cm-diameter stainless-steel bucket auger attached to as many as four 1.2-m sections of threaded pipe was used to core into the streambed. Cores were collected by standing at the water's edge and coring into the bottom of the creek 15 to 25 cm from the bank, where the water generally was less than 20 cm deep. The maximum core depth was 5.2 m below the water surface. Global-positioning system (GPS) coordinates were recorded in the field and locations of the coring sites (fig. 4) were recorded on a topographic map.

Precipitation

Inorganic nitrogen loads from precipitation were calculated using data from the National Atmospheric Deposition Program (NADP) station (ME98) at Acadia National Park, located just outside the boundary of the study area (fig. 4). The station, operated by the National Park Service, is located near the park administrative headquarters at an altitude of 129 m. Weekly concentration data for ammonia and nitrate and sample and precipitation volumes are screened for completeness as part of the NADP program (National Atmospheric Deposition Program, 1999). Data for the period from April 1999 through September 2000 were obtained.

WATER BUDGET FOR THE NORTHEAST CREEK/FRESH MEADOW SYSTEM

Understanding how water enters and leaves the Northeast Creek/Fresh Meadow system is important as a key to understanding how water-borne nitrogen enters the system. The volumes of the following primary non-tidal sources of water to the system were quantified: surface-water inflows, precipitation, evapotranspiration, and deep ground-water inflows. Surface-water outflows were not measured because of the tidal nature of the outlet of Northeast Creek. Tidal streams are difficult to gage because the stage-discharge relation cannot be easily defined.

Estimation of Surface-Water Inflow

Surface-water inflows were calculated using the monthly streamflow measurements and applying a record-extension technique to estimate daily flows for the four measured tributaries. Several methods of streamflow record extension have been proposed or used in the past, including graphical correlation (Searcy, 1959) and linear regression (Hirsch, 1982). The method used in this study is known as MOVE.1 (Maintenance of Variance-Extension, type 1), or the line of organic correlation (Helsel and Hirsch, 1992). The MOVE.1 technique produces streamflow estimates at the partial-record station with a statistical distribution similar to that expected if the streamflow had actually been measured (Helsel and Hirsch, 1992).

The MOVE.1 technique was used to estimate mean daily flows for the period April 1, 1999 to September 30, 2000 at each tributary stream. This technique uses log-transformed streamflow data from the tributary streams, where individual monthly measurements were made (fig. 4), and data from one or more continuous-record index stations (fig. 5). The individual streamflow measurements made at the inflow streams were compared to the daily mean flows at five index stations (the continuous-record gages on upper Old Mill Brook, Cadillac Brook, and Upper Hadlock Brook (all on Mt. Desert Island), and those on East Bear Brook and West Bear Brook (located on the mainland)). A correlation coefficient was calculated for each index-station/inflow-stream pair. R-squared values from these correlations (table 3) were used to select which index station(s) to use to estimate mean daily flows for each tributary stream.

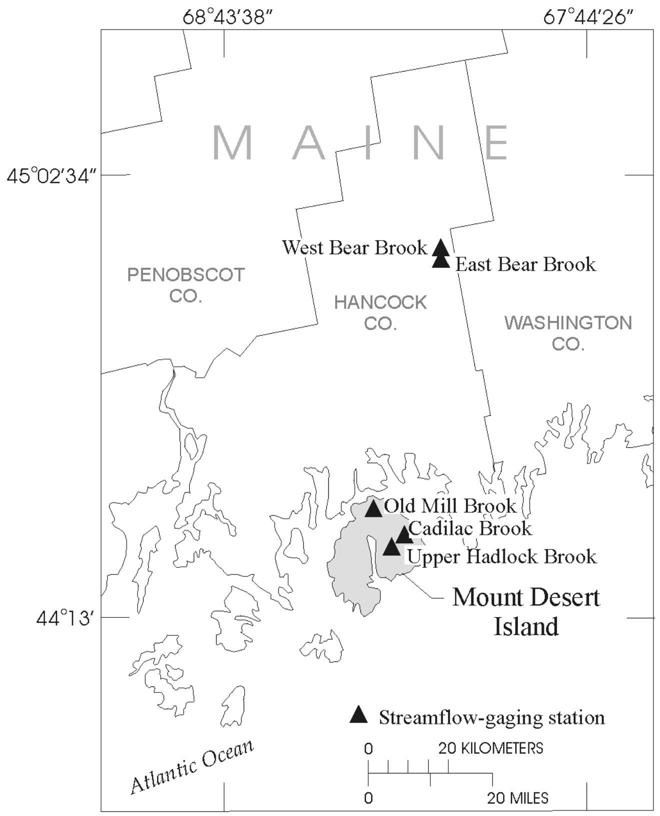


Figure 5. Location of continuous-record streamflow-gaging stations used as index stations for MOVE.1 analysis.

Because streamflow data are highly skewed, a $\log_{10}$ transformation is commonly done to linearize the data. Then, the means ($\bar{Y}$ and $\bar{X}$) and standard deviations (S_y and S_x) of the logs of the concurrent streamflow data are calculated. The MOVE.1 equation is then written as follows:

$$\hat{Y}_i = \bar{Y} + \frac{S_y}{S_x}\left(X_i - \bar{X}\right) \tag{1}$$

where $\hat{Y}_i$ is the estimated daily streamflow at the periodic-measurement site for day *i*,

$\bar{Y}$ is the mean of the periodic measurements,

S_y is the standard deviation of the periodic measurements,

S_x is the standard deviation of the daily streamflows at the index station,

X_i is the mean streamflow on day *i* for the index station, and

$\bar{X}$ is the mean of the daily flows at the index station for the same days as those at the periodic-measurement station.

Estimates of streamflow for the partial-record station were computed by entering known logarithms of the daily streamflow at the continuous-record station (X_i) into the equation and then transforming the estimates $\hat{Y}_i$ from logarithms back into the original units.

Table 3. R-squared values for correlations between streamflow at index stations and monthly measurement stations, Northeast Creek/Fresh Meadow study area

[Bold numbers indicate index station used to calculate daily flows for each monthly measurement station]

Monthly measurement station	Index station				
	Upper Old Mill Brook	Cadillac Brook	Upper Hadlock Brook	East Bear Brook	West Bear Brook
Lower Old Mill Brook	**0.92**	0.66	**0.92**	0.89	0.85
Aunt Betsey's Brook	**0.95**	0.39	0.68	**0.87**	0.79
French Hill Brook	**0.97**	0.61	0.91	**0.96**	0.88
Stony Brook	**0.88**	0.54	0.68	**0.88**	0.81

The two index stations with the highest correlation coefficients were used to estimate flow in each inflow stream. Although the correlation of all stations with Old Mill Brook was good, correlations with some other basins also were good—in some cases equally so. Using both index stations that correlated well to each stream increased the robustness of the calculation. A plot of the measurements against the daily mean flows at the selected index stations also was evaluated for goodness-of-fit, to make sure that the relation between the inflow site and the selected index sites was appropriately linear. A weighting procedure (described below) was used to calculate the final daily flows at each inflow stream from the estimates of daily flow at the two best-fit index sites.

The weighting procedure was as follows: Residual squared errors (rse) from the correlations for the best index stations for each site were compared, and the site with the lower rse was assigned to have weight W_1. The other index station was assigned weight W_2, such that

$$W_1 = 1 - [(rse_1 / (rse_1 + rse_2)] \text{, and} \tag{2}$$

$$W_2 = 1 - W_1 \tag{3}$$

The weighted average $\log_{10}$ flow (F) for each tributary stream was calculated using the log flow estimated from index station 1 (F_1) and the log flow estimated from index station 2 (F_2),

$$F = W_1 F_1 + W_2 F_2 \tag{4}$$

Finally, daily mean streamflow for each inflow stream was calculated by taking the inverse log of F,

$$Q = 10^F \tag{5}$$

The goodness-of-fit for the relation between Lower Old Mill Brook and Upper Hadlock Brook was very good for the range of paired data. However, when the log of the daily mean flow (in cubic feet per second) of Upper Hadlock Brook rose above 0.45, which was at the upper end of the range of paired data, the predicted flows at Lower Old Mill Brook appeared to be much higher than seemed hydrologically reasonable. This unpredicted effect indicated that whereas the available data did not show any deviation in flows between the sites, Upper Hadlock Brook behaved very differently at high flows than Old Mill Brook. Therefore, when the log of the Upper Hadlock Brook daily mean flows rose above 0.45, values for the daily flows at Lower Old Mill Brook were derived solely from those at Upper Old Mill Brook.

The estimated daily flows for the Lower Old Mill Brook station are plotted in figure 6 as an example of the method results. Actual measurements also are shown for comparison with the estimated daily flows. The estimated flows generally closely match the measured flows. Differences may not represent errors in the estimation, but rather reflect the difference between an instantaneous flow measured when the stage was rising or falling quickly and the average flow for that day. Flows during the summer of 1999 generally went to zero, or near zero, in all the streams. This period was one of pronounced drought in this area, with very little rainfall from May through mid-September. The estimated daily flows from each of the four measured tributaries were normalized by drainage area and averaged to obtain an average daily flow per square kilometer of drainage basin in the study area for each day. These daily averages were applied to the drainage areas of the three unmeasured tributary basins to estimate daily inputs to the system.

After the daily flows were calculated, monthly inflows to the Northeast Creek/Fresh Meadow system were calculated (table 4). Very low runoff volumes entered the system during the summer of 1999 (especially July and August), because precipitation during that period was much lower than average. Much higher amounts of runoff in September and October of 1999 were the result of two fall hurricanes. Winter runoff volumes remained high, because, unlike many continental parts of the United States, this area can experience winter storms that result in large runoff events.

