Cover. Aerial photograph of the Englesby Brook watershed (U.S. Geological Survey National Map) and Englesby Brook (top and bottom, left side) and the barnyard from a dairy farm adjacent to Little Otter Creek and Little Otter Creek (top and bottom, right side).

Concentrations and Loads of Nutrients and Suspended Sediments in Englesby Brook and Little Otter Creek, Lake Champlain Basin, Vermont, 2000–2005

By Laura Medalie

Prepared in cooperation with the
Vermont Department of Environmental Conservation,
City of Burlington, and
Lake Champlain Basin Program

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton, short (2,000 lb)	0.9072	metric ton (t)
ton per year per square mile [(ton/yr)/mi^2]	0.3503	metric ton per year per square kilometer [(t/yr)/km^2]

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 micrograms per liter (μg/L).

Concentrations and Loads of Nutrients and Suspended Sediments in Englesby Brook and Little Otter Creek, Lake Champlain Basin, Vermont, 2000–2005

By Laura Medalie

Abstract

The effectiveness of best-management practices (BMPs) in improving water quality in Lake Champlain tributaries was evaluated from 2000 through 2005 on the basis of analysis of data collected on concentrations of total phosphorus and suspended sediment in Englesby Brook, an urban stream in Burlington, and Little Otter Creek, an agricultural stream in Ferrisburg. Data also were collected on concentrations of total nitrogen in the Englesby Brook watershed. In the winter of 2001–2002, one of three planned structural BMPs was installed in the urban watershed. At approximately the same time, a set of barnyard BMPs was installed in the agricultural watershed; however, the other planned BMPs, which included streambank fencing and nutrient management, were not implemented within the study period.

At Englesby Brook, concentrations of phosphorus ranged from 0.024 to 0.3 milligrams per liter (mg/L) during base-flow and from 0.032 to 11.8 mg/L during high-flow conditions. Concentrations of suspended sediment ranged from 3 to 189 mg/L during base-flow and from 5 to 6,880 mg/L during high-flow conditions. An assessment of the effectiveness of an urban BMP was made by comparing concentrations and loads of phosphorus and suspended sediment before and after a golf-course irrigation pond in the Englesby Brook watershed was retrofitted with the objective of reducing sediment transport. Results from a modified paired watershed study design showed that the BMP reduced concentrations of phosphorus and suspended sediment during high-flow events—when average streamflow was greater than 3 cubic feet per second. While construction of the BMP did not reduce storm loads of phosphorus or suspended sediment, an evaluation of changes in slope of double-mass curves showing cumulative monthly streamflow plotted against cumulative monthly loads indicated a possible reduction in cumulative loads of phosphorus and suspended sediment after BMP construction.

Results from the Little Otter Creek assessment of agricultural BMPs showed that concentrations of phosphorus ranged from 0.016 to 0.141 mg/L during base-flow and from 0.019 to 0.565 mg/L during high-flow conditions at the upstream monitoring station. Concentrations of suspended sediment ranged from 2 to 13 mg/L during base-flow and from 1 to 473 mg/L during high-flow conditions at the upstream monitoring station. Concentrations of phosphorus ranged from 0.018 to 0.233 mg/L during base-flow and from 0.019 to 1.95 mg/L during high-flow conditions at the downstream monitoring station. Concentrations of suspended sediment ranged from 10 to 132 mg/L during base-flow and from 8 to 1,190 mg/L during high-flow conditions at the downstream monitoring station.

Annual loads of phosphorus at the downstream monitoring station were significantly larger than loads at the upstream monitoring station, and annual loads of suspended sediment at the downstream monitoring station were larger than loads at the upstream monitoring station for 4 out of 6 years. On a monthly basis, loads of phosphorus and suspended sediment at the downstream monitoring station were significantly larger than loads at the upstream monitoring station. Pairs of concentrations of phosphorus and monthly loads of phosphorus and suspended sediment from the upstream and downstream monitoring stations were evaluated using the paired watershed study design. The only significant reduction between the calibration and treatment periods was for monthly loads of phosphorus; all other evaluations showed no change between periods.

Introduction

Reducing phosphorus inputs to Lake Champlain to slow eutrophication is a high priority for local citizens, businesses, recreationists, and state and federal officials (Lake Champlain Steering Committee, 2003). In addition to impairing the clear natural beauty of the Lake and disrupting native food-chain dynamics, excess phosphorus can lead to potentially toxic blue-green algae blooms (Vermont Department of Health, 2005). Implementation of the management plan that stemmed from the Lake Champlain Special Designation Act of 1990 (Lake Champlain Management Conference, 1996) called for specific phosphorus-reduction goals for each lake-segment watershed in the Lake Champlain Basin in New York and Vermont (Smeltzer, 1999). The plan also generated an international agreement between Quebec and Vermont aimed at sharing responsibilities for phosphorus-load reduction in the Missisquoi River Basin, a large agricultural subbasin within the Lake Champlain Basin (Quebec and Vermont, 2000). Progress towards achieving these targeted reductions is measured, in part, by tracking the implementation of best-management practices (BMPs) and assigning a standardized load-reduction credit for each BMP.

Implementing BMPs to reduce phosphorus and sediment pollution in runoff is expensive, and knowing where to target available dollars is a continual but worthwhile challenge. About $7 million was spent in Vermont from 1995 to 2000 on about 600 agricultural nonpoint-source BMP projects (Lake Champlain Steering Committee, 2003). Implementation of agricultural BMPs in Vermont generally is accomplished via state and federal cost-share programs with individual farms.

Table 1. Project schedule for monitoring best-management practices in an urban setting (Englesby Brook watershed) and in an agricultural setting (Little Otter Creek watershed).

[BMP, best-management practice; USGS, U.S. Geological Survey]

Timing	Activity
	Englesby Brook
Spring 1999	Begin monthly sampling.
Summer 1999	Build weir and install instrumentation; begin to collect continuous water-quality and stage data; begin to collect storm samples.
2001–2002	Construct first BMP: retrofits to golf course irrigation pond[1].
Summer and Fall 2005	Construct two additional structural BMPs[1].
2006–2010	Collect post-BMP data.
	Little Otter Creek
Spring 2000	Begin monthly sampling.
Summer 2001	Install automated samplers and continuous water-quality monitors at upstream and downstream stations, and transducer and datalogger downstream.
2001–2002	Construct barnyard BMPs[1].
Summer 2002	Install transducer and datalogger upstream and begin to collect storm samples.
2002–2005	Collect post-barnyard-BMP data.
September 2005	End data collection.

[1]Agencies responsible for BMP construction were the Burlington Public Works Department (Englesby Brook) and Natural Resource Conservation Service (Little Otter Creek). All other activities were done by the USGS.

In New York, agricultural BMPs from 1995 to 2000 were supported by the State Clean Air/Clean Water Bond Act. The historical tendency to connect phosphorus-pollution issues primarily to agricultural land shifted to include urban land when Hegman and others (1999) demonstrated that urban or developed land generates a larger percentage of nonpoint-source phosphorus loading to the lake per unit area than other land uses. Phosphorus reduction from urban areas in Vermont is addressed in part by the 2005 Stormwater Management Rule (Vermont Agency of Natural Resources Department of Environmental Conservation, 2005) and by the State Land Use Act 250 permitting process. Suspended sediment also is a concern in the Lake Champlain Basin because sediment itself is a contaminant and is associated with phosphorus and many other potentially harmful or toxic substances.

Until recently, the emphasis for state and federal agricultural agencies has been on implementing BMPs. Lately, there has been a greater realization that monitoring and tracking success also is needed, and both the U.S.D.A. Natural Resources Conservation Service (NRCS) and the Vermont Agency of Agriculture Food and Markets have begun to provide some resources to measure the effectiveness of BMPs in improving water quality (Fletcher Potter, U.S. Natural Resources Conservation Service, oral commun., 2006). To address the need for documenting reductions in phosphorus and suspended sediment due to BMPs, the U.S. Geological Survey (USGS), in cooperation with the Vermont Department of Environmental Conservation, the City of Burlington, and the Lake Champlain Basin Program, collected water-quality and streamflow data from 1999 through 2005 at stations in the Lake Champlain Basin with watersheds comprised of predominantly urban and agricultural land.

Purpose and Scope

This report provides information on concentrations and loads of phosphorus and suspended sediment in one urban and one agricultural watershed to investigate the effectiveness of BMPs in reducing phosphorus and suspended-sediment loading in Lake Champlain tributaries. In the urban watershed, Englesby Brook, structural BMPs were installed in two phases: October 2001 through March 2002 and June through October 2005. Monitoring water quality and evaluating the effect of the set of BMPs constructed in 2005 is ongoing. In the agricultural watershed, Little Otter Creek, only the first of several planned BMPs was constructed between November 2001 to April 2002 before the remaining BMPs were cancelled. A timeline of the project schedule is shown in table 1.

This report contains data on concentrations and loads of total nitrogen, total phosphorus, and suspended sediment from Englesby Brook from water years 2000 through 2005[1]. It also contains data on concentrations and loads of total phosphorus and suspended sediment from two stations on Little Otter

[1]A water year is the 12-month period October 1 through September 30 and is designated by the calendar year in which it ends.

Creek from March 2000 through September 2005. Although some nitrogen data were collected at Englesby Brook, the focus for both the urban and agricultural watersheds was on phosphorus because of the phosphorus-reduction goals set by the Lake Champlain Steering Committee (2003). For this reason, evaluations of BMP effectiveness and changes in water quality over time were done only for phosphorus, and to a limited extent, for suspended sediment.

Previous Studies

Previous studies on the effectiveness of urban BMPs have focused generally on the performance of individual structures. Researchers in Wisconsin monitored the ability of a pressurized stormwater-filtration system to treat runoff from rooftops and parking lots and found that loads of constituents associated with particulates were reduced whereas loads of dissolved constituents were not, probably because of ground-water seepage into the system between events (Horwatich and others, 2004). Similar findings were observed in the Rouge River watershed in Detroit, a study site of urban BMPs that included wetland creation and restoration, grassed swales, dry ponds, wet ponds, filtration practices, and infiltration practices (Pennington and others, 2003). These researchers concluded that although some pollutant levels were reduced due to the practices, the structural BMPs alone did not achieve reduction levels necessary for all constituents to meet urban water-quality standards. Removal deficiencies were found for bacteria, dissolved constituents, and for most pollutants during extreme weather events. Data from the International Stormwater BMP database from 1999–2005 showed that for detention basins, biofilters, media filters, retention ponds, and wetland channels, average concentrations of total suspended solids (TSS) in effluent were less than concentrations in influent. For hydrodynamic devices (such as oil-water separators and other prefabricated treatment devices) and wetland basins, there was no difference between influent and effluent concentrations of TSS. Although none of the stormwater BMPs showed a significant reduction in concentrations of total phosphorus in effluent compared to influent, there was a significant reduction in event-mean concentrations of total phosphorus for all structures except detention basins and biofilters. No structural stormwater BMPs demonstrated a significant reduction in concentrations of total nitrogen in effluent compared to influent (Geosyntec Consultants and Wright Water Engineers, Inc., 2006). More information related to urban and stormwater BMPs can be found at the Center for Watershed Protection Web site (*www.cwp.org*); the International Stormwater BMP database—a project originated by the American Society of Civil Engineers and the U.S. Environmental Protection Agency (USEPA) (*www.bmpdatabase.org*); and the USEPA urban nonpoint-source pollution Web site (*http://www.epa.gov/owow/nps/urban.html*).

Demonstration studies across the northern and eastern United States have shown that although improvements in water quality can be traced to implementation of agricultural BMPs, success is not universal. Streambank fencing improved nitrogen and sediment concentrations and the population of benthic macroinvertebrates, but not nitrogen yields or phosphorus concentrations in base-flow samples in Pennsylvania (Galeone, 2000). Also, streambank fencing improved sediment concentrations and some sediment yields but not nitrogen or phosphorus yields for storm samples. Another Pennsylvania study concluded that streambank fencing, in conjunction with other BMPs, resulted in reductions of flow-adjusted concentrations of phosphorus and suspended solids in base flows, and a reduction in suspended solids in storm samples (Koerkle, 2000). A third Pennsylvania study showed that pipe-outlet terracing reduced sediment loads but not nitrogen or phosphorus loads and that nutrient management reduced dissolved nitrate in ground water (Lietman, 1997).

Streambank fencing in Wisconsin, in conjunction with stream crossings, grade stabilization, buffer strips, barnyard-runoff controls, and nutrient management showed significant reductions in concentrations of suspended solids and biological-oxygen demand (BOD_5) but not in concentrations of phosphorus or ammonia for base-flow samples. Also, loads of suspended solids and ammonia in storm samples were reduced over the entire year, and phosphorus was reduced during the nonvegetative season (Corsi and others, 2005). BMPs that treated barnyard wastes, fenced cows, and established a gravel-lined channel crossing, resulted in reduction of phosphorus, ammonia, and BOD_5 loads, and suspended-solids and fecal-coliform concentrations at one treatment area in Wisconsin but not a second (Stuntebeck and Bannerman, 1998).

Agricultural BMP studies in New England have shown various results regarding water-quality improvements. In western Vermont, reduced tillage on corn fields significantly reduced runoff and sediment losses (Clausen and others, 1996). Also in Vermont, Meals (2001) demonstrated that streambank fencing and protection reduced concentrations and loads of phosphorus, nitrogen, suspended solids, and bacteria. In New Hampshire, constructing manure storage pits and concrete pads, redirecting barn-roof runoff, and constructing stream crossings resulted in an improved benthic macroinvertebrate community but no change in concentrations of bacteria, phosphorus, or turbidity (Dates, 1995). In Maine, agricultural practices, which included manure spreading, cropland design, and access of dairy herds to surface water, resulted in reduced annual yields of phosphorus (Maloney and Sowles, 1987).

Study Area Description

The Englesby Brook watershed in Burlington and South Burlington, Vermont, drains into Lake Champlain at the southern end of Burlington Bay (figs. 1 and 2) and has a watershed area of 2.41 square kilometers (km^2). The effective 'sewershed' area is 2.10 km^2, because about 13 percent of the runoff is removed by combined sewers for treatment outside the watershed. The watershed area has slightly more

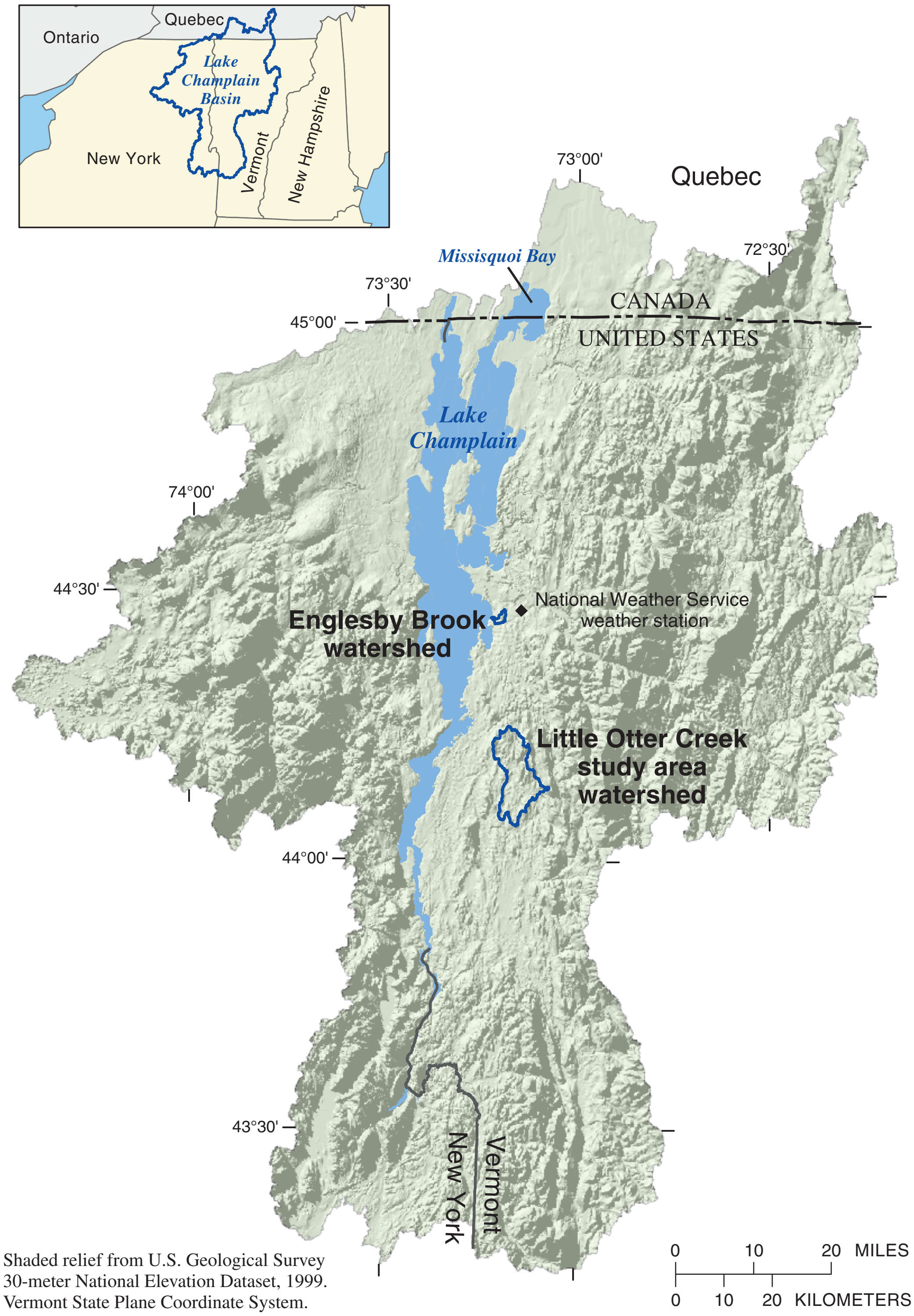

Figure 1. Location of Englesby Brook and Little Otter Creek study areas in the Lake Champlain Basin.

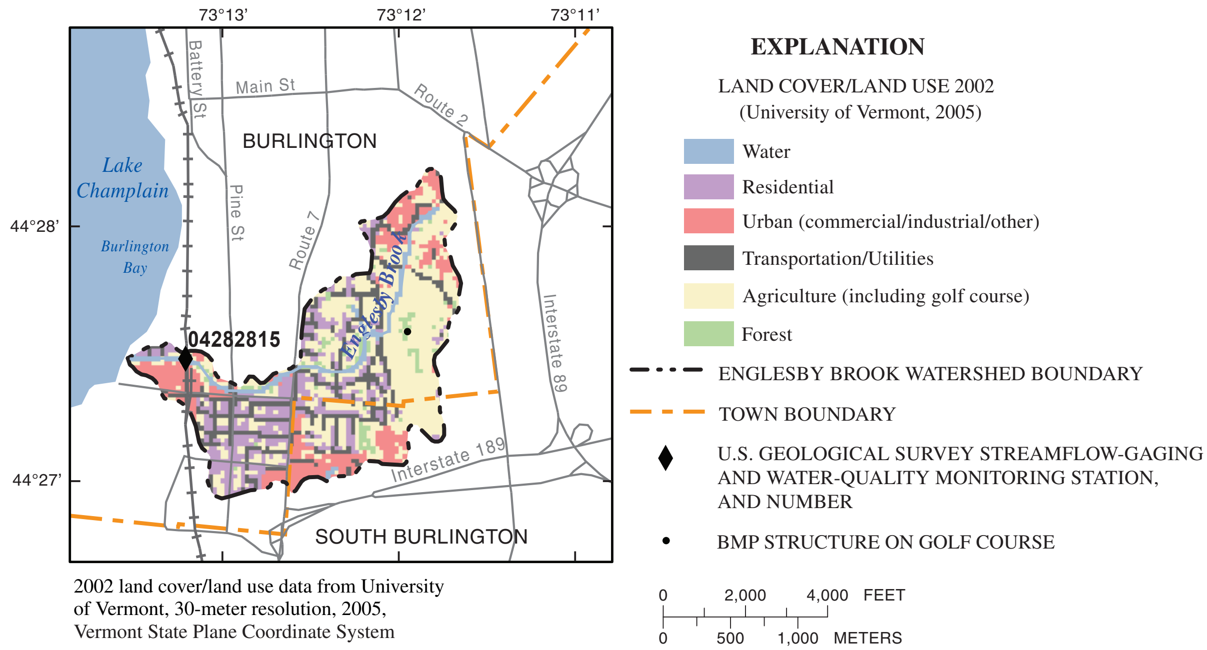

Figure 2. Land use and location of streamflow-gaging and water-quality monitoring station in the Englesby Brook watershed, Vermont. [BMP, best-management practice]

developed or built-up land than undeveloped land. Agriculture (including a golf course) accounts for 40 percent of the land use; commercial, industrial, transportation, and other urban uses (including parts of the University of Vermont campus), together account for 34 percent; residential use accounts for 18 percent; and forest and water account for 4 percent each. Bedrock underlying the western half of the watershed is the Monkton Quartzite, which grades into the Winooski Dolomite in the eastern half (terminology follows Doll and others, 1961). Surficial materials consist of massive gray silt and clay sediments from the younger marine Champlain Sea overlying finely laminated silt and clay sediments from older Lake Vermont (Wright, 2003). Data from 120 years of record at the South Burlington Airport show average annual precipitation of 85 centimeters (cm) and annual evapotranspiration of about 51 to 53 cm (National Weather Service, 2005a). Average annual snowfall in Burlington, based on 59 years of data, is 200 cm (National Weather Service, 2005b).