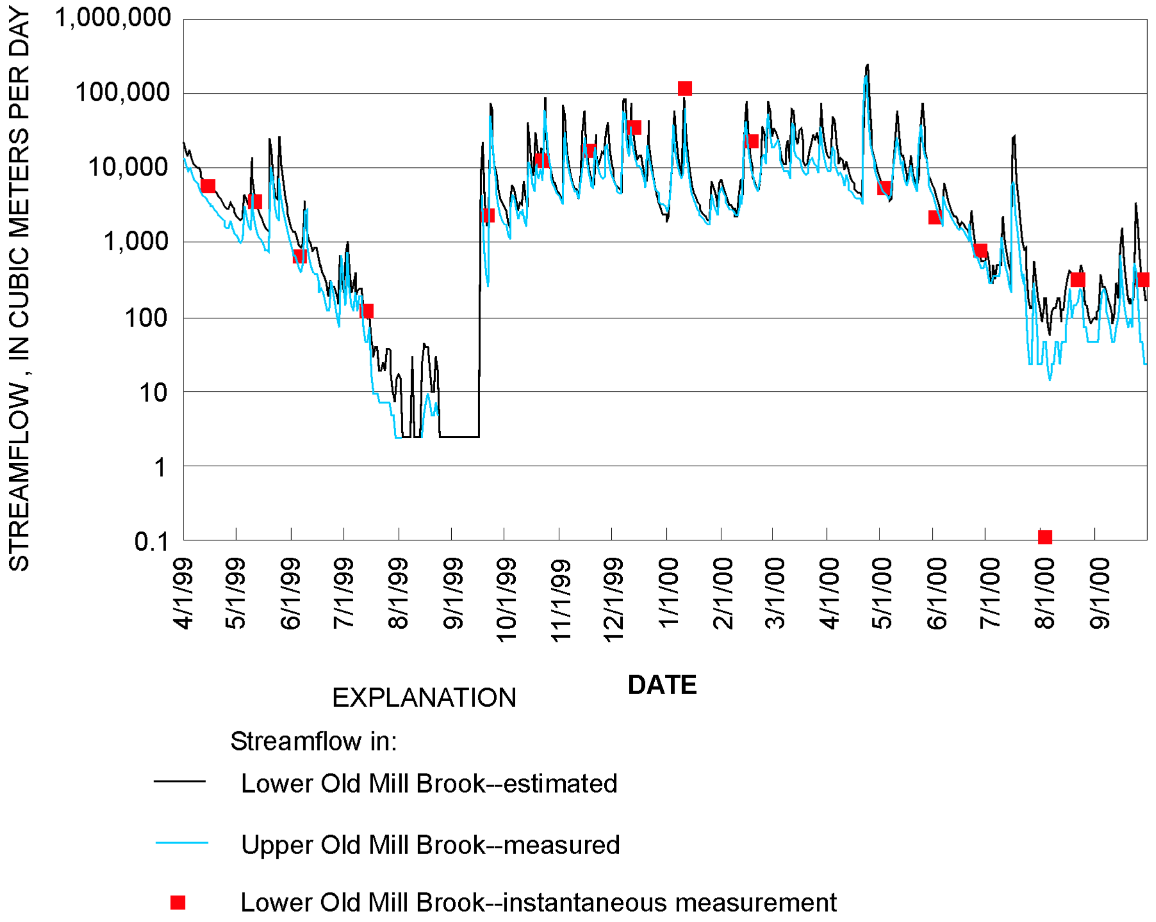


Figure 6. Estimated mean daily streamflow at the Lower Old Mill Brook gage, measured daily streamflow upstream at the Old Mill Brook gage, and periodic measurements of streamflow at the Lower Old Mill Brook gage, April 1, 1999 to September 30, 2000.

Table 4. Estimated monthly surface-water inflows to the Northeast Creek/Fresh Meadow system, April 1999 to September 2000

[Values are in thousands of cubic meters]

Month	Surface-water inflow					
	Total surface-water inflow	Aunt Betsey's Brook	French Hill Brook	Stony Brook	Old Mill Brook	Ungaged streams
Apr. 1999	768	38.8	69.7	303	225	131
May 1999	520	21.0	38.6	197	180	83.3
June 1999	95.0	3.14	5.98	45.9	25.5	14.4
July 1999	18.5	0.40	0.77	9.72	5.04	2.57
Aug. 1999	2.05	0.08	0.03	1.29	0.38	0.27
Sept. 1999	616	34.9	59.5	190	224	108
Oct. 1999	1,162	63.2	108	377	413	201
Nov. 1999	1,562	88.7	152	508	538	275
Dec. 1999	1,821	114	193	591	593	330
Jan. 2000	1,102	65.0	110	369	362	196
Feb. 2000	1,430	83.0	140	428	526	253
Mar. 2000	2,497	153	263	803	828	451
Apr. 2000	2,571	164	269	723	948	467
May 2000	1,420	80.4	138	485	467	249
June 2000	293	13.4	24.8	139	66.9	48.4
July 2000	171	4.48	8.21	55.4	78.2	24.9
Aug. 2000	20.5	0.34	0.69	10.4	6.32	2.75
Sept. 2000	29.5	0.44	0.85	10.9	13.4	3.93

Estimation of Precipitation Inputs

Monthly precipitation volumes for the Fresh Meadow/Northeast Creek system were calculated for the wetland area using the weekly precipitation volumes from the NADP loading data (table 5). Input volumes in thousands of cubic meters (1,000 m^3) (table 5) were calculated by multiplying the monthly precipitation by the area of the wetland (1.85 km^2). (NWS precipitation data also were available, but the NADP data were used to retain consistency between the precipitation volumes and precipitation loads.) Weeks that overlapped months were assigned to the month with the greatest number of days. Precipitation inputs were not calculated for the contributing drainage basins to the wetland, because the surface-water runoff volumes account for this.

Estimation of Evapotranspiration

Evapotranspiration (ET) was calculated for the Fresh Meadow wetland using a multivariate regression model developed by Fennessey and Vogel (1996) of Penman-Montieth ET developed for the northeastern United States. Input parameters for the model include average annual temperature, average monthly temperature, longitude, and elevation. An unlimited moisture supply (as in a wetland) is assumed in the model. Monthly ET was estimated using NWS temperature data for the Acadia National Park weather station for 1999 and 2000 (table 5). As for the precipitation estimates, each monthly ET rate in centimeters per month was multiplied by the wetland area to estimate monthly volumes in thousands of cubic meters. Considerably cooler and wetter conditions during the summer of 2000 than during the summer of 1999 resulted in lower ET rates for the second summer of the study.

Table 5. Monthly estimated evapotranspiration and precipitation for the Northeast Creek/Fresh Meadow system, April 1999 to September 2000

[mm/d, millimeters per day; m^3/mo, cubic meters per month; cm/mo, centimeters per month]

Month	Evapotranspiration		Precipitation	
	mm/d	m^3/mo (in thousands)	cm/mo	m^3/mo (in thousands)
Apr. 1999	2.16	120	1.1	20.7
May 1999	3.20	184	7.7	142
June 1999	4.14	230	4.6	86.0
July 1999	4.46	255	3.8	69.5
Aug. 1999	3.94	226	3.6	67.2
Sept. 1999	2.84	158	21.2	392
Oct. 1999	1.73	99.2	14.8	274
Nov. 1999	1.04	57.5	15.7	290
Dec. 1999	0.82	46.9	13.8	255
Jan. 2000	0.98	56.4	12.6	233
Feb. 2000	1.30	67.5	7.3	135
Mar. 2000	1.78	102	9.1	169
Apr. 2000	2.29	127	22.0	407
May 2000	2.77	159	13.3	246
June 2000	3.13	174	6.2	115
July 2000	3.26	187	9.7	180
Aug. 2000	3.06	175	3.6	67.0
Sept. 2000	2.54	141	8.8	162

Estimation of Ground-Water Inputs

Sediment cores were collected at 15 locations in Northeast Creek and Aunt Betsey's Brook to determine the composition of the bottom material underlying the peat and the bottom of the creek (fig. 4). A blue pebbly clay layer was encountered under the peat in all the cores where the peat was shallow enough for the coring device to penetrate the bottom. The peat ranged in thickness from approximately 1.25 m to more than 5 m. The peat was more than 5 m thick (the maximum depth of the instrument) in five samples; small globules of clay were encountered near the bottom in several of these cores. On the basis of the coring survey and published surficial-geology maps (Hansen, 1980; Gilman and others, 1988), the Presumpscot Formation clay layer appears to be continuous below the peat and to provide an effective barrier to deep ground-water flow from the bedrock aquifer.

Shallow ground-water inflow is another source of water to the wetland. A 4.74-km^2 upland area adjacent to the wetland is not drained by channelized streams. Some of this area is underlain by Presumpscot Formation clay, some by shallow bedrock, and some by till. The areas underlain by till and clay probably contribute shallow ground-water flow to the wetland. The areas underlain by shallow bedrock, however, may contribute surface flow to the wetland and ground-water flow to the deeper bedrock aquifer.

Without specific water-level data and data on the hydraulic properties of the earth materials, estimation of shallow ground-water inflows for all months of the study would be difficult if not impossible. Streamflow data, however, can be used during periods of base flow to roughly estimate shallow ground-water input to the wetland for the same time period. During the summer months, the median daily flow for a given month was assumed to represent base flow—that is, ground-water discharge. The monthly base-flow volume (per unit area) was averaged for the two smaller basins (Aunt Betsey's and French Hill Brooks), because the surficial materials in these basins are similar to those in the areas contributing shallow ground-water flow to the wetland. These monthly discharge rates were applied to the upland areas for the summer months (June through September) of each year for comparison with other sources of water to the wetland. If 75 percent of the 4.74-km^2 upland area is underlain by till or clay, summertime shallow ground-water seepage to the wetland may range from 33 m^3/mo (for the driest month, September 1999) to 6,100 m^3/mo (for June 2000). These numbers are lower than any of the other water inflows calculated and are very small compared to the total water flux of the wetland.

Monthly Water Inputs and Surface-Water Outflows

After surface-water inflows, precipitation, and evapotranspiration are taken into account, the residual of the water budget is assumed to be net surface-water outflow plus or minus changes in storage in the wetland (fig. 7). The bulk of the residual is assumed to be net surface-water outflow. Total surface-water outflow (as opposed to net outflow) includes water that flowed in with the preceding tide, and this volume was not calculated. Deep ground-water inflows and outflows are assumed to be negligible, as the sediments underlying the wetland are not likely to transmit significant flows from the deeper aquifer below. Shallow ground-water inflows are not directly accounted for, but also are assumed to be small in relation to streamflows.