Little Otter Creek is a 185-km^2 watershed that drains into Lake Champlain (fig. 1). All agricultural BMP activities that were planned for this project were to be on a single dairy farm that straddles Little Otter Creek. There is about a 2-km^2 difference in drainage area between the two USGS water-quality monitoring stations that were established for this study to isolate the on-farm BMPs (drainage areas are 109 and 111 km^2 at the upstream and downstream monitoring stations, respectively); thus, land use in the watershed at both monitoring stations is approximately the same. These land-use percentages are about 41 percent forested, 39 percent agricultural, 14 percent water or wetlands, and 6 percent developed (fig. 3). Bedrock in the vicinity of the study area consists predominantly of the Monkton Quartzite, the Winooski Dolomite, and the Danby and Potsdam Formations (terminology follows Doll and others, 1961).

Study Methods

Data-collection activities were designed to provide sufficient information on concentrations and loads of phosphorus and suspended sediment to enable determination of the effectiveness of urban and agricultural BMPs in improving water quality, using several graphical and statistical measures. Procedures described in the following paragraphs pertain to both the Englesby Brook and Little Otter Creek components, unless noted otherwise.

Site Selection and Study Design

Englesby Brook was selected for the urban component of this BMP effectiveness study because: (1) it is a small watershed with considerable urban and suburban land use, and (2) a funded restoration plan was developed, with timing coincidental to project requirements. In 2000, an Englesby Brook Restoration Plan was written for the City of Burlington

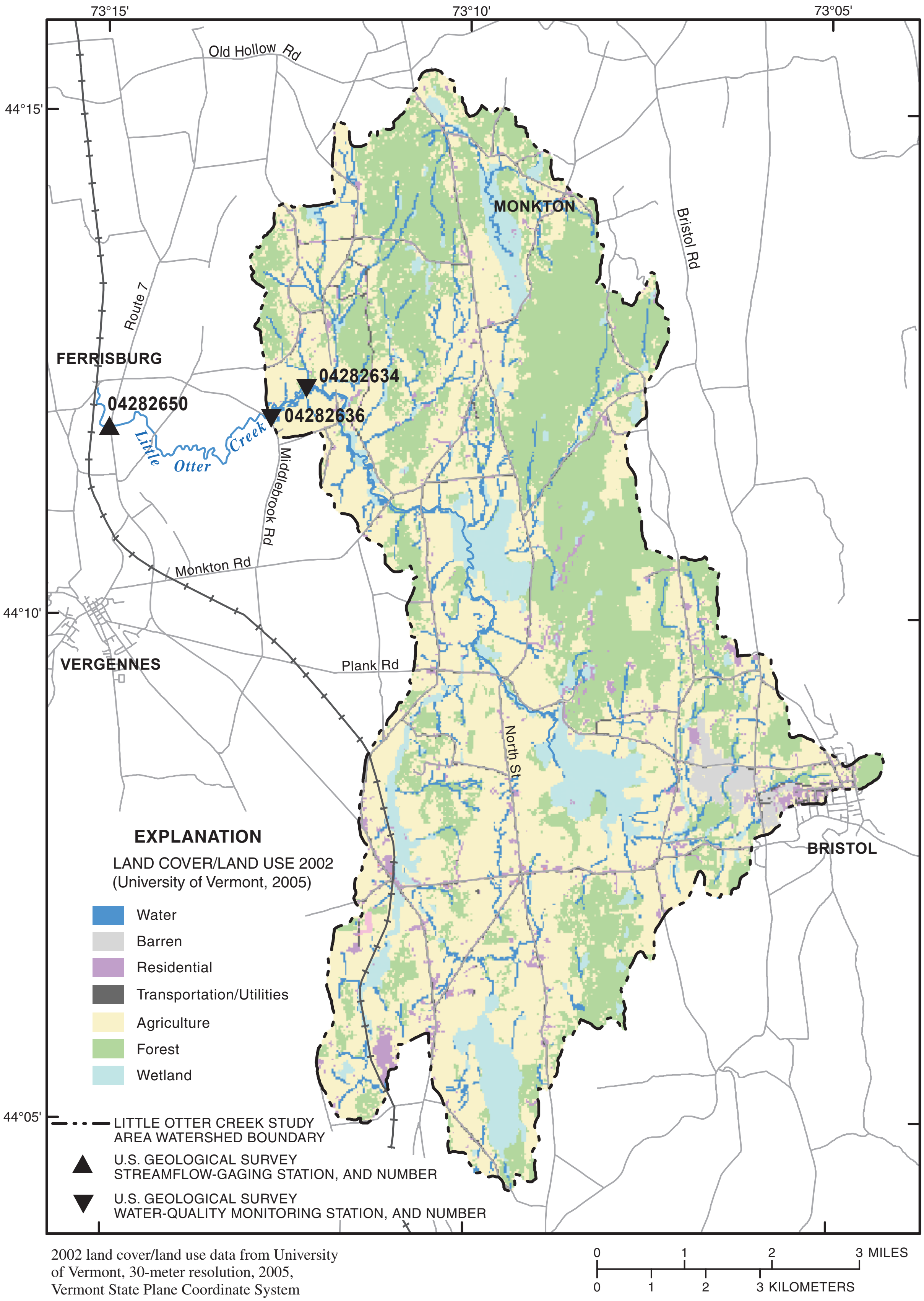

Figure 3. Land use and location of streamflow-gaging and water-quality monitoring stations on Little Otter Creek, Vermont.

(Center for Watershed Protection, written commun., 2000) to present a strategy for mitigating impacts and stresses on the ecosystem. One indicator of stress has been the closure of Blanchard Beach, at the mouth of Englesby Brook, as a result of high bacteria levels. The Restoration Plan estimated watershed imperviousness as 24 percent and enumerated several ecological issues common in urban streams and at Englesby Brook, including increased surface runoff, increased frequency of bankfull streamflow, enlargement of channels, decline in water quality, increased barriers to upstream fish migration, degradation of instream habitat, fragmentation of riparian forests, and reduction in aquatic diversity. A series of recommended BMPs was presented in the Restoration Plan, including costs, benefits, and potential load reductions for total nitrogen, total phosphorus, total suspended solids, and *Escherichia coli* bacteria. A Coordinating Council convened by the USEPA approved the plan, and BMP planning and construction funding was secured. The USGS leveraged the BMP construction plan by adding the monitoring component. The particular location for the streamflow-gaging station and water-quality monitoring station at Englesby Brook was selected because it was above potential lake backwater and in a relatively constricted part of the stream channel.

To assess potential changes in water quality due to BMP implementation at Englesby Brook, a before-after monitoring design was used. At the onset of USGS involvement, there was some uncertainty as to which of several proposed BMPs would be constructed in the watershed, making placement of an upstream monitoring station to target a specific BMP or set of BMPs impracticable. Also, because of the small size of the Englesby Brook watershed and the large scale of the proposed restoration project, it was believed that changes in water quality would be sufficient to be statistically measurable. Thus, a single USGS streamflow-gaging and water-quality monitoring station (station number 04282815) was established near the outlet of Englesby Brook into Lake Champlain, at the lower end of the stream channel (fig. 4).

A reach of Little Otter Creek in Ferrisburg was selected for the agricultural component of the study (fig. 3) because it included a 77-hectare dairy farm with 80–90 cows. This particular site was recommended by the Addison County NRCS field office and was selected as the agricultural study area because: (1) the farm appeared to have some streambank erosion and sediment-runoff problems; (2) there was a high probability of receiving federal funds for farm improvements; and (3) the landowner had indicated willingness to participate in the project and to permit water-quality monitoring on the property. Before the decision was made to invest resources into streamflow and water-quality monitoring equipment, results from several sets of paired grab samples confirmed that concentrations of total phosphorus were higher at the downstream end of the farm than at the upstream end (this assessment was based on 18 sample pairs; mean concentrations of total phosphorus at downstream and upstream stations were 0.093 and 0.079 milligrams per liter (mg/L), with standard errors of 0.014 and 0.011, respectively). This was a necessary condition for selecting a site because implicit for a determination of BMP success were that activities on the farm were affecting water quality, that these activities could be mitigated, and that a measurable and significant reduction in concentrations or loads of phosphorus or suspended sediment at the downstream end of the farm could be achieved.

To assess potential changes in water quality due to BMP implementation at Little Otter Creek, a paired watershed study design (U.S. Environmental Protection Agency, 1993b) was used, with upstream (control) and downstream (treatment) stations serving as the pair of watersheds. Because the only part of the original BMP plan that was implemented was barnyard improvements, the before-after analysis was limited to results before and after the barnyard BMPs. For the upstream-downstream part of the analysis, two USGS water-quality monitoring stations (figs. 3 and 5) were established on Little Otter Creek, close to the eastern ('upstream' station 04282634) and western ('downstream' station 04282636) property boundaries of the dairy farm. The placement of these stations was intended to isolate the on-farm activities, including BMPs. The downstream monitoring station (fig. 5) captured runoff from the barnyard that, prior to the BMP installation, channeled into a ditch draining along Middlebrook Road into Little Otter Creek about 15 m above the station.

Field Procedures

A summary of data-collection activities, equipment, and collection details is shown in table 2. Minor changes in sampling design were implemented after October 2002.

Water samples for total phosphorus and suspended sediment, plus total nitrogen at Englesby Brook, were collected by using automated and manual sampling techniques. Field techniques for data collection and processing followed the USGS National Field Manual (U.S. Geological Survey, variously dated). Both automated and manual sampling was done during non-frozen conditions, typically from March through December. The designation of water samples as either base flow or high flow was determined by their plotted position on the hydrograph at the time of sampling.

If stream velocity was above the minimum 1.5 foot per second (ft/s) required for isokinetic sampling, then manual water samples, following protocols of the equal-width-increment (EWI) method, were collected using a handheld sampler and then were composited into a churn splitter (Wilde and others, 1999). Aliquots from the churn splitter were poured into sample bottles. If stream velocity was less than 1.5 ft/s, then manual samples were collected directly into sample bottles. Manual samples were collected and field parameters (temperature, specific conductance, pH, dissolved oxygen, and turbidity) were measured generally at monthly intervals and during occasional storms.

At Englesby Brook, manual water samples that were collected using the handheld sampler or directly into sample bottles were taken from water entering the v-notch of the weir.

Figure 4. Sampling station on Englesby Brook, showing weir and conduit for automated sampler line leading up to streamflow-gaging station.

Figure 5. View upstream from Middlebrook Road bridge near downstream monitoring station on Little Otter Creek, Vermont.

Table 2. Equipment used, collection interval, and collection period for water-quality monitoring at Englesby Brook and Little Otter Creek, Vermont.

[N, total nitrogen; P, total phosphorus]

Data type	Equipment	Collection interval	Collection period
Englesby Brook			
Concentrations of N, P, suspended sediment	Handheld sampler	Monthly	October [1]1999–2005.
Stage	Transducer	5-minute	July [1]1999–2005.
Temperature, specific conductance, dissolved oxygen, pH, turbidity	Multi-parameter sonde or field meter	15-minute	July 1999–October 2002 continuously; thereafter in tandem with manual sample collection.
Concentrations of N, P, suspended sediment	Automated sampler	Most storms	October [1]1999–2005 (N discontinued in 2003).
Little Otter Creek			
Concentrations of P, suspended sediment	Handheld sampler	Monthly	Spring 2000–September 2005.
Stage (at U.S. Geological Survey station 04282650)	Transducer	15-minute	Spring 1990–September [1]2005.
Temperature, specific conductance, turbidity	Multi-parameter sonde or field meter	15-minute	Summer 2001–October 2002 continuously; thereafter in tandem with manual sample collection.
Dissolved oxygen, pH	Field meter	Discrete	Spring 2003–September 2005, in tandem with manual sample collection.
Concentrations of P, suspended sediment	Automated sampler	Most storms	Spring 2002–September 2005.

[1]Although this report summarizes findings through September 2005, sampling continues beyond that date.

Manual water-quality samples at the downstream monitoring station on Little Otter Creek were collected using the handheld sampler attached to an expandable pole from the Middlebrook Road bridge, using either the EWI method, if conditions were isokinetic, or several representative verticals, if stream velocity was less than 1.5 ft/s. Manual water-quality samples at the upstream monitoring station on Little Otter Creek were collected by wading into the center of the stream and filling sample bottles from a single point if stream velocity was below 1.5 ft/s. If stream velocity was greater than 1.5 ft/s but still wadable, samples were collected according to the EWI method using the handheld sampler. If the stream was not wadable, water samples were collected from several points as far out into the stream as was reachable from the left bank using the handheld sampler attached to an expandable pole because there was no bridge near the station. At high flows, water was very well mixed at the upstream station because of turbulence created from a slight bend in the channel a few hundred feet above the station.

Automated samplers installed at the Englesby Brook and Little Otter Creek monitoring stations pumped streamwater samples during all stages of a storm or a snowmelt event into discrete sample bottles. The automated samplers were programmed to collect frequent samples during rapid increases in stage and fewer samples during decreases in stage. Often, more samples were collected (up to a maximum capacity of 24) than were submitted for analysis. To determine which samples to submit for analysis and which to discard, the continuous record of storm stage was examined onsite, with the goal of including a sufficient number of samples to represent the storm rise, peak, and recession. Generally, if five or fewer samples were collected for a storm, all would be analyzed for phosphorus; if more than five samples were collected, 50 to 75 percent would be submitted for phosphorus analysis. Fewer samples were submitted for suspended sediment than for phosphorus analysis because of budget constraints—about 3 to 6 samples were submitted for suspended-sediment concentration analysis for each of 15 to 20 storms selected throughout each year. The sampling pattern and frequency for nitrogen at Englesby Brook was the same as phosphorus until April 2002. After that date, nitrogen sampling was changed to a schedule of monthly plus occasional storms.

At Englesby Brook, stream stage at USGS streamflow-gaging station 04282815 was measured continuously using a pressure transducer at a small impoundment created by 120-degree v-notch weir with a sloping concrete wall. Although weir geometry created a theoretical stage-discharge relation, a traditional rating curve using manual measurements at various streamflows was developed at this site and was used instead to determine streamflow. Because sediments that accumulated in the weir pool over time were not adequately flushed out, the theoretical relation did not remain constant. However, the rating curve was updated periodically based on measured streamflows and could reflect changes in the weir environment.

Changes in stream stage at the upstream and downstream monitoring stations on Little Otter Creek, measured continuously using pressure transducers installed at stable locations of the river channel, triggered automated samplers to collect water samples. Stage-discharge relations were not established at these stations. Rather, streamflow data, adjusted for drainage-area differences, were from a permanent USGS streamflow-gaging station (04282650) that was established in 1990 on Little Otter Creek in Ferrisburg (drainage area 148 km^2) and located about 5 kilometers (km) downstream from the downstream monitoring station 04282636. Because input to one of the load-estimation programs consisted of sample concentration data and instantaneous streamflow, water-quality sample times at the upstream and downstream monitoring stations were adjusted forward to approximately match the times that the pulses of sample water were measured for stage at streamflow-gaging station 04282650.

Rainfall data, for the period of record that begins in 1884, were from the National Weather Service (NWS) station at the South Burlington Airport about 5.6 km from the Englesby Brook station and about 31 km from the Little Otter Creek study area. Because rainfall data were not collected at either site, they were mainly used qualitatively as a reference to annual and seasonal variability and to identify general wet and dry periods. Climatic effects as potential influences on water-quality data were incorporated through statistical techniques, such as by use of streamflow or data from a control watershed as explanatory variables.

Laboratory Procedures

Analyses for suspended-sediment concentration were conducted at the USGS Sediment Laboratory in Kentucky. Nutrients were analyzed at the Vermont Department of Environmental Conservation (DEC) laboratory in Waterbury, Vermont. Sample holding times and analytical procedures followed protocols established by the USGS Sediment Analysis Quality-Assurance (QA) Plan (Shreve and Downs, 2005) and the Vermont DEC QA Plan (Christina Russo, Vermont Department of Environmental Conservation, written commun., 1999 with 2000 and 2001 updates).

Quality Control

Quality-control sampling was conducted according to protocols outlined in the USGS National Field Manual (Wilde and others, 1999). Quality-control samples collected in the field consisted of (1) field blanks to test the entire onsite automated and manual sampling systems, collected two to four times per year; (2) trip blanks or source-solution blanks, collected as needed if blank-water contamination was suspected; (3) split replicates or duplicates, for automated and manual samples, consisting of about 1 in 15 environmental samples; and (4) concurrent replicates whereby water from the automated sampler was collected simultaneously with a manual sample to test representativeness of the automated point sample, done monthly and during some storms. Over the 6-year study period, for every 11 environmental samples taken at Englesby Brook, 1 quality-control sample was taken; at Little Otter Creek, the ratio was 18 environmental to 1 quality-control sample. While most of the quality-control testing was for phosphorus, the primary focus of this study, some testing was done for nitrogen (at Englesby Brook only) and suspended sediment.

If results of quality-control sampling were unsatisfactory, according to criteria outlined in an internal standard-operating procedure, then sample results were not reported. Concurrent-replicate sampling was problematic because it was difficult to precisely synchronize collection of manual and automated samples during times of rapid changes in stage, which were the times when concentrations were changing rapidly (the automated sampler had at least one purge cycle before collecting the sample), and low streamflows were beyond the range of when the automated sampler was used.

At Englesby Brook, 68 percent of automated-sampler field blanks were below the laboratory reporting level for phosphorus concentration. The highest result of an automated-sampler field blank was 72 percent lower than the lowest phosphorus concentration of an environmental sample collected by the automated sampler. For nitrogen, the median absolute difference between environmental samples and replicates collected with the automated sampler or manually was 0.04 mg/L, the median percent difference was 4 percent, and the range of percent differences was from 0 to 15 percent. For phosphorus, the median absolute difference between environmental and replicate samples was 0.008 mg/L, the median percent difference was 2 percent, the range of percent differences was 0 to 53 percent, and 85 percent of replicate pairs had less than a 10-percent difference and 92 percent had less than a 20-percent difference. For suspended sediment, the median absolute difference between environmental and replicate samples was 1 mg/L, the median percent difference was 3 percent, and the range of percent differences was from 0 to 29 percent. For concurrent replicates at Englesby Brook, the median absolute difference was 0.02 mg/L for nitrogen, 0.013 mg/L for phosphorus, and 18 mg/L for suspended sediment. All but one of the percent differences were less than 6 percent for nitrogen and less than 15 percent for phosphorus, and all but 2 of the percent differences were less than 15 percent for suspended sediment. Additional concurrent replicate samples were taken that are not included in this summary because they were collected at stages below the automated sampler threshold and were beyond the range of its use.