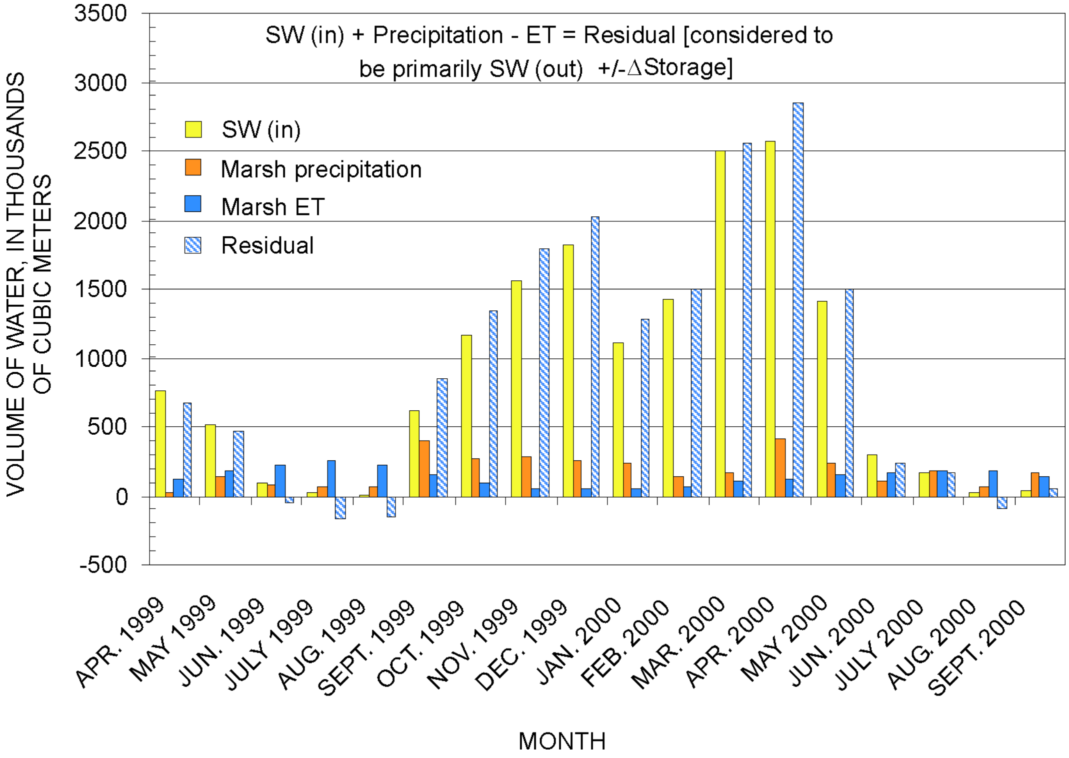


Figure 7. Monthly water budget for the Northeast Creek/Fresh Meadow system.

As figure 7 indicates, the magnitudes of the surface-water inflows and the residual (which is assumed to be surface-water outflow in most months) are similar. One way to evaluate the possible magnitude of surface-water outflows is to make some estimates of changes in storage. Changes in storage are assumed to be greatest when the surface of the wetland floods and holds water, and when water is removed from the peat by ET during the summer. If flooding during a spring month resulted in a 10-cm blanket of water over the whole wetland surface (which is similar to conditions observed in the field), the change in storage for that rise might be +185,000 m^3. During the fall and spring, that amount would represent 5 to 10 percent of the total residual. If, on the other hand, during the summer, the water surface in the peat dropped by 20 cm during a month (which is greater than any drop we observed from casual observation in the field), the resulting change in storage would be approximately –150,000 m^3 (assuming an effective porosity of 0.4 for the peat). This amount could account for 50 to 100 percent of the total residual during the summer.

From September 1999 to May 2000, the residual was larger than the surface-water inflows. Whereas some of the residual undoubtedly represents changes in storage, the general pattern during this time was that surface-water outflows were somewhat larger than surface-water inflows. From June 1999 through Aug. 1999 and Aug. 2000, the residual term was negative, which is consistent with a loss of water from the wetland as a result of ET and, perhaps, drainage of the peat. During these months, net surface-water outflow probably was very small.

Because tidal flows were not measured, the relative magnitude of freshwater inflows and tidal flows to the system is unknown. Salt-tolerant plant species generally are confined to areas close to the banks of Northeast Creek; indicating that saltwater from tidal inflows does not inundate large areas of the wetland on a regular basis and generally is confined to the creek itself. During the hottest and driest months of 1999, when the residual of the water budget was negative, tidal flows may have come in and been partially consumed by ET in the wetland.

To compare the period of data collection with long-term patterns, actual monthly precipitation amounts (fig. 8) were compared to the 19-year averages (herein referred to as “normal”) for each month from the NADP station. The spring and summer of 1999 were extremely dry (as noted earlier), and were followed by a very wet fall. Conditions during the winter of 1999–2000 were relatively normal, whereas the early spring of 2000 also was very wet compared to the 19-year average. Conditions during the summer of 2000 were much closer to normal than those during the summer of 1999.

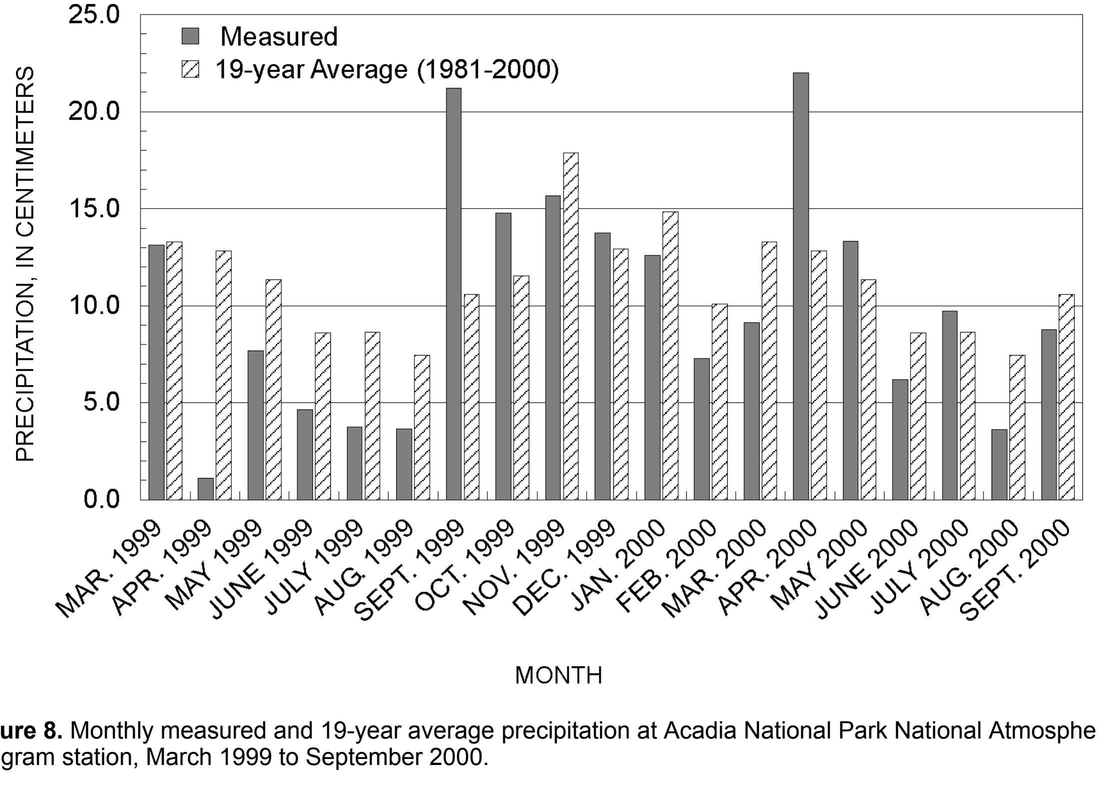


Figure 8. Monthly measured and 19-year average precipitation at Acadia National Park National Atmospheric Deposition Program station, March 1999 to September 2000.

EXTERNAL NITROGEN LOADING TO NORTHEAST CREEK

In contrast to the water budget, the nitrogen load estimates focus on Northeast Creek itself. Potential sources of nitrogen to Northeast Creek that were considered in this study include precipitation on the creek surface, seepage of deep ground water, lateral seepage of ground water from the wetland sediments to the stream, streamflow, and tidal flows. On the basis of the results of the sediment-coring survey, loads from deep ground water are assumed to be negligible. Ground-water seepage of nitrogen from the marsh sediments was not measured in this study; however, conditions in the sediments are favorable for denitrification (C.W. Culbertson, U.S. Geological Survey, oral commun., 2001), and these inputs also are assumed to be small. Surface-water and precipitation loads are both described in detail below.

Surface-Water Loading

There are two basic methods of calculating nitrogen loads to a water body, both of which have some degree of uncertainty. The first method is to quantify and sum all sources of nitrogen in the watershed. This method is unreliable (Alexander and others, 2001), because only a fraction of the total nitrogen released in a watershed reaches the receiving water body because of denitrification, storage, and biological utilization of nitrogen in the watershed. These transformations happen both at the watershed scale and at the stream-channel scale, and are very difficult to reliably quantify.

In the second approach, which does not differentiate among sources, the nitrogen load in the water entering the receiving body is measured. Stream-monitoring data integrate the effect of all nitrogen supply and loss processes upstream from the measuring point, but measurements of flow and concentration would have to be made constantly to determine the load exactly. Commonly used statistical techniques can be used to convert periodic measurements of flow and concentration into estimates of daily flux. Loads of nitrogen entering Northeast Creek were calculated using this method, as the product of the volumes of water and nitrogen concentrations for all sources of flow to the creek.

Water-Quality Data

The monthly sampling program for the inflow streams resulted in a total of 62 water samples that were analyzed for nitrogen, 13 to 17 per site (table 6). French Hill Brook had the fewest samples (13), because it was dry during August and September of both years. A sample could not be collected from Stony Brook in September 2000 because a beaver dam upstream from the site prevented water from flowing past the collection point.

Nitrate concentrations ranged from below detection (< 0.01 mg/L-N) to 0.200 mg/L-N. The smallest average nitrate concentrations were measured in Old Mill Brook, in which the median concentration was 0.012 mg/L-N. Concentrations of nitrate were greatest in Stony Brook (median concentration 0.061 mg/L-N). Concentrations in French Hill Brook and Aunt Betsey's Brook were intermediate (medians of 0.023 mg/L-N and 0.031 mg/L-N, respectively).

Ammonia concentrations ranged from below detection (< 0.05 mg/L) to 0.29 mg/L. Most concentrations were below the detection limit, especially in Old Mill Brook.

Total nitrogen concentrations ranged from 0.19 to 0.98 mg/L, and were lowest in Old Mill Brook, with a median concentration of 0.013 mg/L. Median concentrations in Aunt Betsey's Brook and French Hill Brook were both 0.04 mg/L. The median concentration of total nitrogen in samples from Stony Brook was 0.074 mg/L.

These concentrations are similar to concentrations found in the inflow streams to Bass Harbor Marsh by Doering and others (1995). In that study, nitrate (as N) concentrations ranged from <0.003 to 0.29 mg/L. Mean concentrations for the five streams measured in that study ranged from 0.003 to 0.175 mg/L. Ammonia concentrations ranged from 0.007 to 0.13 mg/L, with mean concentrations of 0.014 to 0.029 mg/L. Total nitrogen concentrations ranged from 0.058 to 0.723 mg/L, with mean concentrations of 0.420 to 0.59 mg/L for the five stations.

Table 6. Water-quality and streamflow data used to estimate nitrogen loads to Northeast Creek

[Numbers in smaller italics represent samples that may be contaminated with saltwater and were not used in the loading calculations. Values in bold are calculated values for use in the loading estimation; ft^3/s, cubic feet per second; µs/cm, microsiemens per centimeter at 25°Celsius; mg/L, milligrams per liter; N, nitrogen; NH_4, ammonia; NO_3, nitrate; --, no data; <, less than]

Stream	Date	Streamflow (ft^3/s)	Specific conductance (µs/cm)	NO_3 (mg/L-N)	Total N (mg/L)	NH_4 (mg/L)	NH_4 (calculated)[1] (mg/L)	Inorganic N (calculated 4) (mg/L	Organic N (total N – inorganic N) (mg/L)
Aunt Betsey's Brook	04/14/99	0.500	60.0	0.012	0.25	< 0.05	**0.025**	**0.037**	**0.213**
	05/12/99	.220	75	.023	.40	<.05	**.025**	**.048**	**.352**
	06/15/99	.060	100	.081	.42	.11	**.11**	**.191**	**.229**
	07/13/99	*.002*	*200*	*.116*	*.70*	*.24*	*.24*	*.356*	*.344*
	08/25/99	*.000*	*253*	*.056*	*.56*	*.13*	*.13*	*.186*	*.374*
	09/21/99	*.030*	*200*	*.092*	*.66*	*.08*	*.08*	*.172*	*.488*
	10/21/99	.500	79.6	.014	.43	<.05	**.025**	**.039**	**.391**
	11/17/99	.930	61.3	.011	.35	<.05	**.025**	**.036**	**.314**
	12/14/99	1.590	51.5	.018	.31	<.05	**.025**	**.043**	**.27**
	01/11/00	6.880	53.5	.031	.30	<.05	**.025**	**.056**	**.24**
	02/16/00	1.210	89.8	.032	.24	<.05	**.025**	**.057**	**.18**
	05/03/00	.520	6.7	.01	.36	<.05	**.025**	**.035**	**.33**
	05/31/00	.350	64.4	<.01	.34	<.05	**.025**	**.035**	**.31**
	06/27/00	.050	140	.04	.59	.17	**.17**	**.212**	**.38**
	08/02/00	*.004*	*344*	*.07*	*.63*	*.29*	*.29*	*.36*	*.27*
	09/25/00	*.020*	*254*	*.07*	*.60*	*.13*	*.13*	*.20*	*.40*
French Hill Brook	04/14/99	.820	32.8	.020	.27	<.05	**.025**	**.045**	**.225**
	05/12/99	.450	43	.026	.44	<.05	**.025**	**.051**	**.389**
	06/15/99	.060	52	.093	.45	.06	**.06**	**.153**	**.297**
	07/13/99	.006	79	.073	.47	.11	**.11**	**.183**	**.287**
	08/25/99	.00	--	--	--	--	--	--	--
	09/21/99	.00	--	--	--	--	--	--	--
	10/21/99	1.130	51.6	.013	.46	<.05	**.025**	**.038**	**.422**
	11/16/99	2.140	44.8	.023	.40	<.05	**.025**	**.048**	**.352**
	12/15/99	2.250	36.3	.023	.35	<.05	**.025**	**.048**	**.30**
	01/12/00	3.430	36.5	.023	.20	<.05	**.025**	**.048**	**.15**
	02/17/00	2.320	42.2	.024	.21	<.05	**.025**	**.049**	**.16**

Table 6. Water-quality and streamflow data used to estimate nitrogen loads to Northeast Creek—Continued

[Numbers in smaller italics represent samples that may be contaminated with saltwater and were not used in the loading calculations. Values in bold are calculated values for use in the loading estimation; ft^3/s, cubic feet per second; µs/cm, microsiemens per centimeter at 25°Celsius; mg/L, milligrams per liter; N, nitrogen; NH$_4$, ammonia; NO$_3$, nitrate; --, no data; <, less than]

Stream	Date	Streamflow (ft^3/s)	Specific conductance (µs/cm)	NO$_3$ (mg/L-N)	Total N (mg/L)	NH$_4$ (mg/L)	NH$_4$ (calculated)[1] (mg/L)	Inorganic N (calculated NH$_4$+NO$_3$) (mg/L)	Organic N (total N – inorganic N) (mg/L)
French Hill Brook, continued	05/02/00	1.030	33.1	0.01	0.27	< 0.05	**0.025**	**0.033**	**0.24**
	05/31/00	.760	35.4	<.01	.31	<.05	**.025**	**.035**	**.28**
	06/27/00	.070	51	.07	.40	.06	**.06**	**.129**	**.27**
	08/02/00	[2].008	71.2	.09	.5	.11	**.11**	**.197**	**.30**
	08/21/00	.00	--	--	--	--	--	--	--
	09/25/00	.00	--	--	--	--	--	--	--
Old Mill Brook (Lower)	04/14/99	2.460	50	.051	.20	<.05	**.025**	**.076**	**.124**
	05/11/99	1.490	54	.012	.50	<.05	**.025**	**.037**	**.463**
	06/15/99	.270	68	.013	.22	<.05	**.025**	**.038**	**.182**
	07/13/99	.050	80	.013	.37	<.05	**.025**	**.038**	**.332**
	08/25/99	*.00*	*350*	*.007*	*.40*	*<.05*	--	--	--
	09/20/99	1.000	110	.010	.62	<.05	**.025**	**.035**	**.585**
	10/21/99	5.300	52.8	.007	.28	<.05	**.025**	**.032**	**.248**
	11/17/99	7.000	45.2	.004	.19	<.05	**.025**	**.029**	**.161**
	12/13/99	15.200	39.8	.016	.20	<.05	**.025**	**.041**	**.16**
	01/11/00	48.500	43.4	.058	.20	<.05	**.025**	**.083**	**.12**
	02/17/00	9.690	49.4	.042	.19	<.05	**.025**	**.067**	**.12**
	05/03/00	2.240	5.9	<.01	.20	<.05	**.025**	**.035**	**.17**
	06/01/00	.910	5.1	<.01	.28	<.05	**.025**	**.035**	**.25**
	06/27/00	.330	79	<.01	.98	<.05	**.025**	**.035**	**.95**
	08/02/00	[2].054	86.0	<.01	.76	.05	**.05**	**.060**	**.70**
	08/21/00	[2].128	75.8	.03	.76	<.05	**.025**	**.050**	**.71**
	09/27/00	[2].127	78.4	<.01	.73	<.05	**.025**	**.035**	**.69**
Stony Brook	04/14/99	2.290	61	.061	.35	<.05	**.025**	**.086**	**.264**
	05/11/99	1.540	66	.034	.52	<.05	**.025**	**.059**	**.461**
	06/16/99	.330	70	.083	.76	.05	**.05**	**.133**	**.627**

Table 6. Water-quality and streamflow data used to estimate nitrogen loads to Northeast Creek—Continued

[Numbers in smaller italics represent samples that may be contaminated with saltwater and were not used in the loading calculations. Values in bold are calculated values for use in the loading estimation; ft^3/s, cubic feet per second; µs/cm, microsiemens per centimeter at 25°Celsius; mg/L, milligrams per liter; N, nitrogen; NH_4, ammonia; NO_3, nitrate; --, no data; <, less than]

Stream	Date	Streamflow (ft^3/s)	Specific conductance (µs/cm)	NO_3 (mg/L-N)	Total N (mg/L)	NH_4 (mg/L)	NH_4 (calculated)[1] (mg/L)	Inorganic N (calculated NH_4+NO_3) (mg/L)	Organic N (total N – inorganic N) (mg/L)
Stony Brook, continued	07/13/99	0.160	72	0.072	0.59	< 0.05	**0.025**	**0.097**	**0.493**
	08/25/99	.001	81	.200	.62	<.05	**.025**	**.225**	**.395**
	09/21/99	.340	77	.014	.70	<.05	**.025**	**.039**	**.661**
	10/20/99	4.320	86.5	.052	.93	.24	**.24**	**.292**	**.638**
	11/16/99	1.300	65	.076	.67	.08	**.08**	**.156**	**.514**
	12/14/99	11.800	52.2	.082	.50	<.05	**.025**	**.107**	**.39**
	01/11/00	17.000	54.8	.118	.50	.07	**.07**	**.188**	**.31**
	02/17/00	16.500	71.2	.149	.43	.07	**.07**	**.219**	**.21**
	05/03/00	2.820	52.3	.01	.31	<.05	**.025**	**.032**	**.28**
	06/01/00	3.030	54.4	<.01	.48	<.05	**.025**	**.035**	**.45**
	06/27/00	.860	59	.04	.62	<.05	**.025**	**.067**	**.56**
	08/01/00	.310	61.8	.08	.63	<.05	**.025**	**.101**	**.53**
	08/22/00	.090	63.0	.11	.65	<.05	**.025**	**.134**	**.51**
	09/25/00	[3].000	--	--	--	--	--	--	--

[1] If NH4 was < 0.05, an assumed value of 0.025 was used for the loading estimation.