At Little Otter Creek, 54 and 64 percent of automated-sampler field blanks were below the laboratory reporting level for phosphorus concentration at the upstream and downstream monitoring stations, respectively. In addition, 77 and 100 percent of automated-sampler field blanks, at the two respective stations, were less than half of the lowest phosphorus concentration from an environmental sample collected by the automated sampler. For phosphorus, the median absolute difference between concentrations of environmental samples and replicates collected with the automated sampler or manually was 0.002 mg/L at both the upstream and downstream monitoring stations, the median percent difference was 3 percent at both stations, and 94 and 96 percent of replicate pairs, at the upstream and downstream monitoring stations, respectively, had less than a 20-percent difference. For suspended sediment, the median absolute difference between concentrations of environmental and replicate samples was 2 and 3 mg/L at the upstream and downstream monitoring stations, respectively, the median percent difference was 7 and 4 percent, respectively, and 57 and 83 percent of replicate pairs, at the respective stations, had less than a 20-percent difference. For concurrent replicates at Little Otter Creek, the median absolute difference of concentrations was 0.005 and 0.006 mg/L for phosphorus and 5 and 8 mg/L for suspended sediment, at the upstream and downstream monitoring stations, respectively. Concentrations of concurrent replicate samples at the upstream and downstream monitoring stations, respectively, showed less than a 20-percent difference for 97 and 87 percent of the phosphorus and 37 and 52 percent of the suspended-sediment samples.

In addition to the procedures documented in the USGS Kentucky Sediment and the Vermont DEC laboratory QA plans, blind-replicate tests to compare suspended-sediment results at the two different laboratories were performed in 2004. This testing was undertaken because for the first 2 years of the project, analysis of suspended sediment was done at the Vermont DEC laboratory as a TSS procedure and subsequently, the analysis was done at the USGS Kentucky Sediment laboratory as a suspended-solids concentration (SSC) procedure. Since results of the blind-replicate tests were favorable and there was a strong linear relation between measured TSS and SSC ($r^2 = 99.5$), results from the two types of sediment analyses (after converting measured TSS data to predicted SSC data using the regression of concurrent samples of measured SSC and TSS) were considered from the same population and were pooled. Also, the Vermont DEC laboratory has participated in the standard reference sample project for nutrients administered two times per year by the USGS Branch of Quality Systems (Woodworth, 2006), with satisfactory results.

Estimation of Loads

Phosphorus and suspended-sediment data in this report are presented as both concentrations and loads. For purposes of this report, loads for days with adequate storm-sample definition (generally one to two samples during the rising limb of the hydrograph, another one to two samples for the peak, and at least two for the recession), were estimated using the USGS Graphical Constituent Loading Analysis System (GCLAS) program (Koltun and others, 2006). Loads for days of base-flow conditions and for non-sampled storms were estimated using the USGS Load Estimator (LOADEST) program (Runkel and others, 2004). Tables and graphs presented in this report show monthly and annual loads.

The GCLAS program multiplies a continuous concentration curve by a continuous streamflow curve. Missing data points were estimated with the assistance of several on-screen aids. Because loads estimated using this integration approach generally were assumed to be the best approach when enough samples exist to adequately describe concentration (Porterfield, 1972), GCLAS was used to estimate daily loads and storm loads when storm-sample coverage was judged adequate.

LOADEST, known as the rating-curve method, forms a regression equation from a calibration data set that consists of sample concentrations paired with instantaneous streamflow, which is then used to estimate daily, monthly, annual, total, or instantaneous loads using daily streamflow data. LOADEST was developed as a load-estimation method primarily for large streams where average daily flow and instantaneous concentration represent storm patterns when expressed as daily averages (C.G. Crawford, U.S. Geological Survey, oral commun., 2006). The effects of hysteresis, where the suspended-sediment load for a given streamflow on the rising limb of the hydrograph is greater than the load for the same streamflow on the falling limb, are not modeled in LOADEST.

LOADEST was used to estimate daily loads for base-flow conditions and for storms that were insufficiently sampled. GCLAS was used to calculate storm loads and daily loads for days with storms when there were sufficient samples to define the storm. Daily loads from GCLAS or LOADEST were used to calculate monthly and annual loads. Because confidence intervals were incalculable for monthly or annual loads that merged daily loads from the two methods, 95-percent confidence intervals for bar charts showing annual loads are solely from the LOADEST model and do not account for integrating LOADEST with GCLAS results. Thus, the depiction of error is conservative.

Storms that are represented adequately by single daily averages in large streams frequently resulted in many samples over short time periods (2 or more hours) for Englesby Brook. This kind of intense sampling created a serially correlated data set, which is not valid in the parametric LOADEST model. Even though GCLAS was used in these instances to estimate loads, data from storm periods were still a component of the calibration data file for LOADEST. In order to more closely imitate a large-stream calibration data file and to synthesize a data set of independent values, a single concentration from each storm with multiple samples was randomly selected to represent the storm for the calibration data file for LOADEST. As long as samples from storm rises, peaks, and recessions are included, this manufactured data set should be fairly reliable (C.G. Crawford, oral commun., 2006).

LOADEST allows the user to (1) select from nine predefined regression models; (2) have the program select the best model according to the Akaike Information Criteria (Helsel and Hirsch, 2002); or (3) custom design a model with one or several explanatory variables. For Little Otter Creek, which more closely resembles a large stream than Englesby Brook, the second option for automatic program selection was used. In light of potential assumptions violations, a single selection criterion did not seem appropriate for the Englesby Brook data set. To calculate loads of phosphorus and suspended sediment at Englesby Brook, all nine predefined regression models were tested using various combinations of transformed and untransformed independent variables including streamflow, decimal time, and seasonal factors. The best model was selected on the basis of examination of residual plots for normality, model terms for significance, correlation matrices for cross-correlation between terms, and variance-inflation factors for multi-collinearity (Helsel and Hirsch, 2002). If more than one model passed all these criteria, the final choice was made by selecting the lowest relative percent difference (RPD) between storm-day annual loads calculated using GCLAS and each of the LOADEST models under consideration (Ebbert and others, 2003):

$$\text{RPD} = (\text{GCLAS load} - \text{LOADEST load}) \times 100 / (0.5 \times (\text{GCLAS load} + \text{LOADEST load})) \qquad (1)$$

The 'storm-day annual load' was calculated as the sum of the daily loads for which there was adequate storm definition and for which GCLAS could therefore be used. LOADEST regression equations are shown in table 3.

Statistical Analysis

For all statistical tests, significance levels were $\alpha = 0.05$. The nonparametric Wilcoxon rank-sum test (Wilcoxon, 1945) was used to compare median concentrations of phosphorus and suspended sediment in base-flow samples, before and after construction of the golf-course pond BMP in the Englesby Brook watershed. Concentrations of phosphorus and suspended sediment were adjusted to remove the effects of streamflow because otherwise, differences in concentrations may be artifacts of climatic conditions rather than attributable to BMPs or other anthropogenic influences in the basin. Adjustments to concentrations were done using the LOcally WEighted Scatterplot Smoothing (LOWESS) technique (Cleveland, 1979; Helsel and Hirsch, 2002), a nonparametric least-squares alternative to regression, on log-transformed concentrations of phosphorus and suspended sediment. An adaptation of this test for paired samples, the Wilcoxon signed-rank test, was used to compare pairs of monthly loads between the upstream and the downstream monitoring stations at Little Otter Creek, to determine whether there was a difference in loads between the two monitoring stations.

The primary method of determining whether there were changes in water quality due to construction of BMPs in the Englesby Brook and Little Otter Creek watersheds was based on the paired watershed study design (U.S. Environmental Protection Agency, 1993b). The method requires two periods of study, calibration (before BMP) and treatment (after BMP),

Table 3. LOADEST regression equations for estimating loads of total nitrogen, total phosphorus, and suspended sediment in Englesby Brook and Little Otter Creek, Vermont.

[ln, natural logarithm; P, total phosphorus; SSC, suspended-sediment concentration; N, total nitrogen; ln$Q$ = ln(streamflow) – center of ln(streamflow); *dtime* = decimal time – center of decimal time]

Dependent variable	Regression equation	Coefficient of determination (R^2)
	Englesby Brook, station 04282815	
ln of P load [1]2000–02	$-8.77 + 1.34\ln(Q) + 0.06\ln(Q)^2 - 0.29\sin(2\pi dtime) - 0.19\cos(2\pi dtime)$	0.94
ln of SSC load [1]2000–02	$-4.46 + 1.44\ln(Q) + 0.08\ln(Q)^2 - 0.21\sin(2\pi dtime) - 0.38\cos(2\pi dtime)$	0.94
ln of N load 2000–05	$-7.14 + 1.11\ln(Q) + 0.01\ln(Q)^2 + 0.04(dtime)$	0.98
ln of P load [1]2003–05	$-8.91 + 1.33\ln(Q) + 0.06\ln(Q)^2 + 0.05(dtime) - 0.27\sin(2\pi dtime) - 0.15\cos(2\pi dtime)$	0.95
ln of SSC load [1]2003–05	$-4.43 + 1.44\ln(Q) + 0.08\ln(Q)^2 + 0.07(dtime) - 0.19\sin(2\pi dtime) - 0.34\cos(2\pi dtime)$	0.94
	Little Otter Creek, upstream station 04282634	
ln of P load 2000–05	$-5.06 + 1.41\ln(Q) + 0.03\ln(Q)^2 + 0.02(dtime) - 0.05(dtime)^2 - 0.45\sin(2\pi dtime) - 0.44\cos(2\pi dtime)$	0.93
ln of SSC load 2000–05	$0.12 + 1.59\ln(Q) + 0.12(dtime)$	0.88
	Little Otter Creek, downstream station 04282636	
ln of P load 2000–05	$-4.88 + 1.29\ln(Q) + 0.04\ln(Q)^2 - 0.46\sin(2\pi dtime) - 0.38\cos(2\pi dtime)$	0.84
ln of SSC load [1]2000–02	$0.15 + 1.24\ln(Q) + 0.12\ln(Q)^2 + 0.22(dtime) + 0.91(dtime)^2 - 0.78\sin(2\pi dtime) - 0.26\cos(2\pi dtime)$	0.95
ln of SSC load [1]2003–05	$0.63 + 1.40\ln(Q) + 0.23\ln(Q)^2 - 0.25(dtime) - 0.39\sin(2\pi dtime) - 0.35\cos(2\pi dtime)$	0.85

[1]LOADEST automatically selected two different regression models for the two time periods 2000–02 and 2003–05 because there was a large gap in the calibration data sets.

and two watersheds, control and treated, with the premise that the water-quality relation between sample pairs from the two watersheds remains unchanged over time apart from the impact of the BMP. Analysis of covariance (ANCOVA) was used to determine whether the linear relation between covariates changed in the treatment period relative to the calibration period. Dependent variables were concentrations and loads of phosphorus and suspended sediment at the Englesby Brook monitoring station and at the Little Otter Creek downstream monitoring station. Because the Englesby Brook design did not include a control watershed, a modification of the method was used, whereby the independent variable was streamflow (Grabow and others, 1998). For Little Otter Creek, the independent variable was data from the upstream monitoring station, a surrogate for the control watershed.

Two preliminary tests on the data sets were needed before attempting the ANCOVA. First, skewness of the covariates, including concentrations, loads, and streamflow, was calculated as an indicator of normality for the parametric ANCOVA. Because skewness of all the raw data was greater than 1, base-10 logarithms of the covariates (all of which had skewness less than one) were used for the ANCOVA. Second, the presence of a significant relation between paired data from the upstream and downstream monitoring stations needed to be established for each test period (calibration and treatment) before comparing regression relations between the periods (U.S. Environmental Protection Agency, 1993b).

ANCOVA was executed with data from Englesby Brook to determine whether the relations between: (1) mean storm concentrations (of phosphorus or suspended sediment) and mean storm streamflow, and (2) storm loads (of phosphorus or suspended sediment) and total stormwater volume, changed from the calibration to the treatment periods. Mean storm concentrations, mean storm streamflow, and storm loads used in the Englesby Brook analysis were calculated in GCLAS. Storms were included as data points in the analysis only if there were enough samples to provide an adequate representation of the constituent curve over the course of the entire storm. Total stormwater volume, used as the covariate with storm loads, was calculated as the mean storm streamflow in cubic feet per second (ft^3/s) from GCLAS, times the span of the storm in hours, times the conversion factor to hours.

ANCOVA was done with data from Little Otter Creek to determine whether relations between paired data from the downstream and the upstream monitoring stations, including mean storm concentrations of phosphorus and monthly loads of phosphorus and suspended sediment, changed from the calibration to the treatment periods. The phosphorus concentration data set consisted of monthly manual samples and, for storms for which there was a sufficient number of samples at both stations to use GCLAS, the average storm concentration, as calculated in GCLAS. There were too few matched pairs of suspended-sediment concentration data to do the analysis. The calculation of monthly loads was explained in the previous section. If relations between the two periods were different, the percent change due to treatment was calculated based on the difference of the mean predicted and observed values.

The final approach used with data from Englesby Brook to determine whether there were changes in water quality from the golf-course pond BMP, was a hybrid of the ANCOVA, as described above, and double-mass curve analysis. Double-mass curves were constructed by plotting cumulative monthly streamflow versus cumulative monthly loads of phosphorus and suspended sediment. Double-mass curves are generally used to get a visual sense of whether there is a change in relation between two mass quantities, as indicated by a break in slope. In theory, if two quantities are proportional, then the accumulation of one quantity plotted against the accumulation of the other during the same period is a straight line. A break in the slope of the line indicates that a change in the relation between the variables has occurred and the difference in the slope indicates the degree of change (Searcy and Hardison, 1960). For this study, the traditional use of double-mass curves was extended to determine whether the slopes of the regression lines between the covariates changed statistically, using the same ANCOVA technique used earlier to compare relations of water-quality parameters between calibration and treatment periods.

Water Quality of the Englesby Brook Watershed

Summaries of streamflow, concentration data, and estimated loads are presented in the following section. Nitrogen and phosphorus yields are compared to yields from other urban watersheds in New England. Yield equals load (concentration multiplied by instantaneous streamflow) divided by drainage area, with the divisor normalizing the comparison of water-quality constituents between stations with different drainage areas. Concentrations and loads are analyzed in several different ways to determine whether there were any changes in the relation between these variables and streamflow before and after construction of a golf-course pond BMP.

Hydrology

Mean annual streamflow at Englesby Brook ranged from 0.40 ft^3/s in 2003 to 0.90 ft^3/s in 2004 (Coakley and others, 2001, 2002; Kiah and others, 2003, 2006; Keirstead and others, 2004, 2005). Cumulative streamflow for water years 2000 through 2005 is shown in figure 6. Monthly precipitation at the South Burlington Airport National Weather Service station, with record-setting months highlighted, is shown in figure 7. Annual and seasonal streamflow and precipitation patterns differed among water years. Streamflow for 2002 and 2005 was distributed fairly evenly throughout the year. In contrast, in 2001, one half of the total annual streamflow occurred in April. The years 2000 and 2004 had at least twice the streamflow as 2003. From October 2003 through March 2004, cumulative streamflow was almost as great or greater than the total annual streamflow for water years 2001, 2002, 2003, and 2005. The storm response at Englesby Brook was extremely "flashy," with a rise in stage often occurring in minutes and a decrease occurring over several hours. Months with precipitation, including rainfall equivalents from snowfall, that ranked among the five highest for the period of record were April and May 2000; March 2001 (mostly in the form of snowfall); June 2002; December 2003; and August 2004. Months with precipitation that ranked among the five lowest for the period of record were July 2001 and August 2002.

Concentrations of Nutrients and Suspended Sediment

Factors that contribute to nutrient concentrations in streams include nutrient inputs, local climatic characteristics, influence of surficial geology on drainage, surface- and ground-water interactions, and seasonal influences (U.S. Geological Survey, 1999). Sources of nutrients in urban streams can be natural, such as wild animal wastes, plants, and eroded sediment with attached soil nutrients, or contributed from human activities, such as fertilizers, pet wastes, wastewater-treatment plants, on-site disposal systems, non-storm water connections, and from some industries (U.S. Environmental Protection Agency, 1993a).

The primary components of total nitrogen in streams are ammonia, organic nitrogen, and nitrate (U.S. Geological Survey, 1999). Total phosphorus is composed largely of phosphates plus particulate organic phosphorus. The predominant dissolved and readily available forms of nitrogen and phosphorus are nitrate and orthophosphate, respectively. Total nitrogen and total phosphorus concentrations are not regulated at the state or federal level; however, the USEPA has established a 10 mg/L drinking-water limit for nitrate (U.S. Environmental Protection Agency, 2002b) and, for rivers and streams in Ecoregion VIII (includes Vermont), recommended criteria of 0.01 mg/L for total phosphorus and 0.38 mg/L for total nitrogen (U.S. Environmental Protection Agency, 2002a).

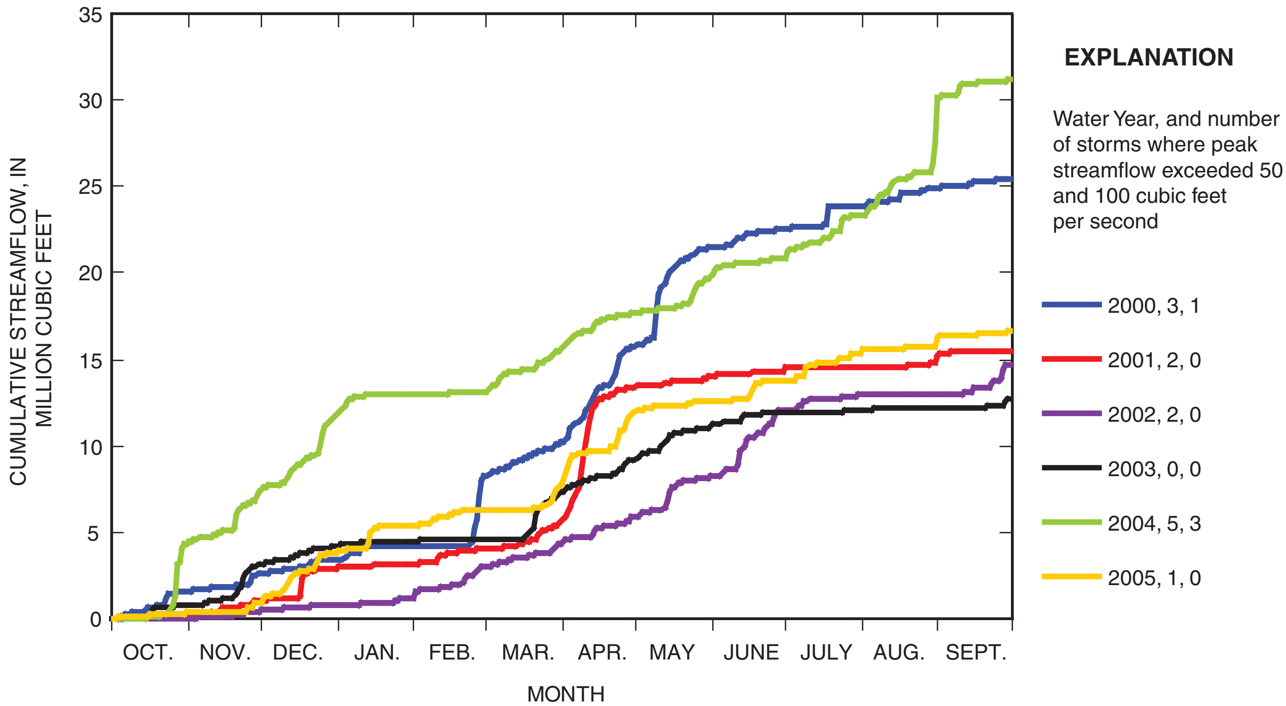

Figure 6. Annual cumulative streamflow curves for Englesby Brook, water years 2000–2005.