[2] No flow measurement; flows assigned from MOVE.1 calculations.

[3] No flow due to beaver activity; could not sample.

Estimation of Loads

Chloride-concentration and specific-conductance data indicated that some samples were collected after tidal inflow had reached upstream to that sampling site and, therefore, the nitrogen concentrations may reflect tidal input rather than runoff from the watershed. Five samples from Aunt Betsey's Brook and one sample from Old Mill Brook were discarded from the load estimation calculations for this reason. Values for these samples are italicized in table 6.

Several methods exist for the computation of surface-water loads to a given water body. Hodgkins (2001) compared methods for calculating loads from forested watersheds in the Northeast. These methods fall into one of three general categories—averaging methods, ratio methods, and regression methods. Of these, regression methods often provided the best estimates, if the assumptions of the regression were met for each individual stream. Even so, errors commonly may exceed 30 percent or more (Robertson and Roerish, 1999).

Regression methods can be used if the relation between concentration and streamflow is discernible. Plots of concentration against streamflow for nitrate and total nitrogen (fig. 9) do show a relation. The regression method was used to estimate nitrogen loads from Old Mill Brook, Stony Brook, Aunt Betsey's Brook, and French Hill Brook. After these estimates were completed, an average nitrogen yield on an areal basis was computed and applied to the three ungaged tributaries to Northeast Creek.

To compute the regression equations for each tributary, loads were computed for each set of concentration and streamflow data and then transformed to the natural log of the daily load. (In water-quality studies, concentrations and streamflows typically are log-transformed to normalize the data set.) Natural log of load was the dependent variable. Various combinations of the natural log of streamflow, the square of the natural log of streamflow, time, sine (time), and cosine (time) (representing seasonality) were tested using a load-estimation computer program to determine the best regression equations at each site. Equations were fit individually for each constituent at each stream (table 7).

Table 7. Equation coefficients used to calculate the natural logarithm of the load for each nitrogen species in each tributary basin to Northeast Creek

[Coefficients as determined from load estimation output, for the equation of the form ln(load) = b0 + b1 ln(flow) + b2 ln(flow)2 + b3 dectime + b4 sin(dectime) + b5 cos(dectime); values for constituents in italics based on calculated values shown in table 6; b, coefficient; LSA, log streamflow adjustment applied to logs of streamflow before applying equation; N, nitrogen; --, no coefficient used]

Basin	Constituent	LSA	Load calculation equation coefficients					
			b0	b1	b2	b3	b4	b5
Aunt Betsey's Brook	Nitrate-N	0.69315	-2.7759	0.89651	0.19103	-0.56574	--	--
	Total N	.69315	-.04604	1.0006	.023159	--	-0.28724	-0.2838
	Inorganic N	.69315	-2.1633	.78193	.12478	--	--	--
	Organic N	.69315	-.19061	1.0732	--	--	-.37037	-.35137
Stony Brook	Nitrate-N	-.63017	-.9920	1.1655	.11221	--	--	--
	Total N	-.63017	1.8706	1.0844	--	-.19641	-.46823	-.26386
	Inorganic N	-.63017	-.26065	1.1820	.083886	--	--	--
	Organic N	-.63017	1.6300	1.1671	--	-.26218	-.61519	-.60094
Old Mill Brook	Nitrate-N	-.19939	-2.5739	1.1772	--	--	--	--
	Total N	-.19939	.43931	.81348	--	.36983	--	--
	Inorganic N	-.19939	-1.3530	.93449	.039337	--	.31891	.25970
	Organic N	-.19939	.10729	1.0059	--	.36438	-.54586	-.66633
French Hill Brook	Nitrate-N	.19845	-2.1327	-.53582	-.18040	--	.48500	2.0160
	Total N	.19845	.66276	1.0198	--	-.22755	-.41877	-.32648
	Inorganic N	.19845	-1.3881	.23169	-.068059	--	.17224	.84521
	Organic N	.19845	.54126	1.1363	--	-.2871	-.5184	-.50693

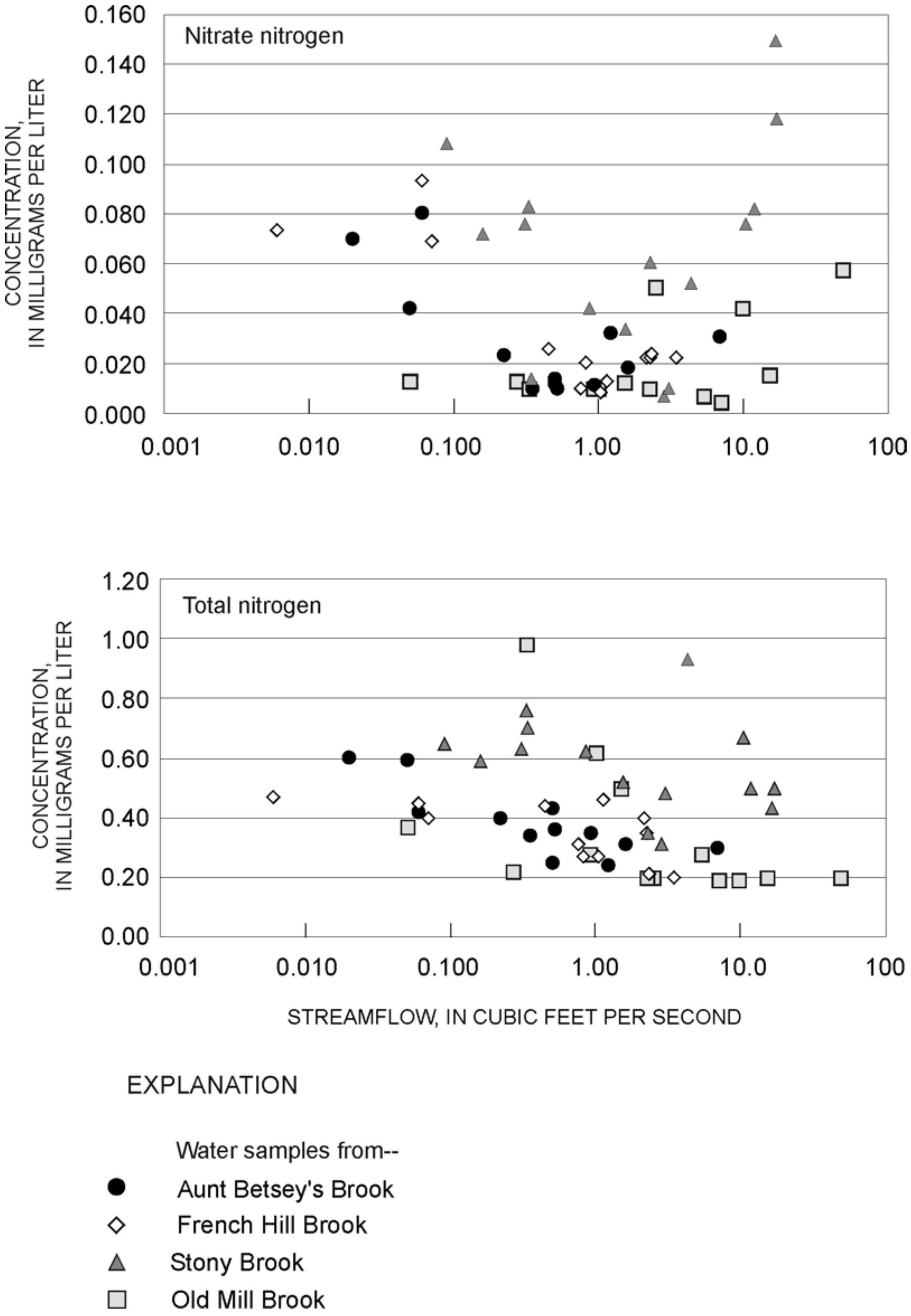


Figure 9. Relation of nutrient concentrations and streamflow in tributaries to Northeast Creek.

These regression equations were used to estimate daily loads of total nitrogen, nitrate (as N), inorganic nitrogen, and organic nitrogen for the four measured tributaries. Concentrations of ammonia were below the detection limit in a sufficient number of samples to violate the conditions of the regression method. In order to compare inorganic- to organic-nitrogen sources, however, a gross assumption was made so that when the ammonia concentration was below the detection limit of 0.05 mg/L, half that value (0.025 mg/L) was used for the regression (table 6). This value was added to the nitrate concentration to obtain an "inorganic nitrogen" term. This inorganic nitrogen term was subtracted from the total nitrogen to obtain a rough estimate of the relative importance of inorganic and organic nitrogen entering the system. Daily loads of these "inorganic nitrogen" and "organic nitrogen" terms also were calculated.

A range of regression diagnostics was performed to test the regression assumptions for each constituent in each tributary. Residual plots of concentration against streamflow were analyzed, and non-normality of the residuals was examined for each constituent with the Turnbull-Weiss Likelihood Ratio Normality Test statistic (Turnbull and Weiss, 1978). Residual plots did not exhibit any curvature or other characteristics that would violate the assumptions of the regression method.

Daily mean streamflows calculated using the MOVE.1 method described earlier were applied to the regression equations for each constituent above. Daily loads were then summed to seasonal loads for the period April 1999 through September 2000. Generalizing the data to seasonal loads reduced the reliance on specific days or months of data for both the surface-water and precipitation inputs (described later). Seasonal loads for the smaller, unmeasured tributaries were estimated on the basis of the average per-unit-area yields from the other four streams.