Concentrations for the 46 total nitrogen base-flow samples collected during 2000–2005 at Englesby Brook ranged from 0.5 to 1.91 mg/L and the median was 0.91 mg/L (table 4). Base-flow concentrations were lowest during summer and highest during winter (fig. 8). This seasonal pattern of low concentrations during summer low-flow conditions indicates that point sources were probably not significant sources of nitrogen in the Englesby Brook watershed. This is consistent with conclusions drawn from urban stream data in a nationwide water-quality synthesis report (U.S. Geological Survey, 1999). Concentrations for the 80 total phosphorus base-flow samples collected during 2000–2005 at Englesby Brook ranged from 0.024 to 0.3 mg/L and the median was 0.06 mg/L (table 4). Phosphorus concentrations during base-flow conditions generally showed a seasonal pattern, with low and high concentrations found in the winter and mid-range concentrations found in the summer (fig. 8). Concentrations for the 55 suspended-sediment base-flow samples collected during 2000–2005 at Englesby Brook ranged from 3 to 189 mg/L and the median was 10 mg/L (table 4). Suspended-sediment concentrations in base-flow samples generally did not show a seasonal pattern, as high and low base-flow concentrations were observed throughout the year (fig. 8).

Concentrations for the 441 nitrogen high-flow samples ranged from 0.4 to 3.43 mg/L and the median was 1.3 mg/L (table 4). There were 1,192 phosphorus high-flow samples that ranged in concentration from 0.032 to 11.8 mg/L, with a median of 0.188 mg/L. Concentrations for the 626 suspended-sediment high-flow samples ranged from 5 to 6,880 mg/L and the median was 69 mg/L. Nitrogen concentrations for high-flow samples only varied by one order of magnitude, whereas phosphorus and suspended-sediment concentrations for high-flow samples varied by three orders of magnitude. The highest phosphorus concentration of 11.8 mg/L, measured during a large and intense storm on July 5, 2005, was 5.7 mg/L greater than the next highest concentration of 6.1 mg/L, measured on July 23, 2004. The July 2005 storm took place after 12 days with no precipitation; it also was at the beginning of the BMP construction work upstream in the watershed. Suspended-sediment concentrations also were high during that storm, reaching 2,480 mg/L, or within the highest 2 percent of concentrations for all measured storms. The highest suspended-sediment concentration of 6,880 mg/L, measured on July 23, 2004, was more than two times the next highest suspended-sediment concentration of 3,174 mg/L, measured on July 18, 2000. Four of the five highest measured suspended-sediment concentrations were observed during different July storms.

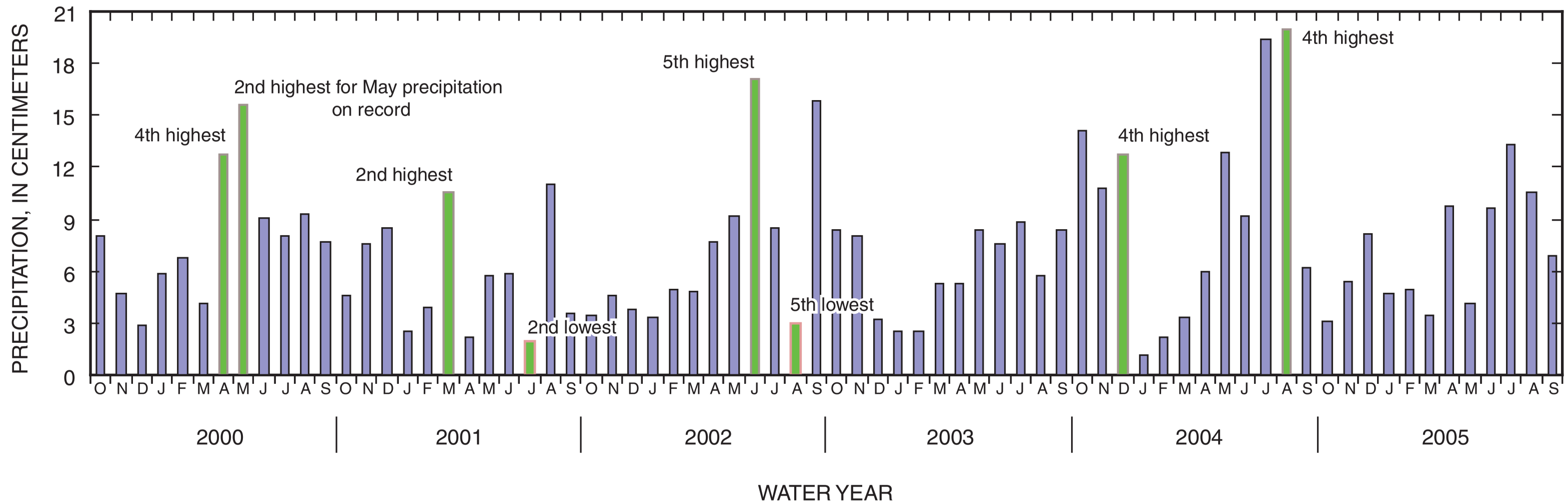

Figure 7. Monthly precipitation at the South Burlington Airport National Weather Service station (National Weather Service, 2005a, 2005c). [Green bars represent months with monthly precipitation amounts in the top five high or low for the period of record that begins in 1884]

Table 4. Summary statistics for concentrations of total nitrogen, total phosphorus, and suspended sediment, collected during base-flow and high-flow conditions, in Englesby Brook and Little Otter Creek, 2000–2005.

[mg/L, milligrams per liter; NA, not applicable]

Constituent	Number/percent of storms sampled (0.5 inch of precipitation and greater)	Sample size	Minimum	Median	Maximum
BASE FLOW					
Englesby Brook, station 04282815					
Nitrogen, total (mg/L as N)	NA	46	0.5	0.91	1.91
Phosphorus, total (mg/L as P)	NA	80	.024	.06	.3
Suspended sediment (mg/L)	NA	55	3	10	189
Little Otter Creek, upstream station 04282634					
Phosphorus, total (mg/L as P)	NA	72	0.016	0.054	0.141
Suspended sediment (mg/L)	NA	35	2	6	13
Little Otter Creek, downstream station 04282636					
Phosphorus, total (mg/L as P)	NA	82	0.018	0.067	0.233
Suspended sediment (mg/L)	NA	39	10	25	132
HIGH FLOW					
Englesby Brook, station 04282815					
Nitrogen, total (mg/L as N)	35/28	441	0.4	1.3	3.43
Phosphorus, total (mg/L as P)	85/68	1,192	.032	.188	11.8
Suspended sediment (mg/L)	77/62	626	5	69	6,880
Little Otter Creek, upstream station 04282634					
Phosphorus, total (mg/L as P)	49/39	419	0.019	0.09	0.565
Suspended sediment (mg/L)	33/26	142	1	33	473
Little Otter Creek, downstream station 04282636					
Phosphorus, total (mg/L as P)	53/42	587	0.019	0.119	1.95
Suspended sediment (mg/L)	38/30	196	8	50	1,190

Examples of phosphorus and suspended-sediment concentrations throughout five storms in different seasons are shown in figure 9. Nitrogen concentrations also are shown for two storms. The March 20–21, 2003, example shows a winter rain (2.49 cm). This storm illustrates the effects of hysteresis, where the point directly after the suspended-sediment peak at about 02:00 on March 21st showed a decrease in magnitude of about one third while the streamflow peak remained elevated. On June 9, 2005, a moderate rainfall (1.65 cm) resulted in very high phosphorus concentrations compared to a moderate streamflow, which may be the result of early summer fertilizer applications to fairways, lawns, or gardens. The preceding 12 days had been very dry with no days of recorded rainfall above 0.13 cm. The September 28, 2003, storm illustrates an event (5.10 cm) with three streamflow and concentration peaks of synchronized descending magnitudes. The first and highest phosphorus and suspended-sediment peaks were about 0.5 hour before the streamflow peak. The four days prior to the storm were dry. The May 9–11, 2000, example shows a series of large spring storms (8.94 cm) (Steven Roy, Burlington Public Works, oral commun., 2001). Results of samples collected during a moderate rainfall event (1.73 cm) on November 14, 2000, show low nitrogen, phosphorus, and suspended-sediment concentrations relative to other storms. Nitrogen concentrations diverged from the basic streamflow pattern during recessions (fig. 9), by increasing slightly during the initial part of the falling limb.

Loads of Nutrients and Suspended Sediment

Total phosphorus in Vermont streamwater, as regulated by the Vermont water-quality standards, is expressed relative to loading (Vermont Water Resources Board, 2000). The phosphorus standard states that loading needs to be limited to prevent excess eutrophication.

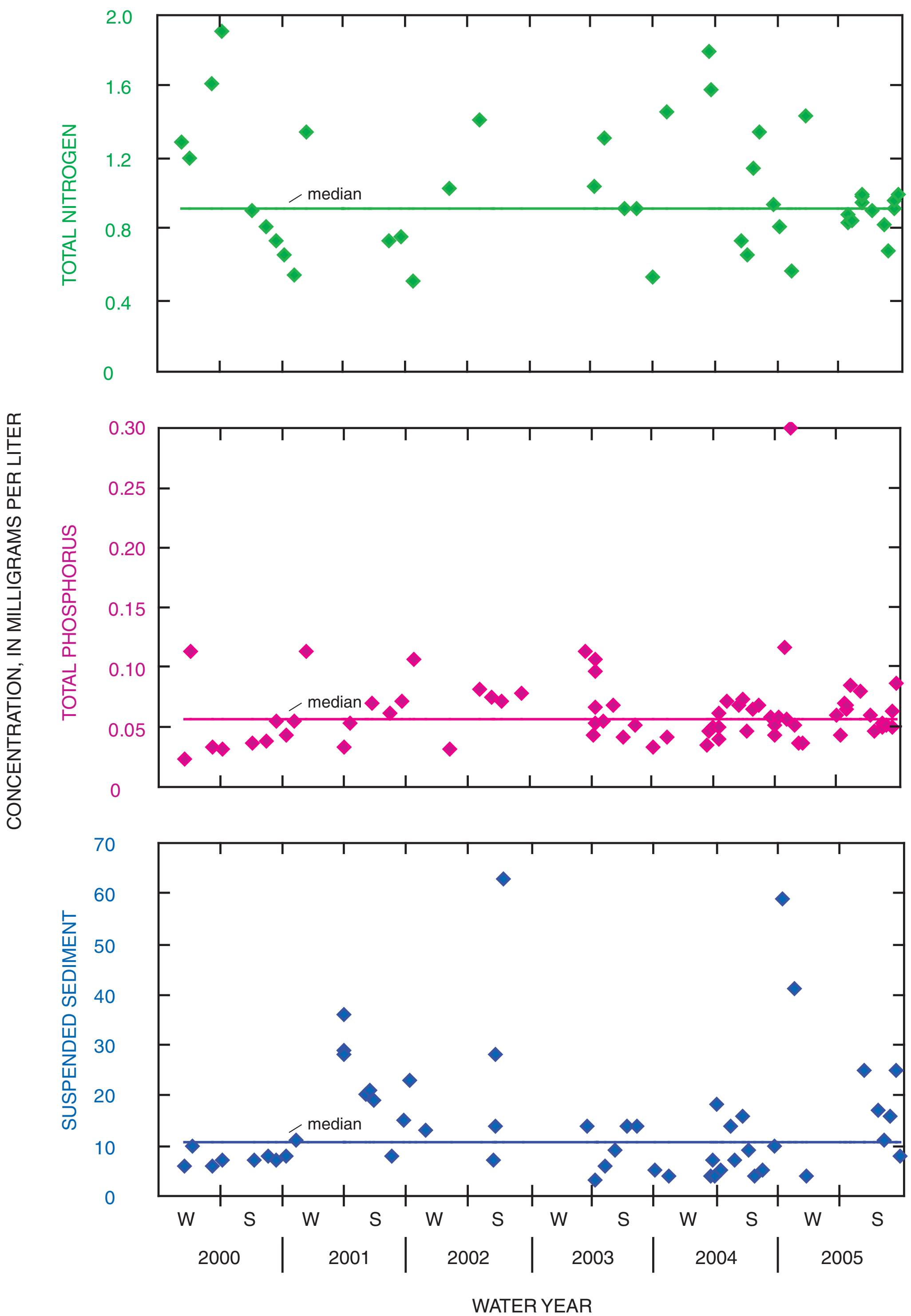

Figure 8. Base-flow concentrations of total nitrogen, total phosphorus, and suspended sediment at Englesby Brook, water years 2000–2005. [W, winter (October through March); S, summer (April through September)]

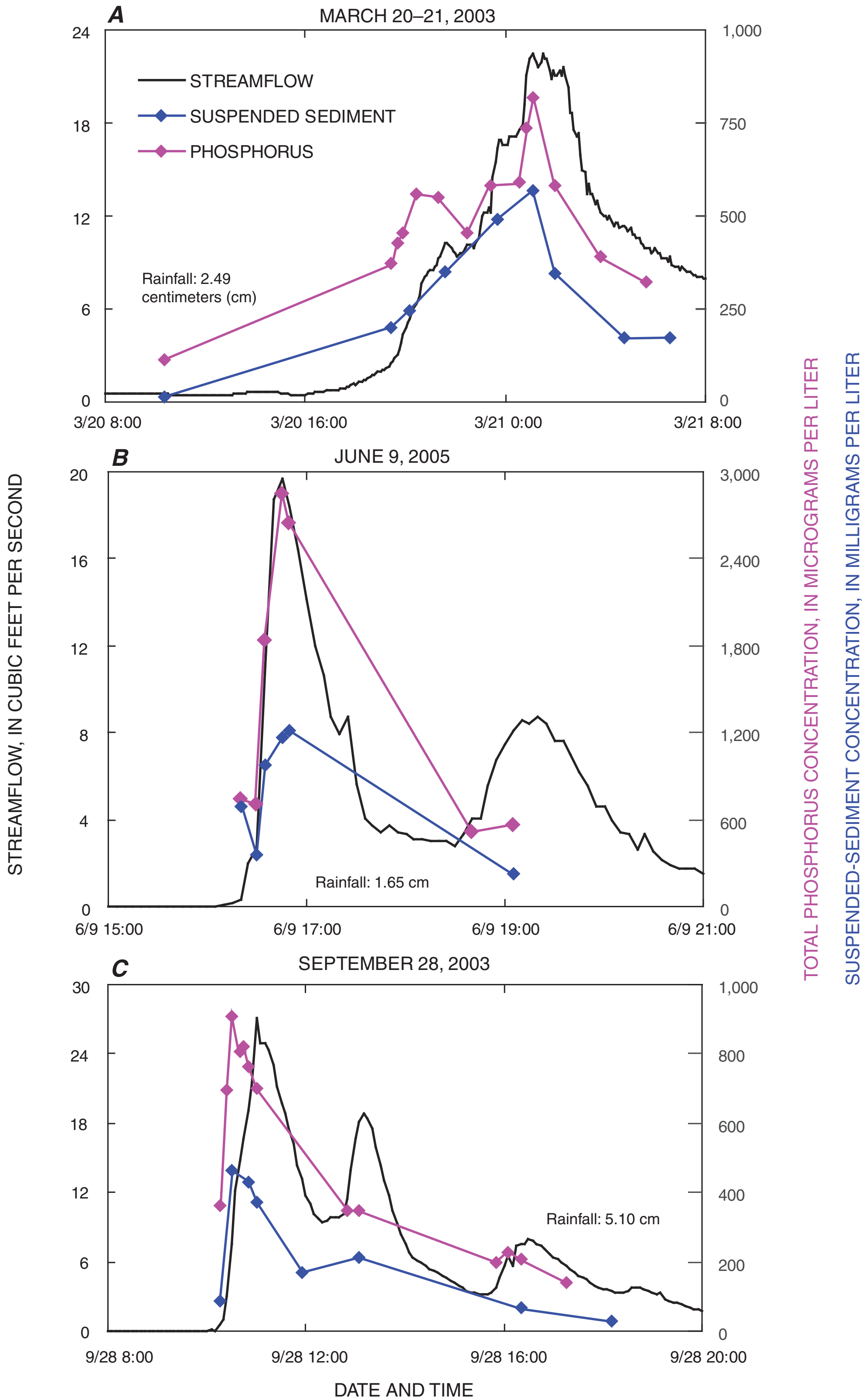

Figure 9. Concentrations of total nitrogen, total phosphorus, and suspended sediment for selected storms at Englesby Brook.

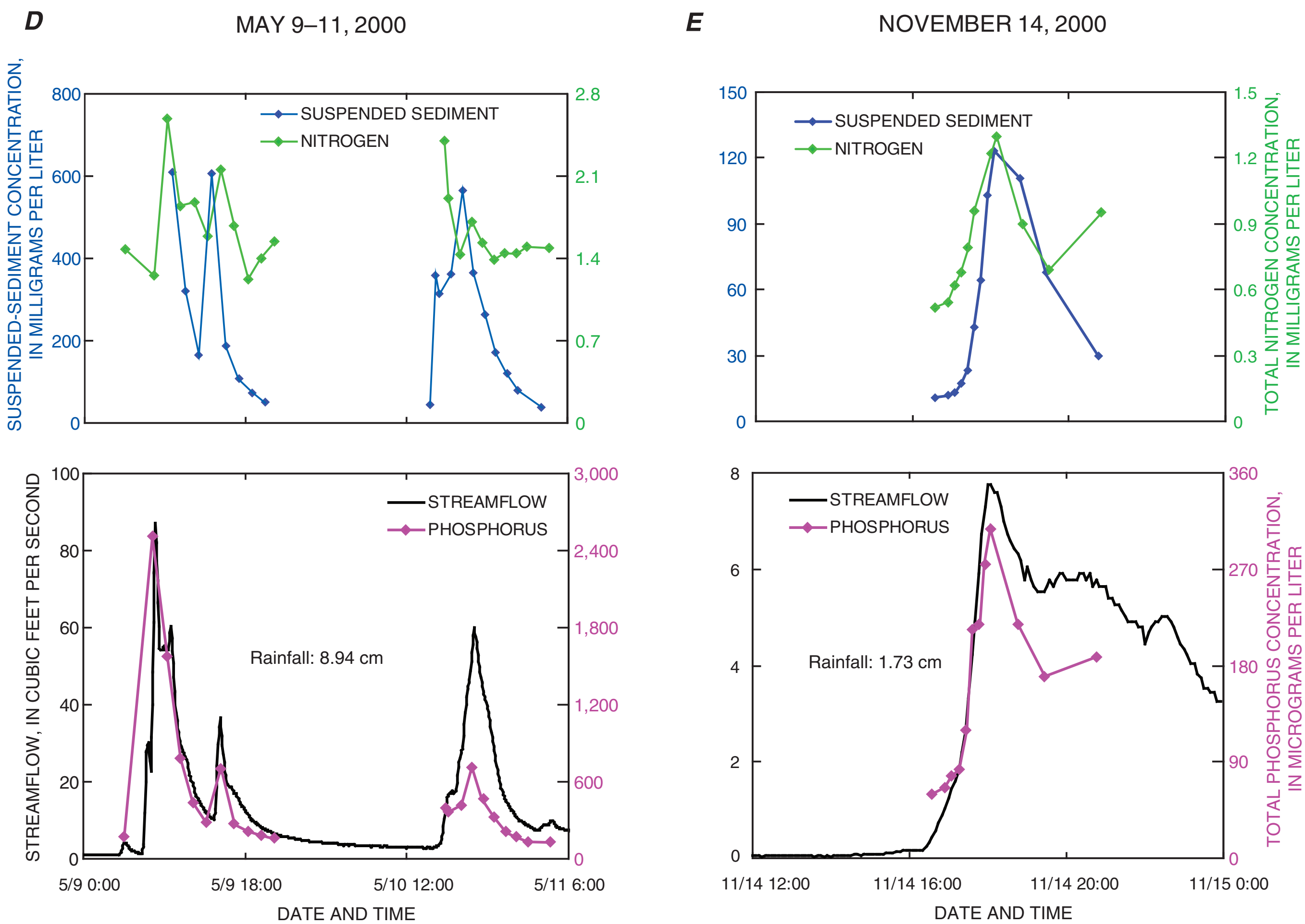

Figure 9. Concentrations of total nitrogen, total phosphorus, and suspended sediment for selected storms at Englesby Brook. —Continued

Monthly and annual nitrogen, phosphorus, and suspended-sediment loads for water years 2000–05 are in table 5. Annual loads with percentages contributed during high-flow and base-flow conditions, average streamflow, and precipitation for Englesby Brook are shown in figure 10. Annual nitrogen loads ranged from 0.5 metric tons (t) in 2002 and 2003 to 1.3 t in 2004; phosphorus loads ranged from 0.1 t in 2001, 2002, 2003, and 2005 to 0.3 t in 2004; and suspended-sediment loads ranged from 28 t in 2003 to 236 t in 2004. The percentage of annual loads contributed during high-flow conditions (as opposed to base flow) ranged from 67 in 2001 to 79 in 2005 for nitrogen, 53 in 2000 to 96 in 2005 for phosphorus, and 76 in 2001 to 96 in 2004 for suspended sediment.

Annual patterns for all three constituents were similar to the streamflow pattern, with the highest loads in 2004, a decrease in loads from 2000 to 2003, and 2001 and 2005 loads being similar. Annual precipitation among years showed a slightly different pattern. Precipitation in 2002 was higher than in 2003 and precipitation in both years was higher than in 2001. Wide error bars for the 2004 annual phosphorus and suspended-sediment loads were probably due to high variability in concentrations and hysteresis. Confidence in these annual estimates may be greater than indicated, however, because the GCLAS-generated portion of the annual loads, which ranged from 18 to 73 percent for phosphorus and from 0 to 75 percent for suspended sediment (not shown), was not reflected in the error bars.

A comparison of monthly loads estimated using the two different methods provides an indication of the reliability of the LOADEST load estimates shown in figure 11. There were no GCLAS load estimates for nitrogen because storm sampling for nitrogen was limited. Out of 53 months for which there were phosphorus load estimates using both methods, 72 percent of the time, the estimates were within 75 percent of one another. Out of 37 months for which there were suspended-sediment load estimates using both methods, 57 percent of the time, the estimates were within 75 percent of one another. When load estimates differed, merged estimates were usually larger than LOADEST estimates. Thus, if GCLAS estimates were not integrated with LOADEST estimates for the merged method, loads would be underestimated. As data in figure 11 are presented on a logarithmic scale, for some months, the potential for underestimation by disregarding the inclusion of GCLAS estimates would be substantial.

Mean loads for nitrogen, phosphorus, and suspended sediment at Englesby Brook are shown for each month in figure 12. Error bars are not provided because GCLAS loads are part of these estimates; however, one can get a sense of the data reliability from figures 10 and 11. The graphs on the right of figure 12 show the percentage of each year's annual load that was contributed by the largest daily load of that year—these percentages ranged from 5 to 15 for nitrogen, 9 to 37 for phosphorus, and 14 to 52 for suspended sediment. These largest events usually were during the spring or summer. The greatest single-day load for all constituents was on August 31, 2004, as 4.06 cm of rain fell after 6.35 cm during the previous 48 hours. Coincidentally, the largest single days' suspended-sediment load for 2005 also was on August 31. These results explain why the largest mean monthly load for phosphorus and suspended sediment was August (fig. 12). In general, small monthly loads were transported most often during fall and winter, moderate to large monthly loads in April and May, and occasional extremely large loads were transported in June through August, when large and intense storms eroded and conveyed considerable volumes of streambed and streambank material.

As with concentrations, monthly loads of phosphorus at Englesby Brook showed similar patterns to monthly loads of suspended sediment (fig. 12). The monthly nitrogen pattern (fig. 12) also was similar to the phosphorus and suspended-sediment patterns with the exception that April loads were larger and August loads were smaller. Because nitrate dissolves more readily in water than orthophosphate (U.S. Geological Survey, 1999), it was likely that nitrogen loads in the Englesby watershed, compared to phosphorus loads, were more affected by large sustained streamflows seen in April and less affected by contributions from individual episodes that carried sediment to the brook via overland flow. Thus, the relative importance of the August 2004 storms, for example, would have been less on the monthly nitrogen load, in comparison to the effects of those events on the loads of phosphorus and suspended sediment.

In areas of the country that receive from 51 to 102 cm of annual rainfall, such as most of Vermont, nutrient loads of urban-storm runoff generally are a function of nutrient inputs, total storm rainfall, drainage area, impervious area, precipitation intensity (for phosphorus) and mean annual nitrogen input from precipitation (for nitrogen) (Driver and Tasker, 1990). Data from Englesby Brook indicated that storms characterized by rapid increases of streamflow were related to phosphorus load. The ten storms with the largest and most rapid rates of increase of streamflow generated among the largest phosphorus loads of the storms that were sampled (table 6). There are some discrepancies between the ranking in table 6 and the largest day's loads in figure 12 (right-side graphs), because the loads in figure 12 refer to 24-hour days and the loads in table 6 refer to storms, which may include just part of a day or span several days.

Comparison of Nitrogen and Phosphorus Yields at Englesby Brook with Other Urban Watersheds

Quartiles and median yields of nitrogen and phosphorus from six urban New England streams including Englesby Brook are shown in figure 13. The other five streams were part of the USGS New England Coastal Basins National Water-Quality Assessment (NAWQA) Program fixed-site surface-water network and were characterized as having at least 30 percent urban land use (Campo and others, 2003). Nitrogen and phosphorus samples were collected at these NAWQA stations from October 1998 to September 2001 on

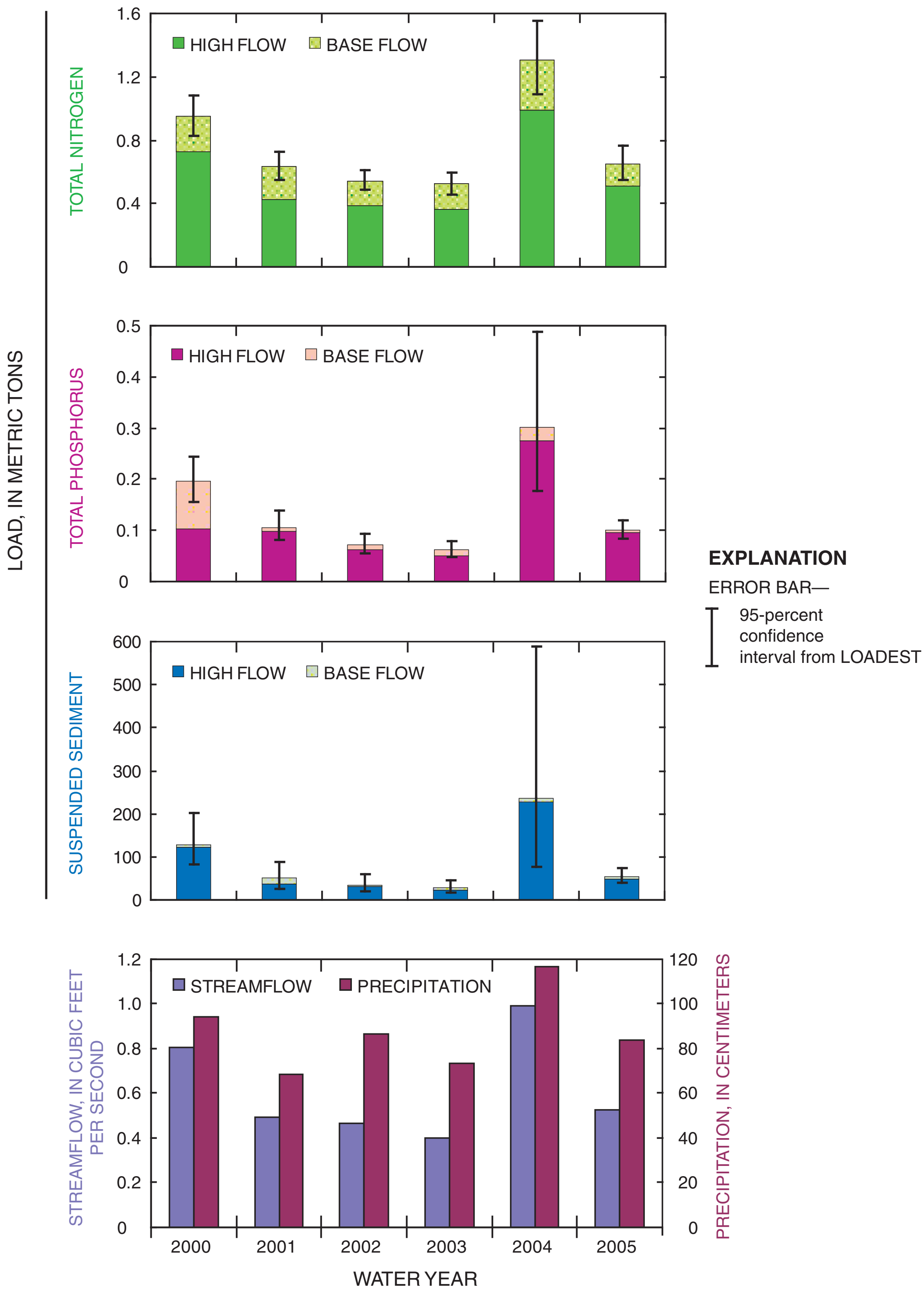

Figure 10. Annual loads of total nitrogen, total phosphorus, and suspended sediment from high-flow and base-flow contributions, mean annual streamflow, and total precipitation at Englesby Brook, water years 2000–2005. [Error bars show 95-percent confidence intervals from LOADEST output only and therefore, provide greater than 95-percent confidence in the annual estimates shown, due to supplementing LOADEST with results from GCLAS]

Table 5. Monthly and annual loads of total nitrogen, total phosphorus, and suspended sediment at Englesby Brook, Vermont, and loads of total phosphorus and suspended sediment at Little Otter Creek, Vermont, water years 2000–2005.

Constituent	Water year	October	November	December	January	February	March	April	May	June	July	August	September	Annual
		Load (metric tons)												
		Englesby Brook, station 04282815												
Total nitrogen	2000	0.1	0.03	0.02	0.03	0.2	0.1	0.2	0.2	0.03	0.05	0.04	0.02	0.9
	2001	0.01	0.03	0.1	0.01	0.03	0.1	0.4	0.02	0.02	0.002	0.02	0.01	0.6
	2002	0.002	0.01	0.01	0.01	0.1	0.1	0.04	0.1	0.2	0.03	0.003	0.1	0.5
	2003	0.03	0.1	0.03	0.01	0.01	0.1	0.1	0.1	0.03	0.01	0.01	0.02	0.5
	2004	0.1	0.1	0.2	0.04	0.001	0.1	0.1	0.1	0.05	0.1	0.4	0.1	1.3
	2005	0.01	0.02	0.1	0.1	0.03	0.1	0.2	0.02	0.1	0.1	0.04	0.01	0.7
Total phosphorus	2000	0.01	0.004	0.002	0.003	0.03	0.004	0.02	0.06	0.004	0.04	0.01	0.004	0.2
	2001	0.001	0.003	0.02	0.0004	0.002	0.01	0.07	0.002	0.002	0.0002	0.004	0.002	0.1
	2002	0.0002	0.001	0.001	0.001	0.01	0.01	0.01	0.01	0.02	0.004	0.0003	0.01	0.1
	2003	0.004	0.01	0.003	0.001	0.001	0.02	0.005	0.01	0.003	0.001	0.001	0.004	0.1
	2004	0.01	0.01	0.02	0.004	0.0000	0.01	0.01	0.01	0.01	0.04	0.17	0.01	0.3
	2005	0.002	0.003	0.01	0.01	0.002	0.01	0.02	0.002	0.01	0.02	0.02	0.004	0.1
Suspended sediment	2000	3.2	1.4	0.9	1.2	19	1.5	12	54	1.6	29	3.2	2.8	129
	2001	0.1	0.8	8.6	0.1	0.7	2.2	33	0.5	1.0	0.04	2.0	0.7	50
	2002	0.03	0.3	0.1	0.2	2.0	1.1	1.6	6.2	15	1.7	0.1	6.6	35
	2003	1.3	4.8	0.6	0.1	0.2	10	2.0	4.6	1.5	0.2	0.7	1.7	28
	2004	7.3	7.9	8.1	1.2	0.01	1.9	2.6	7.6	2.4	26	164	6.9	236
	2005	0.9	1.0	8.0	3.4	0.7	2.1	9.0	0.5	5.5	9.9	11	1.6	53
		Little Otter Creek, upstream station 04282634												
Total phosphorus	2000	0.4	0.2	0.1	0.3	1.2	0.6	1.1	1.0	0.1	0.1	0.1	0.02	5.2
	2001	0.05	0.3	1.2	0.04	0.04	0.1	4.9	0.04	0.05	0.1	0.01	0.01	6.7
	2002	0.01	0.01	0.02	0.02	0.1	0.3	0.5	0.3	0.3	0.04	0.01	0.1	1.6
	2003	0.1	0.6	0.1	0.03	0.02	1.0	0.7	0.7	0.3	0.1	0.1	0.1	3.8
	2004	1.8	1.7	1.5	0.2	0.04	0.6	0.4	1.1	0.1	0.1	1.1	0.8	9.5
	2005	0.03	0.1	0.3	0.1	0.03	0.1	0.9	0.2	0.9	0.2	0.1	0.04	2.8
Suspended sediment	2000	110	86	43	192	733	324	497	313	8.5	8.9	18	1.5	2,330
	2001	6.9	86	471	13	15	22	2,010	8.6	7.0	15	0.7	0.7	2,660
	2002	0.4	1.5	4.3	5.1	23	115	190	120	49	3.7	0.3	6.1	517
	2003	11	192	28	9.1	7.0	482	232	236	51	13	9.2	13	1,280
	2004	497	520	703	93	17	365	170	275	21	11	452	165	3,290
	2005	4.4	30	165	68	16	34	569	77	324	53	12	8.1	1,360

Table 5. Monthly and annual loads of total nitrogen, total phosphorus, and suspended sediment at Englesby Brook, Vermont, and loads of total phosphorus and suspended sediment at Little Otter Creek, Vermont, water years 2000–2005.—Continued

Constituent	Water year	October	November	December	January	February	March	April	May	June	July	August	September	Annual
						Little Otter Creek, downstream station 04282636								
Total phosphorus	2000	0.8	0.5	0.2	0.6	1.8	0.9	1.7	1.4	0.1	0.1	0.2	0.04	8.3
	2001	0.1	0.4	1.5	0.1	0.1	0.1	5.2	0.1	0.1	0.2	0.02	0.02	7.7
	2002	0.01	0.02	0.03	0.03	0.1	0.3	0.6	0.4	0.3	0.1	0.01	0.1	1.9
	2003	0.1	0.7	0.1	0.04	0.03	1.0	0.7	0.7	0.3	0.1	0.1	0.1	3.9
	2004	1.9	1.9	1.6	0.2	0.1	0.7	0.4	0.8	0.1	0.1	2.0	0.9	11
	2005	0.04	0.1	0.5	0.2	0.05	0.1	1.0	0.2	1.1	0.3	0.1	0.1	3.7
Suspended sediment	2000	926	443	165	394	1,110	312	446	347	20	27	53	13	4,260
	2001	24	97	409	11	7.7	9.3	1,070	7.9	10	25	8.0	9.0	1,690
	2002	7.7	9.5	12	9.4	21	91	183	184	165	46	30	111	868
	2003	37	431	41	16	11	951	315	318	82	39	30	35	2,310
	2004	671	803	1,020	74	14	332	149	485	31	26	1,620	313	5,540
	2005	14	27	110	35	10	19	435	51	517	62	21	15	1,320

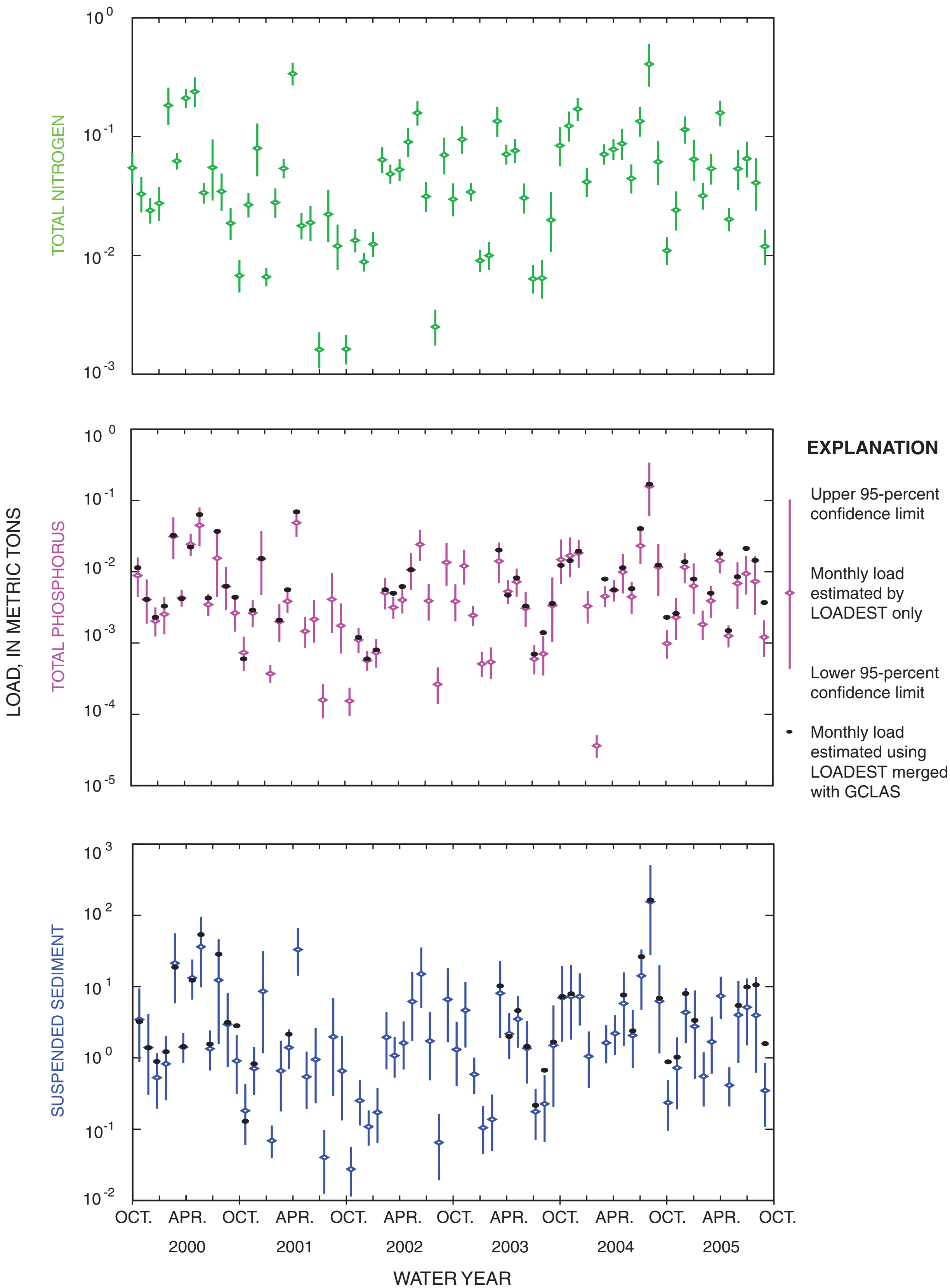

Figure 11. Monthly loads of total nitrogen, total phosphorus, and suspended sediment, estimated using two methods, at Englesby Brook, water years 2000–2005. [Months with missing blackened ovals had insufficient data for a 'LOADEST merged with GCLAS' load estimate]