An error analysis was not conducted. Alexander and others (2001) used a similar load-estimation procedure, and included an uncertainty analysis as described by Gilroy and others (1990). Their uncertainties in mean fluxes ranged from about 2 to 19 percent, but they note that prediction errors are larger in small basins with fewer water-quality samples (they used 374 sites with a mean of 90 samples each). Because of the small number of samples in the data set for Northeast Creek, the uncertainty in these calculations is expected to be much larger than 20 percent.

Total loads for each tributary were summed for the 18-month study period to analyze differences in loading rates among streams (table 8). Because of the method used to estimate "inorganic" and "organic" nitrogen loads (described above), these numbers are intended as a rough estimate for purposes of comparing inorganic- to organic-nitrogen loads. Load is the amount of nitrogen leaving each basin; yield is the amount leaving each basin per unit area.

Table 8. Nitrogen loading rates for inflow streams to Northeast Creek

[Values in italics are intended as rough estimates for the purpose of comparing inorganic and organic nitrogen loads; km^2, square kilometer; kg/km^2/yr, kilogram per square kilometer per year; N, nitrogen; NO$_3$, nitrate; --, not calculated]

Basin	Area (km^2)	Estimated load over 18 months (kg)				"Organic" N (percent of total)	Yield (kg/km^2/yr)	
		Total N	NO$_3$-N	"Inorganic" N	"Organic" N		Total N	NO$_3$-N
Old Mill Brook	6.13	1,400	140	*300*	*1,100*	*79*	150	15
Stony Brook	6.73	2,700	460	*800*	*1,900*	*70*	270	44
Aunt Betsey's Brook	1.62	310	26	*50*	*260*	*84*	130	13
French Hill Brook	1.40	490	39	*50*	*440*	*90*	225	19
Total ungaged streams	3.40	990	110	*200*	*790*	--	190	22
Total	19.3	5,890	775	*1,400*	*4,500*	--	--	--

The data show very different loading functions for different basins. Stony Brook, whose drainage basin is only slightly larger than that of Old Mill Brook, had almost twice the total nitrogen load for the 18-month period, and French Hill Brook had more than 50 percent more total nitrogen load than Aunt Betsey's Brook, despite its smaller drainage basin. Yields of total nitrogen range from 130 kg/km^2/yr for Aunt Betsey's Brook to 270 kg/km^2/yr for Stony Brook. Alexander and others (2001) reported that the total nitrogen export from 374 streams in the United States resulted in estimates of total nitrogen yield to coastal estuaries ranging from 38 to 2,500 kg/km^2/yr nationally. North Atlantic streams (from Maine to Chesapeake Bay) were determined to export a median 520 kg/km^2/yr of total nitrogen.

Eutrophication in estuaries is commonly caused by increases in the load of inorganic nitrogen (Kinney and Roman, 1998). Stony Brook contributed 59 percent of the total nitrate-N load to Northeast Creek, whereas Aunt Betsey's Brook contributed only 3 percent. Yields of nitrate ranged from 11 to 46 kg/km^2/yr (as N). Loads of ammonia were not estimated because of small number of samples that contained detectable ammonia (the detection limit for ammonia is much higher than that for nitrate).

The ratio of organic nitrogen to total nitrogen ranged roughly from 70 percent in Stony Brook to 90 percent in French Hill Brook. Meyer and Likens (1979) reported on the net transformation of nutrients from inorganic forms to organic or particulate forms by instream processes, so this result was expected. Similarly, a study by Doering and others (1995) of nutrients in Bass Harbor Marsh found that dissolved inorganic nitrogen accounted for 5 to 35 percent of the total nitrogen load from freshwater sources.

Reasons for differences in yields among watersheds have not been fully investigated, although some of the basin characteristics discussed earlier may be important factors. Stony Brook Basin has a larger population than the other basins, and homes there tend to be older, with older septic technology. It also is the only basin (besides the ungaged tributary between Old Mill Brook and French Hill Brook) with any appreciable agricultural activity (a horse farm). Finally, a large pond is directly upstream from the Stony Brook measurement site, and several older homes are located near the pond. The reasons for the higher nitrogen loading rates from French Hill Brook than from Aunt Betsey's brook are unclear. The characteristics of their drainage basins are similar, but recent development patterns have not been fully quantified in either basin since 1996. Some of the responses of nitrogen to streamflow indicate the possible presence of a point source upstream from the sampling location on French Hill Brook.

Differences in surface-water loads among the basins also may result from differences in the degree of nitrogen saturation in each watershed. Nitrogen saturation in forested watersheds occurs when the atmospheric supply outpaces the watershed's internal demand for nitrogen. A watershed can absorb atmospheric nitrogen only to the extent to which watershed plants and microbes can utilize it. Factors that can lead to nitrogen saturation in forested watersheds include high rates of nitrogen deposition, advanced stand age, and large pools of soil nitrogen (Stoddard, 1994). The upper part of the Old Mill Brook watershed was burned in the Mt. Desert fire of 1947, and all the available atmospheric nitrogen may be consumed by the forest as it recovers from the fire, lowering the yield.

Total nitrogen and nitrate-nitrogen loads by season and tributary stream are shown in figure 10. A strong seasonality, which is largely a function of the seasonality in streamflow, is evident. Surface-water loads are largest in the fall, winter, and spring, and are quite low in the summer. The dominance of Stony Brook in the total load is evident and holds for all seasons. Because of the large amount of precipitation in March 2000 and the comparatively small amount of precipitation in April to May 1999, the overall spring load for 2000 is much larger than the load for April–May 1999. Summertime loads also were smaller in 1999 than in 2000, primarily because the lack of rainfall resulted in long periods of no surface-water inflow to Northeast Creek during the 1999 season. A similar lack of rainfall in September 2000 is reflected in the very small loads during that month as well.

Although most of the nitrogen input to the system takes place outside the growing season, sequestration of nitrogen coming in during spring runoff may occur through remineralization and could provide a source of nitrogen that could be released internally during the growing season. There is evidence that this process occurs in Chesapeake Bay and several of its subtributaries (Doering and others, 1995). The hydrologic holding time for the Northeast Creek system is

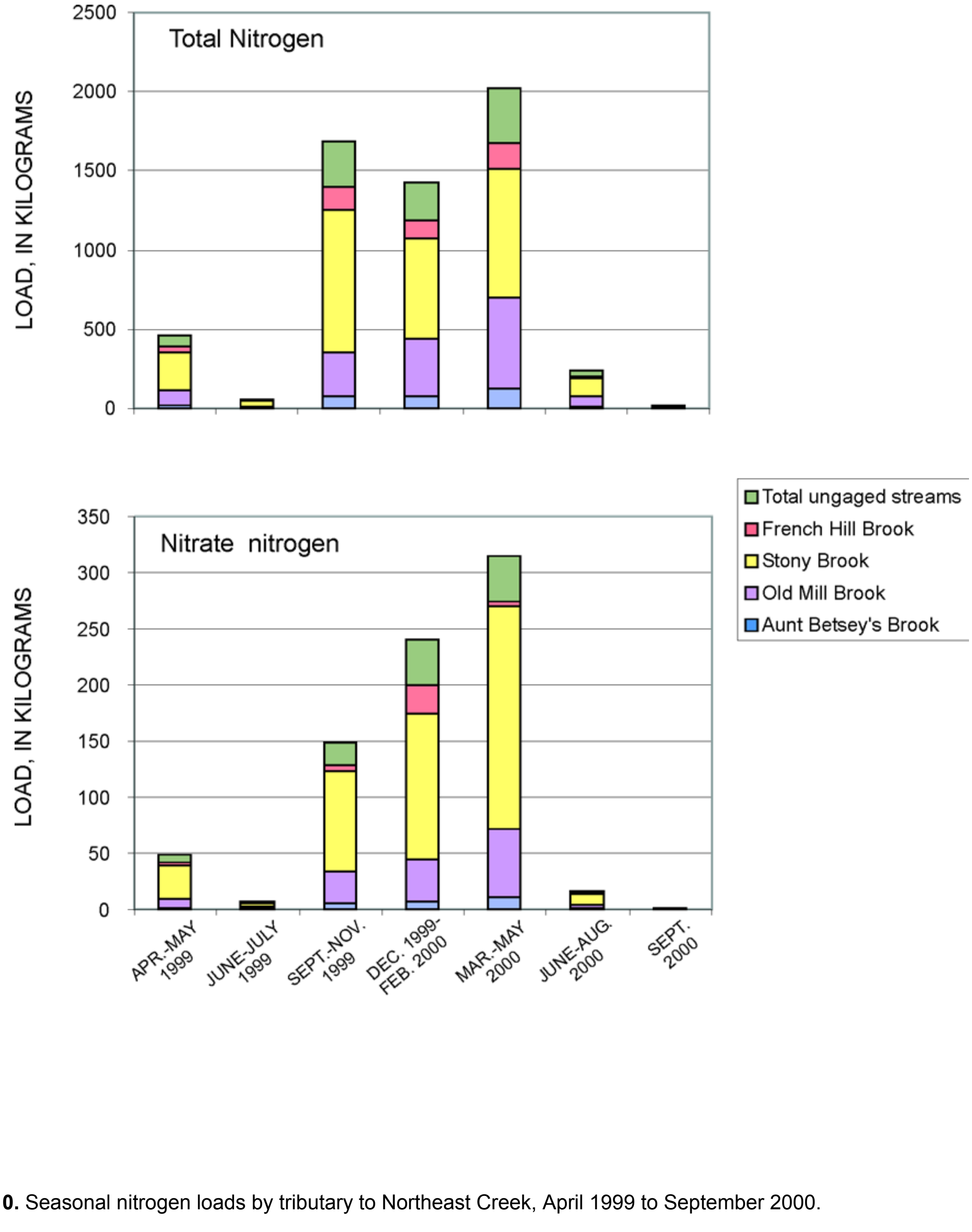


Figure 10. Seasonal nitrogen loads by tributary to Northeast Creek, April 1999 to September 2000.

very short—water flowing in from the tributaries exits in a matter of hours to days (depending on surface-water inflow rates), because of its short and narrow geometry. Doering and others (1995) estimated the residence time (during the summer) of the Bass Harbor estuary, which is hydrologically similar to Northeast Creek, to be 3 days. The degree to which spring sequestration can occur is limited by the spring residence time, which is shorter than the summer residence time because flow rates are greater in the spring. Therefore, there may be insufficient time for remineralization of spring-runoff nitrogen to be a factor during the growing season.