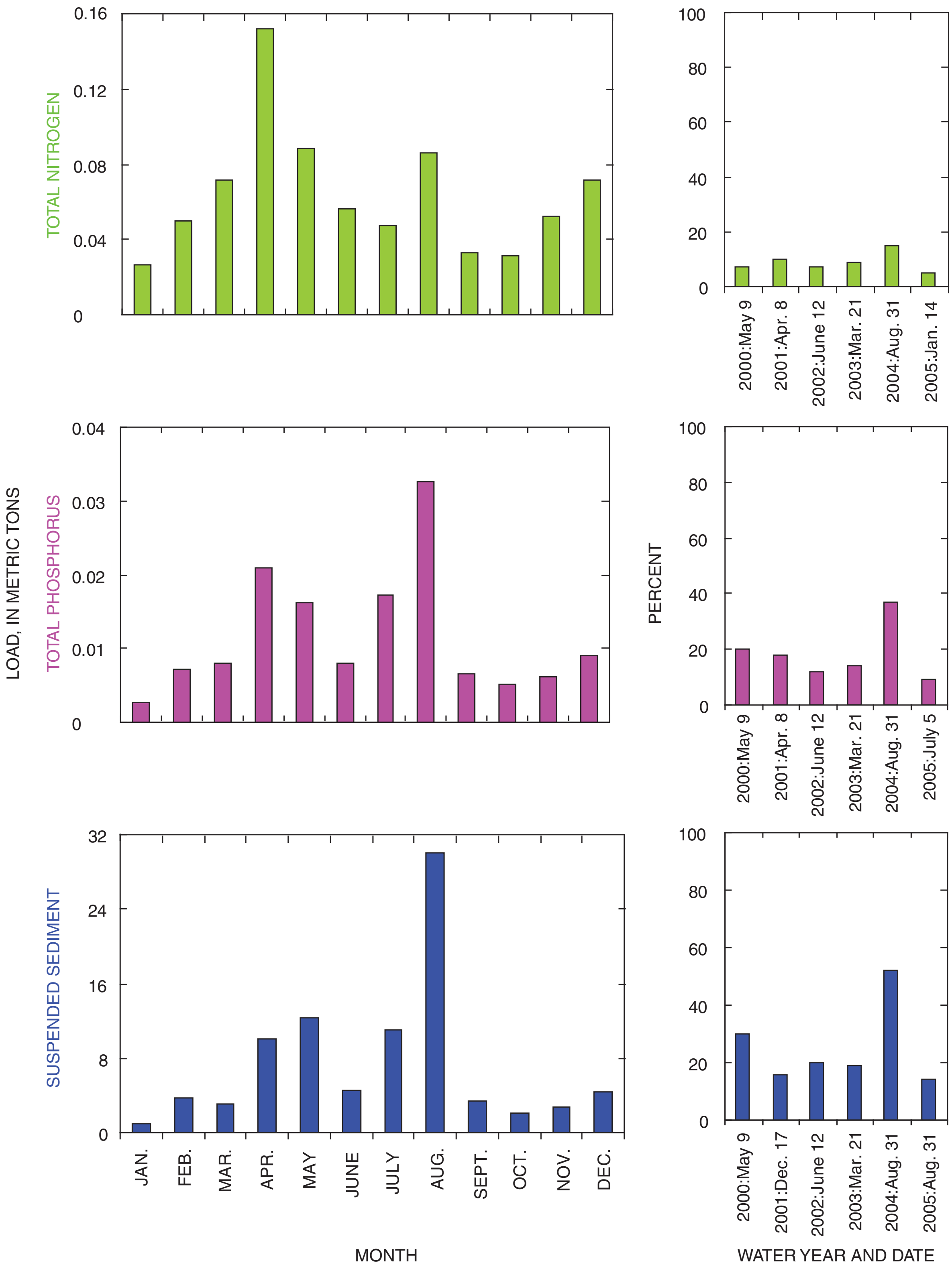

Figure 12. Mean loads by month for total nitrogen, total phosphorus, and suspended sediment at Englesby Brook, water years 2000–2005. Right-side graphs show percentage that the largest single days' load contributed to the respective annual load.

Table 6. Loads of total phosphorus and storm characteristics for 10 large measured storms at Englesby Brook, listed in decreasing order of rate of increase of streamflow.

[P, total phosphorus; t, metric tons; ft^3, cubic feet; <, less than; ft^3/s, cubic feet per second; cm, centimeters]

Storm date	P load (t) for sampled storms	Ranking of magnitude of P load for sampled storms	Total storm streamflow (ft^3)	Rate of increase of streamflow	Storm rainfall (cm)	Rainfall in 3 days preceding storm (cm)
8/30/04	0.028	4	1,065,600	10 to 95 ft^3/s in 15 minutes	5.61	4.19
7/1/04	.015	7	352,800	2 to 86 ft^3/s in 15 minutes	1.90	1.74
7/5/05	.009	12	226,800	5 to 78 ft^3/s in 15 minutes	1.37	.00
7/23/04	.017	5	576,000	<1 to 109 ft^3/s in 25 minutes	2.77	4.85
7/18/00	.036	2	615,600	<1 to 110 ft^3/s in 30 minutes	3.12	1.96
8/7/04	.007	15	345,600	1 to 81 ft^3/s in 30 minutes	.28	.36
8/29/04	.005	21	230,400	0 to 66 ft^3/s in 30 minutes	2.21	.00
8/1/05	.003	31	138,240	<1 to 32 ft^3/s in 15 minutes	.89	.00
8/3/04	.005	17	328,320	0 to 63 ft^3/s in 30 minutes	2.67	.71
5/9/00	.038	1	1,296,000	1 to 87 ft^3/s in 75 minutes	4.85	.76

either a monthly plus occasional extreme-event basis or on a weekly or biweekly basis. Comparisons between Englesby Brook and these other stations should be made cautiously because the different sampling strategies, especially in small streams, can result in large differences in load and yield estimates (Robertson and Roerish, 1999). The Englesby Brook sampling design, heavily weighted for high-flow events, may bias comparisons to the fixed-time interval sampling done at the NAWQA stations.

Nitrogen yields from Charles River were much larger than the other five stations. Englesby Brook nitrogen yields were slightly larger than those from the Aberjona River, and the 25th percentile yield from Englesby Brook was of similar magnitude as the 75th percentile yields from the Saugus, Ipswich, and Neponset Rivers. Quartiles of phosphorus yields from Englesby Brook were larger than those from the Charles River, but medians were similar. Median phosphorus yields were over 10 times greater at Englesby Brook and Charles River compared to the other four stations, and the 25th quartiles at Englesby Brook and Charles River were substantially larger than the 75th quartiles at the remaining four stations. In short, median nutrient yields at Englesby Brook, while larger than some, were within ranges seen at other New England urban streams.

Evaluation of the Effect of a BMP in the Water Quality of Englesby Brook

One of the goals of installing BMPs at Englesby Brook was to reduce pollutant loads to Lake Champlain (Center for Watershed Protection, written commun., 2000). Phosphorus and suspended-sediment data from before and after the BMP retrofit of the golf-course pond (before November 2001 and after April 2002), referred to as the calibration and treatment periods, were compared to evaluate changes in water quality of Englesby Brook. The treatment period data set was analyzed with data only through May 31, 2005, not the end of the water year, because additional BMP construction took place during the summer of 2005.

Quartiles and median flow-adjusted concentrations of phosphorus and suspended sediment by calibration and treatment periods for base-flow conditions are shown in figure 14. In a visual comparison of concentrations of phosphorus, the median and quartiles are seen to increase from the calibration to the treatment period. A statistical comparison of the medians corroborates this increase between periods (p-value = 0.004). The only difference in suspended sediment is that there were some low values in the treatment period that were not present in the calibration period, although they did not render the medians statistically different (p-value = 0.462).

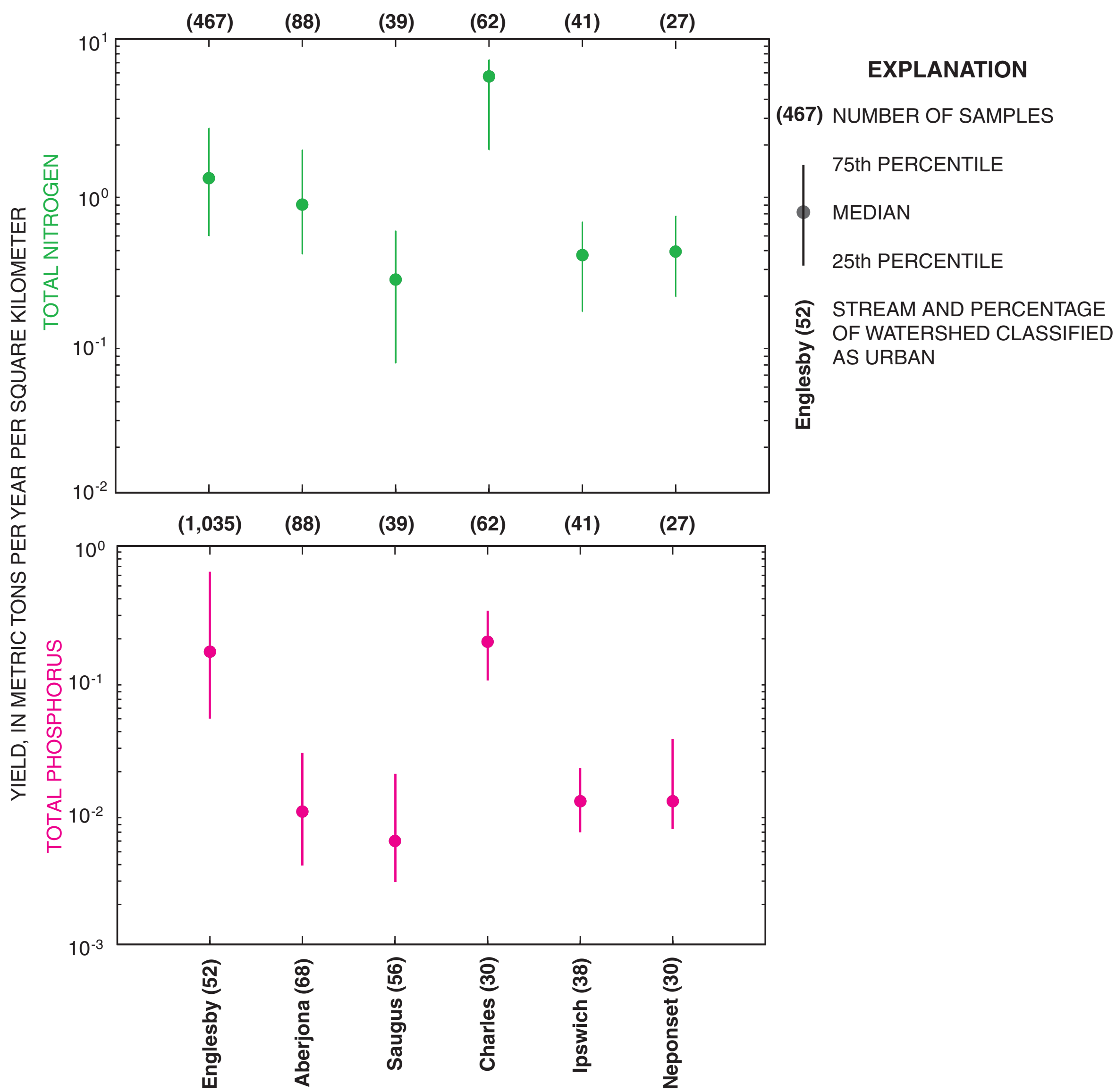

Figure 13. Quartiles and median yields of total nitrogen and total phosphorus from selected urban streams in New England.

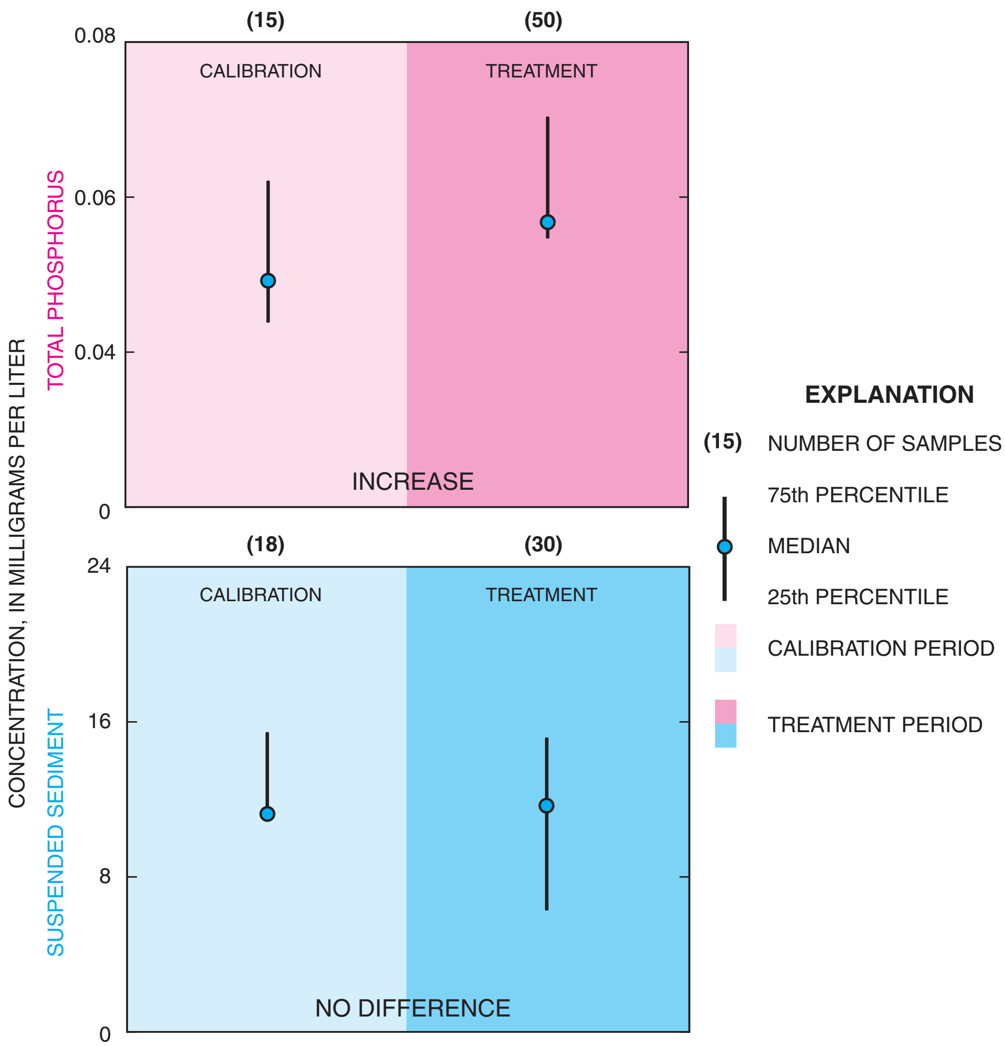

Figure 14. Quartiles and median concentrations of total phosphorus and suspended sediment for base-flow samples during the calibration and the treatment period at Englesby Brook. Concentrations have been adjusted to remove the effects of streamflow.

Logarithms of mean storm concentrations of phosphorus and suspended sediment were plotted against mean storm streamflow, and linear regression lines were drawn (fig. 15). For both constituents, the slopes were steeper and y-intercepts were lower for the calibration lines compared to slopes and y-intercepts of the treatment lines. Also in both cases, the regression lines crossed in the vicinity of the logarithm of 0.5 ft^3/s, or 3 ft^3/s, a streamflow which was exceeded about 4 percent of the time (Kenneth Toppin, U.S. Geological Survey, written commun., 2007). This means that for small storms resulting in average streamflows of less than 3 ft^3/s, concentrations during the treatment period were higher than concentrations during the calibration period. The opposite happened for large storms greater than 3 ft^3/s—concentrations during the calibration period were higher than concentrations during the treatment period. Since large proportions of the annual load were transported during high-flow events, this reduction in concentration at high flows signified a potentially positive result of construction of the golf-course pond BMP. However, the low R-squared values, less than or near 0.5 for 3 of the 4 regression lines, may weaken this conclusion.

Log-transformed storm loads of phosphorus and suspended sediment plotted against total stormwater volume are shown as scatterplots in figure 16, with data and linear regression lines classified as either calibration or treatment period. Snowmelt periods were omitted from this analysis because of the wide variation of snowmelt duration. As expected, phosphorus and suspended-sediment loads showed a strong positive relation to total stormwater volume. There were no differences in slopes or y-intercepts of the regression lines for the calibration or treatment period data sets for either phosphorus or suspended-sediment. This means that there was no evidence of reduction in storm loads of phosphorus or suspended sediment resulting from construction of the golf-course pond BMP.

In a final analysis of Englesby Brook data with respect to the golf-course pond BMP, double-mass curves were used to compare changes in cumulative mass quantities of phosphorus and suspended sediment plotted against cumulative mean monthly streamflow over the period of record (fig. 17). For both phosphorus and suspended sediment, the slopes of cumulative monthly load versus cumulative streamflow for calibration and treatment periods, using all of the data, were statistically the same. However, there was a marked break in the treatment line as cumulative streamflow approached 80 million cubic feet (ft^3), corresponding to a series of large storms during August 2004. This group of storm events, by virtue of its magnitude, may have resulted in a shift to the y-intercept (Glysson, 1987) or to the slope (Thompson, 1982). If the treatment data were divided into two discrete periods, before and after August 2004, it can be seen that the slopes of these two treatment-period lines (green lines) were similar with a step change in y-intercept. The difference in slope between the black calibration line and the first part of the treatment line (before the August 2004 step) was significant for loads of both phosphorus and suspended sediment. The slope for the calibration period was greater than for the treatment period. This indicates that after BMP construction, the same magnitude of streamflow resulted in a lower mass of phosphorus or suspended-sediment loading and suggests a possible improvement in water quality. Furthermore, one may observe that the calibration line also can be separated into two approximately parallel segments (orange lines) before and after the April through June 2000 data points (up to 15 million and after 23 million ft^3 of streamflow), a response to unusually high levels of precipitation during spring of 2000 (fig. 7). A comparison of the slope of the first part of the calibration line with the slope of the first part of the treatment line shows that slopes for phosphorus were not significantly different and that slopes for suspended sediment were significantly different. That the treatment-period slope for suspended sediment was less than the calibration-period slope, for these tightly linear segments, reinforced the previous result that loads were less in the treatment period compared to the calibration period.

To summarize the comparisons between periods, for phosphorus, concentrations during base-flow conditions and storms with average streamflow less than 3 ft^3/s were higher in the treatment than the calibration period, while concentrations during storms with average streamflows greater than 3 ft^3/s were lower in the treatment period compared to the calibration period. Storm loads showed no difference between periods, while cumulative monthly loads showed a possible reduction in the treatment period depending on how much the data were qualified (for example, whether parts or complete sets of calibration or treatment period lines were used in tests of regression slopes for the double-mass curve analysis). These results indicated that construction of the BMP in the Englesby Brook watershed possibly reduced phosphorus concentrations during the highest-flow events—but did not reduce loads. Results for suspended sediment were similar to those for phosphorus, except that there was more evidence of reduced concentrations and loads due to construction of the BMP. Concentrations of suspended sediment during base-flow conditions did not increase after treatment, as they did for phosphorus, but like phosphorus, they decreased in the treatment period for storms with average streamflow greater than 3 ft^3/s. Furthermore, the decrease in load of cumulative monthly suspended sediment in the treatment period was more convincing than the decrease for phosphorus, because the reduction in treatment-period slope for suspended sediment occurred regardless of how the calibration period was defined. This sparse evidence of reductions in concentrations or loads was notable given that the BMP being assessed was in the upper third of the Englesby Brook watershed, at least 1.7 km from the location of the water-quality monitoring site, with considerable impairment in between (Center for Watershed Protection, written commun., 2000).