Atmospheric Loading

Atmospheric loading to Northeast Creek was estimated for the direct deposition onto the water surface of the creek (0.14 km^2). Dissolved inorganic nitrogen loads were estimated from weekly concentration and precipitation-volume data from the Acadia National Park NADP station (ME98). No corrections were made for weeks for which no data were available. Concentrations of both ammonia-nitrogen and nitrate-nitrogen varied greatly. Overall, ammonia accounted for approximately 30 percent of the total nitrogen load.

Monthly wet-deposition loads for April 1999 through September 2000, along with measured precipitation at the Acadia National Park weather station, are shown in figure 11. (Precipitation amounts from the weather station are shown because there were periods of missing record at the NADP station.) Monthly nitrogen deposition ranged from a low of 1 kg (May 1999) to a high of almost 10 kg (May 2000). The period of record is too short to discern seasonal trends in deposition. The relative heights of the load bars and the precipitation bars show the variation in the concentration of nitrogen in the precipitation. Months for which the bars are of similar height indicate relatively high nitrogen concentrations. Months, such as September 1999, for which the precipitation bar is much higher than the nitrogen bar, reflect the occurrence of storms with low nitrogen concentrations. In fact, in September 1999, precipitation was dominated by large Atlantic hurricanes, which do not form over land areas with large nitrogen sources.

Total inorganic wet deposition rates for the study period averaged 430 $kg/km^2/yr$. This rate is smaller than the total nitrogen deposition rate (wet and dry) of 730 +/- 100 $kg/km^2/yr$ reported by Jordan and Talbot (2000), but larger than other estimates, such as that reported by Alexander and others (2001), who estimated a deposition rate for nitrate-nitrogen of only 187 $kg/km^2/yr$ for the Casco Bay watershed in southern Maine. Jordan and Talbot (2000) reasoned that the discrepancy between their data and data from the NADP program may be the result of differences in sample-preservation techniques; it also may result from the different methods of using the nitrogen-concentration and precipitation volume data in the yearly load calculations. In the NADP program, weekly loads are not calculated, rather a volume-weighted mean concentration is used to estimate yearly loads, to reduce the effects of weeks for which no data are available. Only wet-deposition inorganic nitrogen values were used in the loading calculation for Northeast Creek.

A recent study of atmospheric deposition in the Gulf of Maine (Jordan and Talbot, 2000) determined that organic nitrogen typically accounted for only 3 percent of the total wet deposition.Adjusting the inorganic nitrogen wet deposition rate at Northeast Creek for organic nitrogen and dry deposition would give a value of 510 $kg/km^2/yr$, which is closer to the figure reported by Jordan and Talbot (2000).

The NADP data represent wet deposition only. Dry deposition was measured to be 10 to 20 percent of the total nitrogen deposition (Jordan and Talbot, 2000). Average yearly dry deposition of NO_3-N and HNO_3-N at Howland, Maine, for the period June 1987 through November 1997 was 160 $kg/km^2/yr$ (National Oceanic and Atmospheric Administration, 2001).

Ground-Water Loading

Deep ground water is not considered a significant source of nutrients to Northeast Creek (see section on Ground-Water Inflows), as available evidence indicates that little ground water is discharged to the Fresh Meadow/Northeast Creek system. The ultimate fate of ground water in the bedrock aquifer beneath the Northeast Creek drainage basin was not determined.

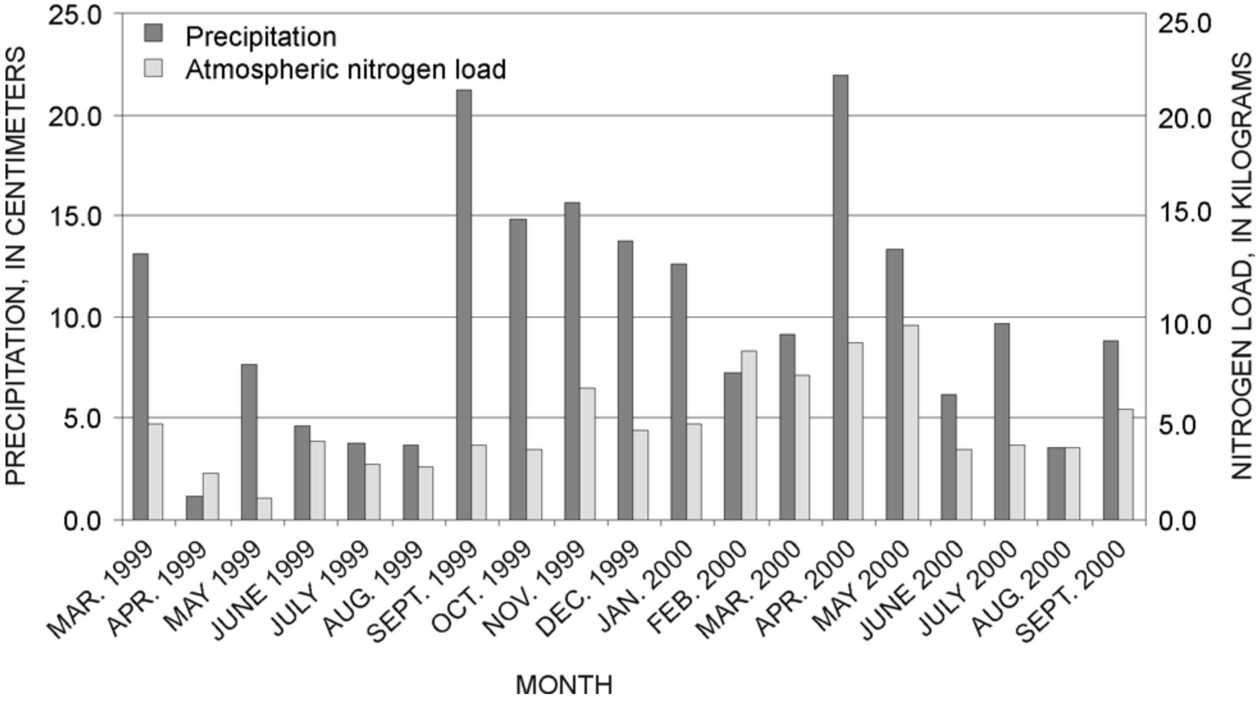


Figure 11. Monthly precipitation and wet deposition of atmospheric nitrogen on Northeast Creek, March 1999 to September 2000.

Another potential source of nutrients to Northeast Creek is shallow ground water in the soils of the wetland, which discharges into the creek at the stream banks. Determining the flow of water from the wetland soils and nutrient concentrations in this water was beyond the scope of the present study. In general, however, the process of denitrification within the wetland soils largely controls the concentration of nitrogen in water flowing from the wetland soils to the creek. Results of one recent study on the role of denitrification in mediating the inflow of nitrogen-containing ground water to a coastal wetland on Cape Cod (Nowicki and others, 1997) indicates that denitrification rates were highest in soils with a high organic content and lowest in sandy soils. Denitrification was not determined to directly mediate nitrogen loading from ground water on Cape Cod because, unlike ground water in the Northeast Creek area, most ground water there enters the wetland through sandy soils, where denitrification rates are low and ground-water velocities are high. Overall, denitrification losses were found to equal approximately 25 to 40 percent of the nitrate-nitrogen inputs from ground water. In Narragansett Bay, denitrification reduced about 50 percent of the inorganic nitrogen load from anthropogenic sources (Seitzinger and others, 1984). The processes of mineralization of organic nitrogen to inorganic nitrogen and nitrification within the organic soils of the wetland complicates the potential for denitrification to reduce nitrogen inputs from shallow ground water.

Tidal Loading

Although tidal inputs to Northeast Creek were not directly measured in this study, Doering and others (1995) measured tidal volumes and nutrient concentrations at Bass Harbor Marsh, another estuarine creek/wetland on Mt. Desert Island, and estimated that tidal inputs were roughly similar to freshwater inputs. The Bass Harbor estuary is similar hydrologically to Northeast Creek, and both receive tidal inflow that is highly restricted by a berm slightly below the high-tide level. Tidal ranges in both estuaries are about 10 to 20 cm. Doering and others (1995) estimated that 52 percent of the dissolved inorganic nitrogen load to Bass Harbor estuary was from surface water and 48 percent was from tidal inputs. It is anticipated that tidal inputs will be found to be an important component of the total nutrient budget of Northeast Creek as well.

Total External Nitrogen Loads

A seasonal summary of the measured external nitrogen loads to Northeast Creek is shown in figure 12. Estimated surface-water loads show a pronounced seasonality, which corresponds primarily to the seasonality of surface-water streamflow. Surface-water loads are on average at least two orders of magnitude greater than atmospheric loads. Fall, winter, and spring surface-water loads are an order of magnitude greater than summer loads. Nitrate plus ammonia loads are much smaller than the total nitrogen loads, which is typical for surface-water-dominated systems.

Of the individual streams, Stony Brook is responsible for 46 percent of the total nitrogen load during the study period, and for 59 percent of the nitrate-nitrogen load (table 9). The ratio of nitrate-nitrogen to other nitrogen sources is higher in Stony Brook than in the other streams; this finding probably is related to the greater amount of old development in this basin than in the other basins.

Atmospheric loads of nitrogen (totaling 85 kg) represent only 1 percent of the total external nitrogen load for the study period, and less than 10 percent of the inorganic nitrogen load. Seasonally, atmospheric loads range from 3 to 25 kg of nitrogen and account for 1 to 23 percent of the total external nitrogen load to Northeast Creek.