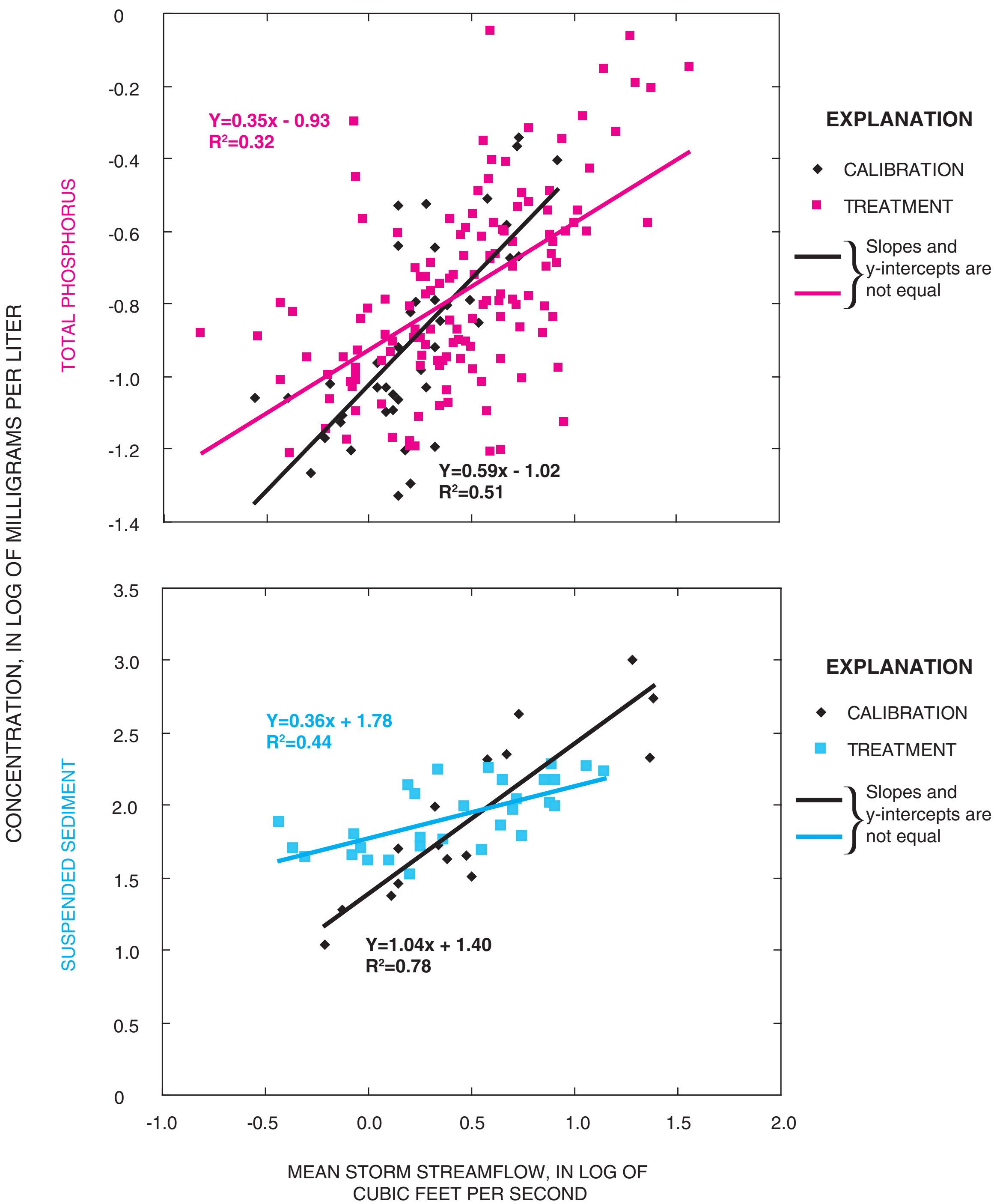

Figure 15. Mean storm concentrations of total phosphorus and suspended sediment plotted against mean storm streamflow for measured storms during the calibration and the treatment period at Englesby Brook.

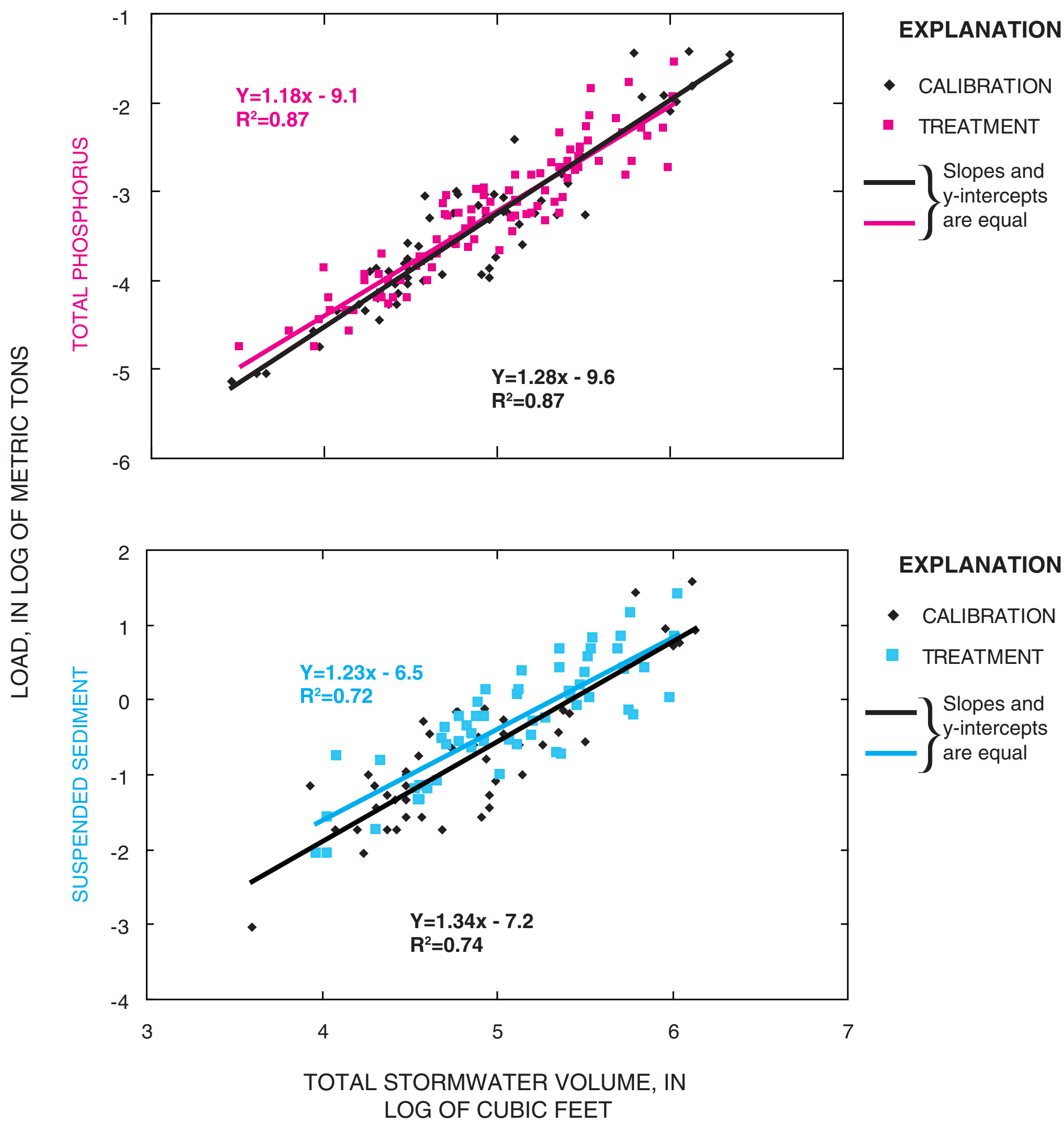

Figure 16. Storm loads of total phosphorus and suspended sediment plotted against total stormwater volume for measured storms during the calibration and the treatment period at Englesby Brook.

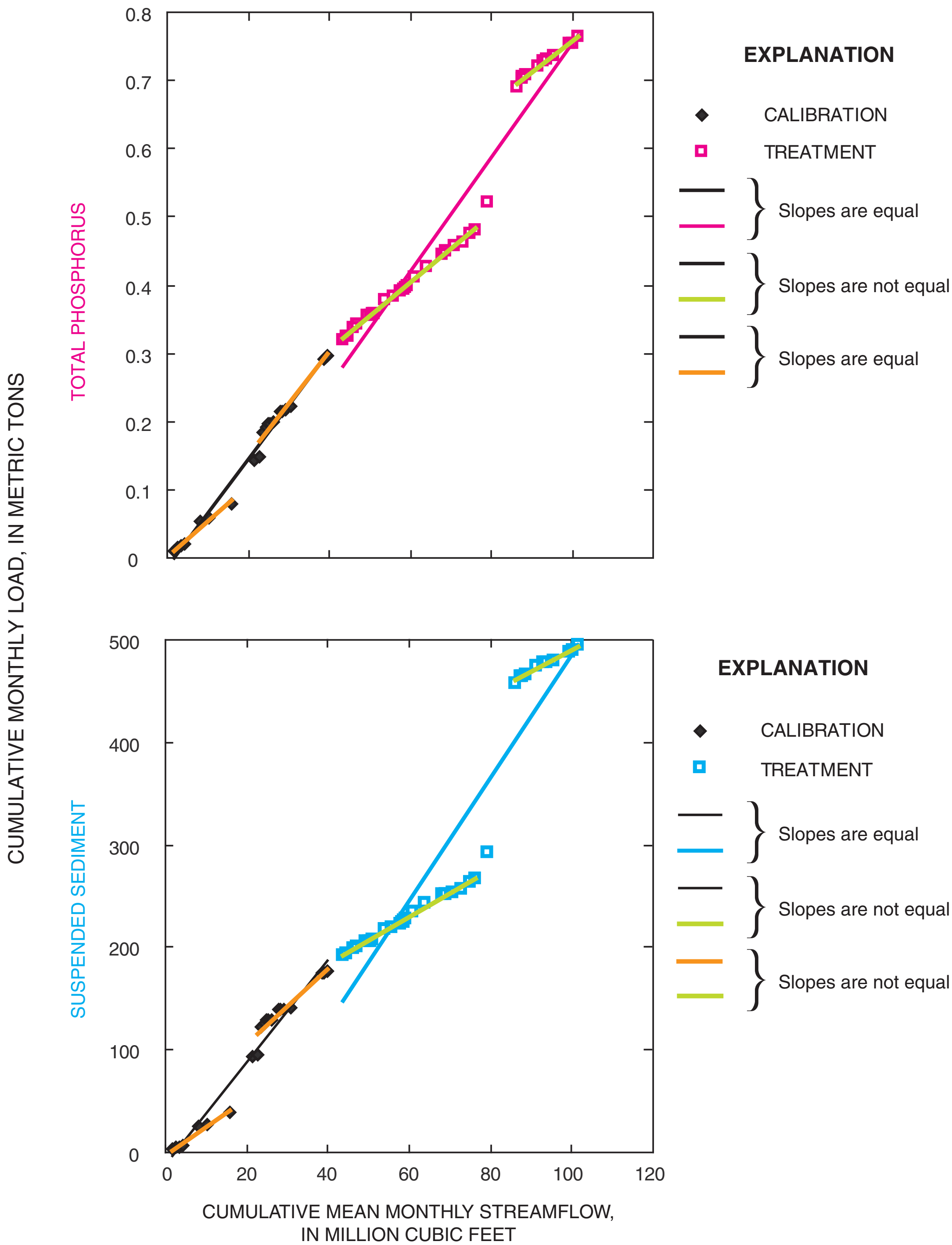

Figure 17. Double-mass curves for cumulative monthly streamflow and cumulative monthly loads of total phosphorus and suspended sediment at Englesby Brook, water years 2000–2005. [Orange and green lines represent best-fit lines for cumulative loads during calibration and treatment periods, respectively, segmented by large shifts in y-intercept]

Water Quality of the Little Otter Creek Watershed

Results from the upstream and downstream monitoring stations are presented concurrently in this section. Evaluation of the impacts to water quality from BMPs should be viewed in the context of the premature end to BMP construction. Greater attention is given to the impact of the farm on water quality, as determined by differences in loads between the upstream and downstream monitoring stations.

Hydrology

Mean annual streamflows at Little Otter Creek, station 04282650, for water years 2000 through 2005, ranged from 26.8 ft^3/s in 2002 to 80.5 ft^3/s in 2004 (Coakley and others, 2001, 2002; Kiah and others, 2003, 2006; Keirstead and others, 2004, 2005). Cumulative streamflow for these 6 years is shown in figure 18. Streamflow differed widely from year to year, however, some general seasonal patterns were observed. For example, streamflow in the summer was lower than streamflow at other times of the year. Extended periods with high streamflows were during snowmelt. The 2000 snowmelt was at the end of February, and the 2001 April snowmelt resulted in about half of the 2001 total annual streamflow. The years 2000 and 2004 had total annual streamflow of slightly more than 2,500 million ft^3, which was about three times the streamflow in 2002 of 846 million ft^3. Cumulative streamflow from October through December, 2004, was almost as great as or greater than the cumulative annual streamflow for 2002, 2003, and 2005.

Concentrations of Phosphorus and Suspended Sediment

For the 72 phosphorus samples collected at the upstream monitoring station on Little Otter Creek (USGS Station 04282634) during base-flow conditions, concentrations ranged from 0.016 to 0.141 mg/L and the median was 0.054 mg/L (table 4). Concentrations for the 82 phosphorus samples collected at the downstream monitoring station (USGS Station 04282636) during base flow ranged from 0.018 to 0.233 mg/L and the median was 0.067 mg/L (table 4). During base-flow conditions, phosphorus concentrations were often greater at the downstream compared to the upstream monitoring station (fig. 19). A weak seasonal pattern in concentrations of phosphorus during base flow was observed, with lower concentrations in winter and higher concentrations in the summer at both stations (fig. 19). This pattern is consistent with concentrations of phosphorus during base flow found in an agricultural stream in Pennsylvania (Koerkle, 2000).

Concentrations for the 35 suspended-sediment samples collected at the upstream monitoring station on Little Otter Creek during base flow ranged from 2 to 13 mg/L and the median was 6 mg/L (table 4). For the 39 suspended-sediment samples collected at the downstream monitoring station during base flow, concentrations ranged from 10 to 132 mg/L and the median was 25 mg/L (table 4). Concentrations of suspended sediment during base flow at the downstream monitoring station were much more variable and had many more high values than concentrations at the upstream monitoring station (fig. 19). This scatter may have been the consequence of cows wading in the stream just above the downstream monitoring station, causing sediment resuspension from the streambed and erosion from unvegetated streambanks. Higher concentrations of suspended sediment were always observed during the summer compared to the winter at the downstream monitoring station, but this was not the case at the upstream monitoring station.

Similarly, ranges of concentrations of phosphorus and suspended sediment during high-flow conditions were greater at the downstream compared to the upstream monitoring station (table 4). The 419 samples of phosphorus collected during high-flow conditions at the upstream monitoring station ranged from 0.019 mg/L to 0.565 mg/L and the 587 samples of phosphorus collected during high-flow conditions at the downstream monitoring station ranged from 0.019 mg/L to 1.95 mg/L. Median phosphorus concentrations at the upstream and downstream monitoring stations during high flows were 0.09 and 0.119 mg/L, respectively. The 142 samples of suspended sediment during high-flow conditions at the upstream monitoring station ranged from 1 to 473 mg/L and the 196 samples at the downstream monitoring station ranged from 8 to 1,190 mg/L. Median concentrations of suspended sediment at the upstream and downstream monitoring stations during high-flow conditions were 33 and 50 mg/L, respectively.

Comparisons between concentrations of phosphorus and suspended sediment at the upstream and downstream monitoring stations during one snowmelt period and selected storms from different seasons are shown in figure 20. Storms selected for this example had multiple samples at both stations. The flow curves show data from USGS streamflow-gaging station 04282650. Sampling times were adjusted forward in time to correspond to the appropriate position on the hydrograph, typically by about three hours for the downstream monitoring station and about four hours for the upstream monitoring station. Storm hydrographs were less flashy than at Englesby Brook—the duration of storms at Little Otter Creek was typically 2 to 4 days rather than hours. Many storms had double or rounded streamflow peaks and recessions were typically gradual. These characteristics are typical for a low-gradient stream and a non-urban watershed with storage, negligible impervious surface area, and a relatively large drainage area. During storms for which several samples were collected at both stations, phosphorus concentrations at the downstream monitoring station were generally greater than concentrations at the upstream monitoring station; however, concentrations of suspended sediment at the two stations often were similar.

Sample collection in March 2003 began on the first day the stream had melted enough to enable collection of a

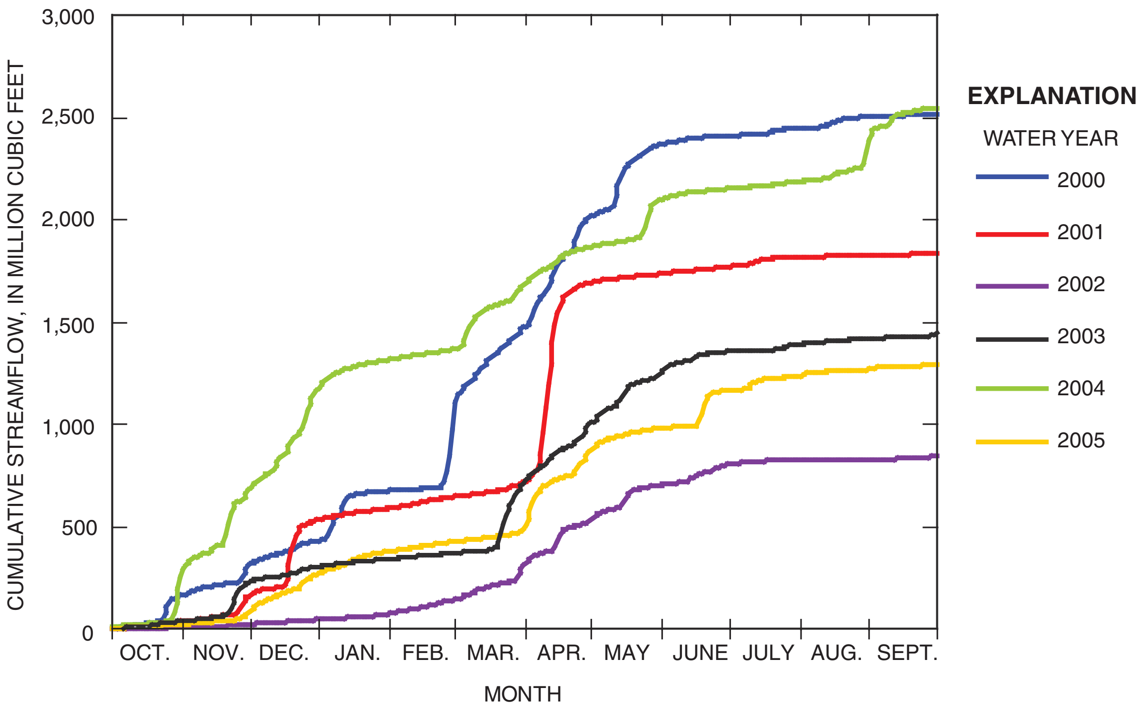

Figure 18. Annual cumulative streamflow curves for Little Otter Creek, water years 2000–2005.

manual sample. A good example of the first pulse effect from the snowpack is shown by the March 2003 data in figure 20, where phosphorus concentrations in the initial water from the snowpack during low streamflow were almost as high or higher than the concentration three days later when streamflow increased tenfold. During non-snowmelt events, secondary streamflow peaks, even if greater than first peaks such as for the April 13–16, 2002 storm (fig. 20), usually corresponded to lower concentrations of phosphorus.

The May 2002 and November 2003 storms (fig. 20) are shown to illustrate contrasting phosphorus responses to similar storms. Both graphs show data over a 3 to 4 day period, with the storm peak occurring in less than 24 hours. For the May 2002 storm, phosphorus concentrations increased with streamflow at the upstream and downstream monitoring stations and then decreased gradually after the streamflow peak. During the November 19–23, 2003 storm, a steep increase in phosphorus concentration at the downstream monitoring station followed by a similar decrease took place prior to the streamflow peak. One reason for these contrasting results may be that when the two monitoring stations had similar patterns of concentrations, like the May 2002 storm, there was no additional source of suspended sediment or phosphorus between the stations. In contrast, for the November 2003 storm, the shape of the downstream chemograph indicates that there may have been moderate to substantial deposition between the two stations. The deposition source could have been from overland runoff between the upstream and downstream monitoring stations—either from a previous event, such as the large storm that was 23 days prior, or from the November storm that is illustrated. The deposition source also could be from within the stream. The November storm, which was approximately three times greater than the May storm, may have caused streambed or streambank scouring between the stations.