Tidal loads, which were not measured in this study, are not shown in figure 12. Because tidal flows vary less with precipitation and runoff than do freshwater streams, tidal loads are expected to remain more constant during the year. During periods of maximum runoff, tidal loads are prevented from entering the creek because the water level during a large runoff event is higher than the high-tide level (unpublished data available at the U.S. Geological Survey office in Augusta, Maine). Therefore, tidal nitrogen inputs would be reduced during the months when surface-water inflows were highest, resulting in a seasonal load pattern that is the opposite of the surface-water load pattern. If the ratio of tidal load to surface-water load in Northeast Creek is similar to that observed in the Bass Harbor estuary (Doering and others, 1995), then tidal loads may dominate nitrogen input to the creek during the summer.

SUMMARY AND CONCLUSIONS

A calculation of the freshwater inflows to the Northeast Creek/Fresh Meadow system shows that surface-water flows are the dominant source of freshwater to the system. Freshwater inputs are highly seasonal, with relatively little input during the growing season (May through September). Evapotranspiration from the wetland surface ranged from a low of less than 2 cm/mo in the winter to highs of 14 cm/mo in July 1999 and 10 cm/mo in August 2000. Precipitation inputs were highly variable. Spring and summer 1999 were dry—precipitation was approximately half of the 19-year average recorded at the Acadia National Park headquarters monitoring station. Fall, winter, and spring of 1999–2000 were normal to wet. Precipitation patterns were near-normal in summer 2000, whereas September 2000 was very dry. Ground-water inputs from the deep bedrock aquifer below the system are believed to be negligible because of the presence of a marine clay layer under the peat sediments of the wetland and Northeast Creek. Shallow ground-water inputs to the system were unquantified, but summer estimates based on base flow in nearby streams indicate that shallow ground-water inputs during the summer months are an order of magnitude smaller than other inputs. Surface-water outflows plus storage were calculated as the residual of the above terms in the water budget. Changes in storage can account for approximately 5 to 10 percent of the residual during months of flooding and floodwater recession, and 60 to 100 percent of the residual during summertime drawdown from evapotranspiration. Otherwise, net surface-water outflows generally followed the surface-water inflows in magnitude. Outflows were greater than inflows during the fall, winter, and spring months, but were usually less than inflows during the summer months because of evapotranspiration.

External nitrogen loads also were estimated for Northeast Creek. Total nitrogen and nitrate-nitrogen loads were calculated for each of the tributaries entering Northeast Creek. Inorganic nitrogen loads from precipitation were calculated using data from the National Atmospheric Deposition Program site at the Acadia National Park headquarters. Because of the relation between streamflow and load, the surface-water nitrogen loads to the creek are highly seasonal; nitrogen inputs were approximately an order of magnitude lower in the summer than in the other seasons.

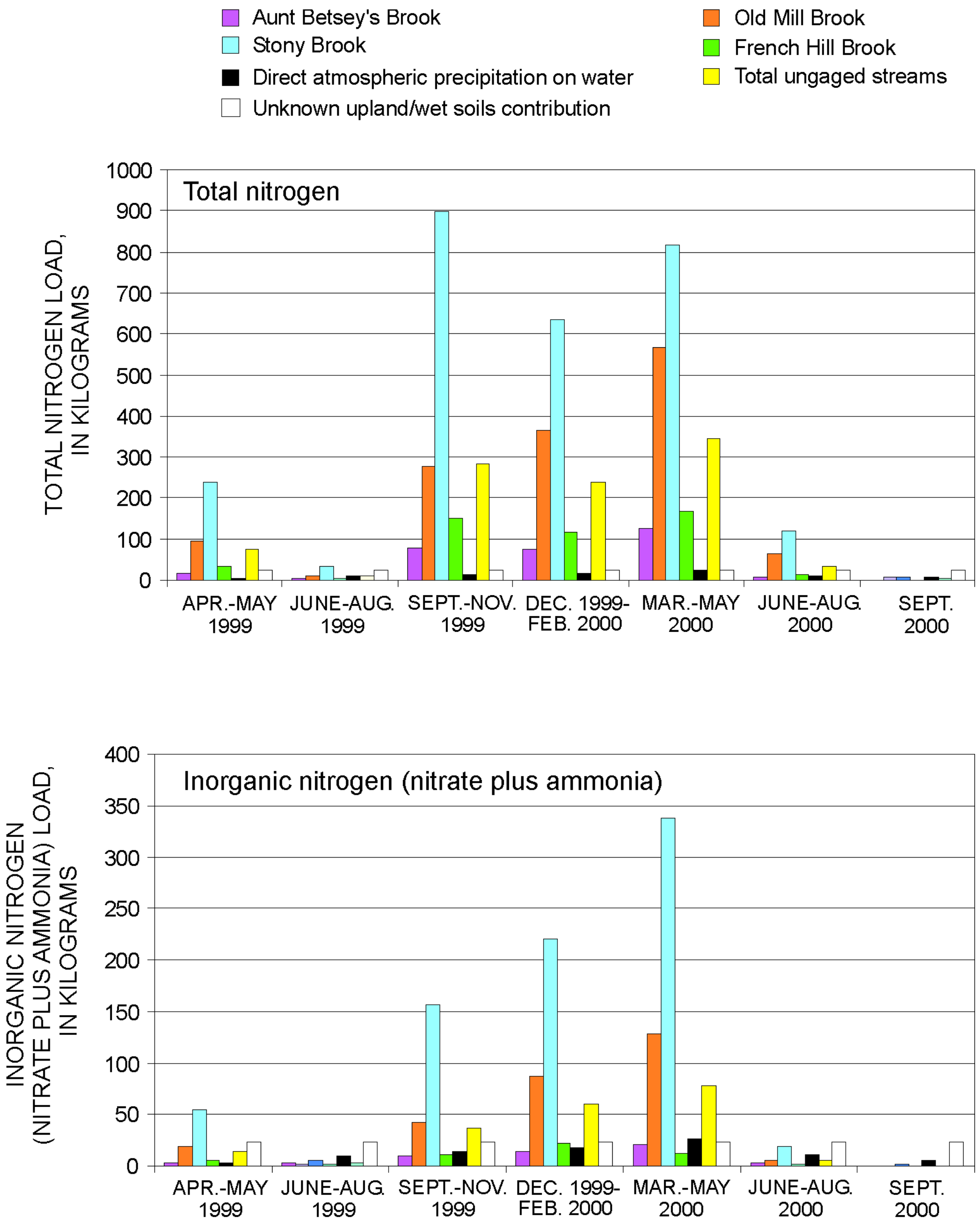


Figure 12. Seasonal nitrogen loads to Northeast Creek from all hydrologic sources.

Table 9. Seasonal loading ratios for surface-water and atmospheric sources to Northeast Creek

[kg, kilogram; N, nitrogen; --, no data]

Source	Entire study period (April 1999-September 2000)				April-May 1999		June-August 1999		September-November 1999		December 1999-February 2000		March-May 2000		June-August 2000		September 2000	
	Total N flux		Nitrate-N flux		Percent of total		Percent of total		Percent of total		Percent of total		Percent of total		Percent of total		Percent of total	
	Total N (kg)	Percent of total	Nitrate-N (kg)	Percent of total	Total N	Nitrate-N	Total N	Nitrate-N	Total N	Nitrate-N	Total N	Nitrate-N	Total N	Nitrate-N	Total N	Nitrate-N	Total N	Nitrate-N
Surface-water loads[1]																		
Old Mill Brook	1,400	23	140	18	21	18	20	6	16	20	26	16	28	19	27	18	45	11
Stony Brook	2,700	46	460	59	52	60	58	44	53	59	44	54	40	63	49	60	38	39
Aunt Betsey’s Brook	310	5	26	3	4	3	3	23	5	3	5	3	6	3	4	4	2	15
French Hill Brook	490	8	39	5	8	5	5	5	9	4	8	11	8	1	6	4	2	13
Total ungaged streams	990	17	110	15	16	14	15	21	17	14	17	17	17	13	15	14	13	22
Total surface-water loads	5,900	100	780	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Atmospheric load[2]																		
	85	1	--	--	1	--	13	--	1	--	1	--	1	--	4	--	23	--

[1] “Percent of total” values represent percentages of surface-water loads.

[2] “Percent of total” values represent percentages of total load, including atmospheric load.

Ammonia loads were not calculated because of the large number of samples in which ammonia levels were below the 0.05-mg/L detection limit. The surface-water nitrogen loads were estimated on the basis of data from 18 monthly samples collected from the four perennial tributaries and on estimated daily streamflows.

Over the study period, total nitrogen loads to Northeast Creek from the tributary basins ranged from 310 kg from Aunt Betsey's Brook to 2,700 kg from Stony Brook. Stony Brook also contributed 59 percent of the nitrate-nitrogen load to Northeast Creek (460 kg), whereas Aunt Betsey's Brook contributed only 3 percent (26 kg). Total nitrogen yields ranged from 130 kg/km^2/yr in Aunt Betsey's Brook to 270 kg/km^2/yr in Stony Brook. Nitrate-nitrogen yields ranged from 13 kg/km^2/yr in Aunt Betsey's Brook to 44 kg/km^2/yr in Stony Brook. Overall, these yields are lower than yields to eutrophic estuaries elsewhere on the East Coast. Differences in the yields of nitrate-nitrogen and total nitrogen may result from differences in the numbers, ages, and proximity of household septic systems to surface waters; amount and degree of agricultural activity in each basin; and natural factors such as burn history and geologic materials.

Atmospheric loading to the creek surface accounted for a very small portion of the total load of nitrogen to Northeast Creek. Seasonal atmospheric loads ranged from 3 to 25 kg, which represent 1 percent (in most seasons of the study period) to 23 percent (in September 2000) of the external nitrogen load entering the creek.

Several factors that relate to water and nitrogen inputs to this system remain unstudied. The volume of shallow ground-water inflow to the Northeast Creek/Fresh Meadow system was not quantified during this study. Tidal flows and nitrogen concentrations in incoming tidal waters would be useful in determining the relative importance of all nitrogen sources to Northeast Creek. Water entering the creek from within the Fresh Meadow wetland is another unquantified potential source of nitrogen. Information on denitrification rates in the wetland soils, nitrogen concentrations in the water in these soils, and ground-water levels in the wetland is needed to improve the estimates of the magnitude of nitrogen entering the creek.

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