Fewer storms were sampled for concentrations of suspended sediment than for phosphorus because of budget constraints. Two storms that were sufficiently sampled to provide a reasonable picture of suspended sediment are shown in figure 20. Concentrations at the upstream monitoring station were higher than concentrations at the downstream monitoring station during the storm that began May 29, 2003; however, concentrations were low and the difference never exceeded 40 mg/L, or 30 percent. The second and larger streamflow peak for the October 27–30, 2003 storm corresponded to an increase in suspended-sediment concentration at the downstream monitoring station (suspended sediment at the upstream monitoring station was not sampled). Thus, it appeared that the relative magnitude of sediment peaks was proportional to streamflow peaks, for example, a small streamflow and peak concentration of suspended sediment may be followed by a larger streamflow and peak concentration of suspended sediment. Conversely, concentrations of phosphorus tended to peak for the first streamflow peak, whether or not there were larger subsequent streamflow peaks.

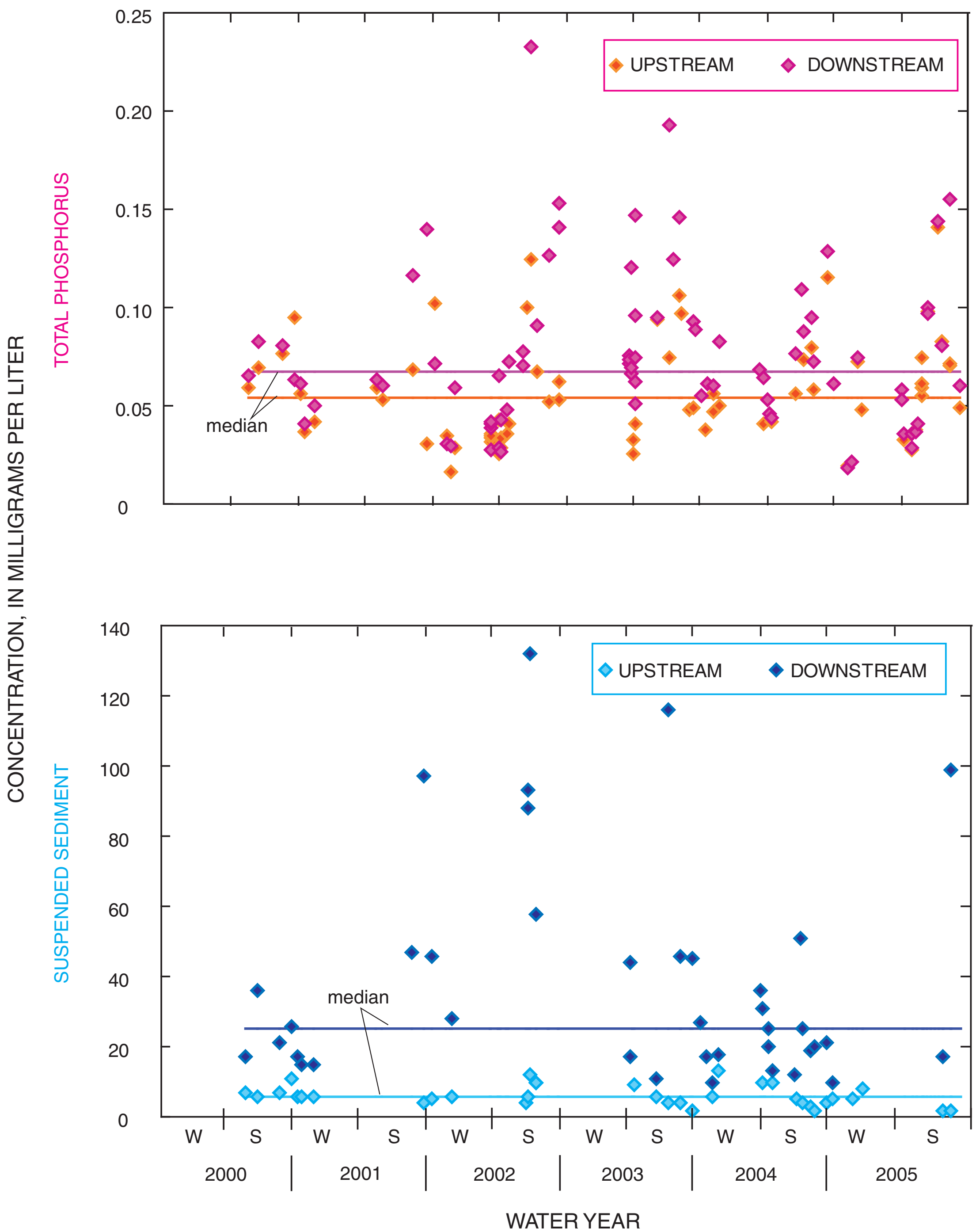

Figure 19. Base-flow concentrations of total phosphorus and suspended sediment at upstream and downstream monitoring stations on Little Otter Creek, water years 2000–2005. [W, winter (October through March); S, summer (April through September)]

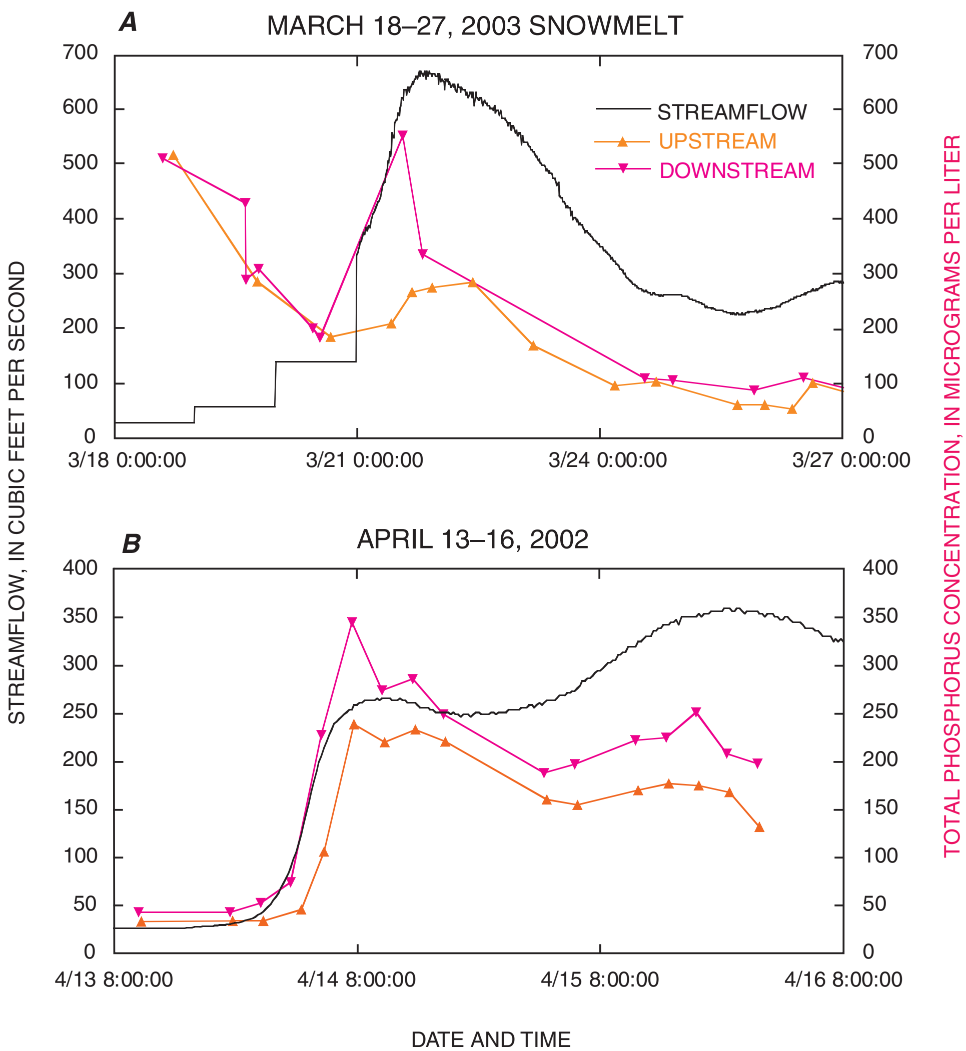

Figure 20. Concentrations of total phosphorus and suspended sediment for selected storms at upstream and downstream monitoring stations, Little Otter Creek. [The first three days of the March 2003 snowmelt period show mean daily streamflow data as horizontal lines, because frozen conditions precluded the presentation of data meaningful on a smaller time step]

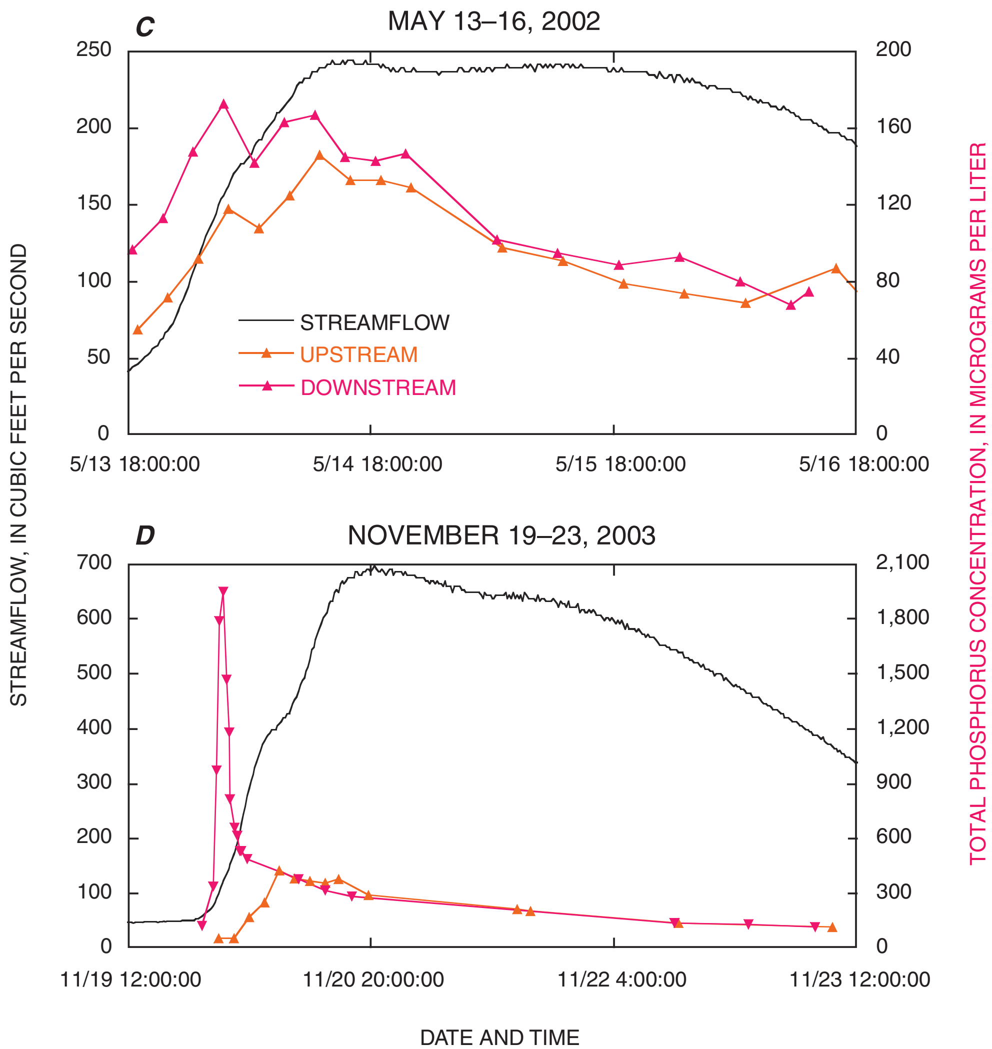

Figure 20. Concentrations of total phosphorus and suspended sediment for selected storms at upstream and downstream monitoring stations, Little Otter Creek.—Continued

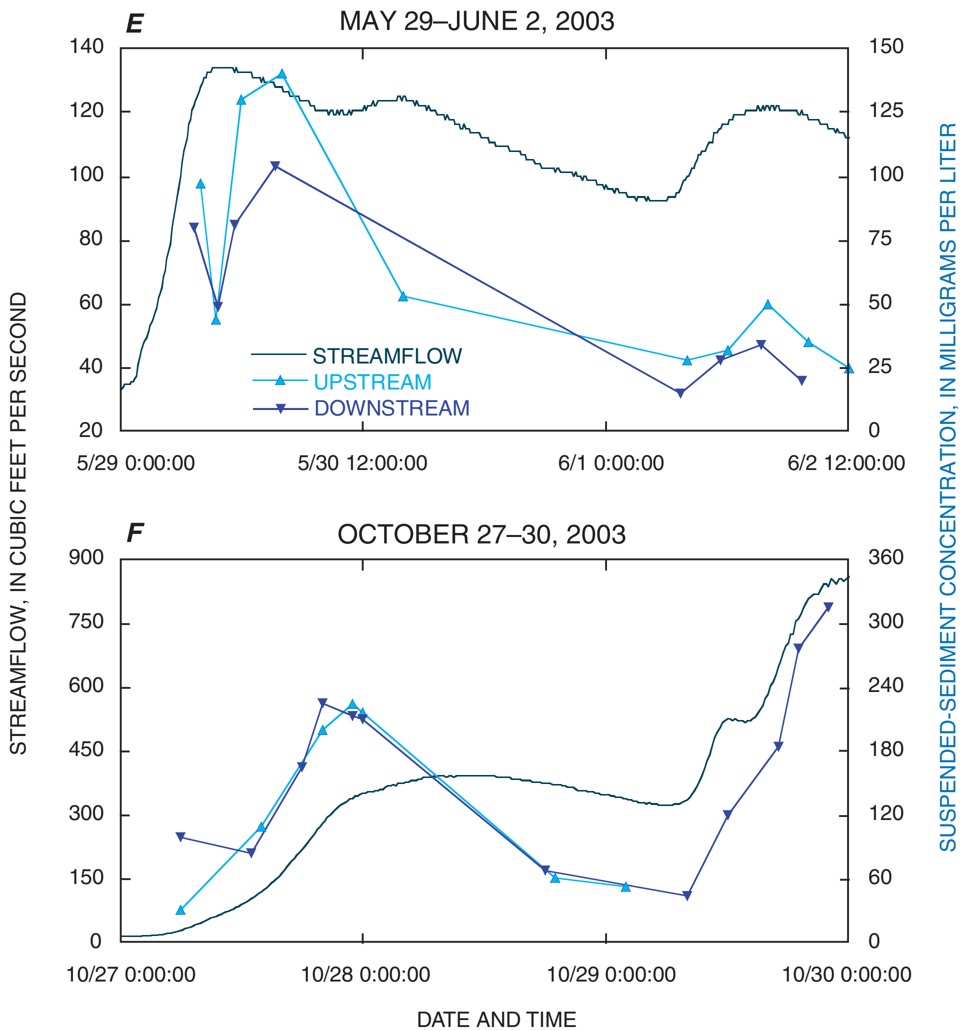

Figure 20. Concentrations of total phosphorus and suspended sediment for selected storms at upstream and downstream monitoring stations, Little Otter Creek.—Continued

Loads of Phosphorus and Suspended Sediment

Monthly and annual loads of phosphorus and suspended sediment for the upstream and downstream monitoring stations on Little Otter Creek are shown in table 5. Annual loads with percentages contributed during high-flow and base-flow conditions, average streamflow, and precipitation are shown in figure 21. All estimates of loads of phosphorus and suspended sediment were smallest in 2002 and largest in 2004. At the upstream monitoring station, annual loads of phosphorus ranged from 1.6 t in 2002 to 9.5 t in 2004 and loads of suspended sediment ranged from 517 t in 2002 to 3,290 t in 2004. At the downstream monitoring station, annual loads of phosphorus ranged from 1.9 t in 2002 to 11 t in 2004 and loads of suspended sediment ranged from 868 t in 2002 to 5,540 t in 2004. Annual loads of phosphorus and suspended sediment were larger at the downstream than the upstream monitoring station for all years except 2001 and 2005 for suspended sediment (table 7). For both monitoring stations, the percentage of annual loads of phosphorus and suspended sediment contributed during high-flow conditions was highest in 2001. The percentage of annual loads contributed during high-flow conditions ranged from 61 in 2003 to 83 in 2001 for phosphorus at the upstream monitoring station, 64 in 2005 to 86 in 2001 for suspended sediment at the upstream monitoring station, 59 in 2000 and 2003 to 80 in 2001 for phosphorus at the downstream monitoring station, and 58 in 2002 to 82 in 2001 for suspended sediment at the downstream monitoring station.

Mean monthly loads for phosphorus and suspended sediment at Little Otter Creek are shown in figure 22 and individual monthly and annual loads are listed in table 5. For the upstream and downstream monitoring stations, the mean April phosphorus load was at least twice that of any other month. Although the same was true for the suspended-sediment load in April at the upstream monitoring station, the comparative magnitude of April loads was not as pronounced at the downstream monitoring station for suspended sediment. For all months except April, loads of phosphorus and suspended sediment at the downstream monitoring station were greater than loads at the upstream monitoring station. April stands out as the exception primarily due to the 2001 estimates: 2,010 t of suspended-sediment load at the upstream monitoring station and 1,070 t at the downstream monitoring station. As previously mentioned, April 2001 had the largest single-month cumulative streamflow of any month during the 6 years of record (fig. 18). The April load estimates were generated solely by the regression program LOADEST, because there were no sets of well-defined storm samples for suspended sediment during 2001 to use in GCLAS. Mean loads of phosphorus and suspended sediment were lowest in January, July, and September (fig. 22), although no month had a consistently large or small load (table 5). Mean loads of suspended sediment at the downstream monitoring station were at least 50 percent greater than mean loads at the upstream monitoring station from July through November. The largest daily loads of each year generally contributed from 4 to 12 percent of the annual phosphorus load and from 6 to 17 percent of the annual suspended-sediment load (fig. 22). These percentages were less than at Englesby Brook, which was more sensitive to extreme events. Also, a daily load at Englesby Brook usually encompassed an entire storm, whereas it usually took several days at Little Otter Creek for an entire storm load to pass by the sampling station.

Phosphorus and Suspended-Sediment Export from a Dairy Farm

Estimates of annual export from the dairy farm on Little Otter Creek that was monitored for this study were calculated by subtracting the load at the upstream monitoring station from the load at the downstream monitoring station (table 7). Changes in storage through the stream reach that went through the farm were assumed to be negligible on an annual basis. Estimates of annual export from the farm, based on the drainage-area differential between the two monitoring stations (2.28 percent) times the load at the downstream monitoring station, also are provided in table 7. These latter estimates provide a theoretical baseline for exports based solely on drainage-area differences between stations. The calculated export averaged over the study period was 13 times larger for phosphorus (1.3 compared to 0.1 t) and 12 times larger for suspended sediment (753 compared to 61 t) than the theoretical export averaged over the study period. Because annual loads based on the calculated differences were so much larger than the averages based on the theoretical drainage-area differences, evidence was provided that some farm-related activities were affecting export in this reach of Little Otter Creek.

On an annual basis, loads of phosphorus at the downstream monitoring station were always greater than loads at the upstream monitoring station. Annual loads of suspended sediment at the downstream monitoring station were greater than loads at the upstream monitoring station in 4 of the 6 years. When monthly loads were averaged over 6 years, each load of phosphorus and suspended sediment at the downstream monitoring station was greater than the paired load at the upstream monitoring station (fig. 22), except for suspended sediment in April. For individual months, loads of phosphorus at the downstream monitoring station were greater than loads at the upstream monitoring station for 70 of the 72 months of estimated loads, and loads of suspended sediment at the downstream monitoring station were greater than loads at the upstream monitoring station in 50 of the 72 months (table 5), both statistically significant results. These results indicated that phosphorus and sediment were being added to the stream by the farm, despite confidence intervals for the annual loads that were larger than differences between the two monitoring stations (fig. 21).

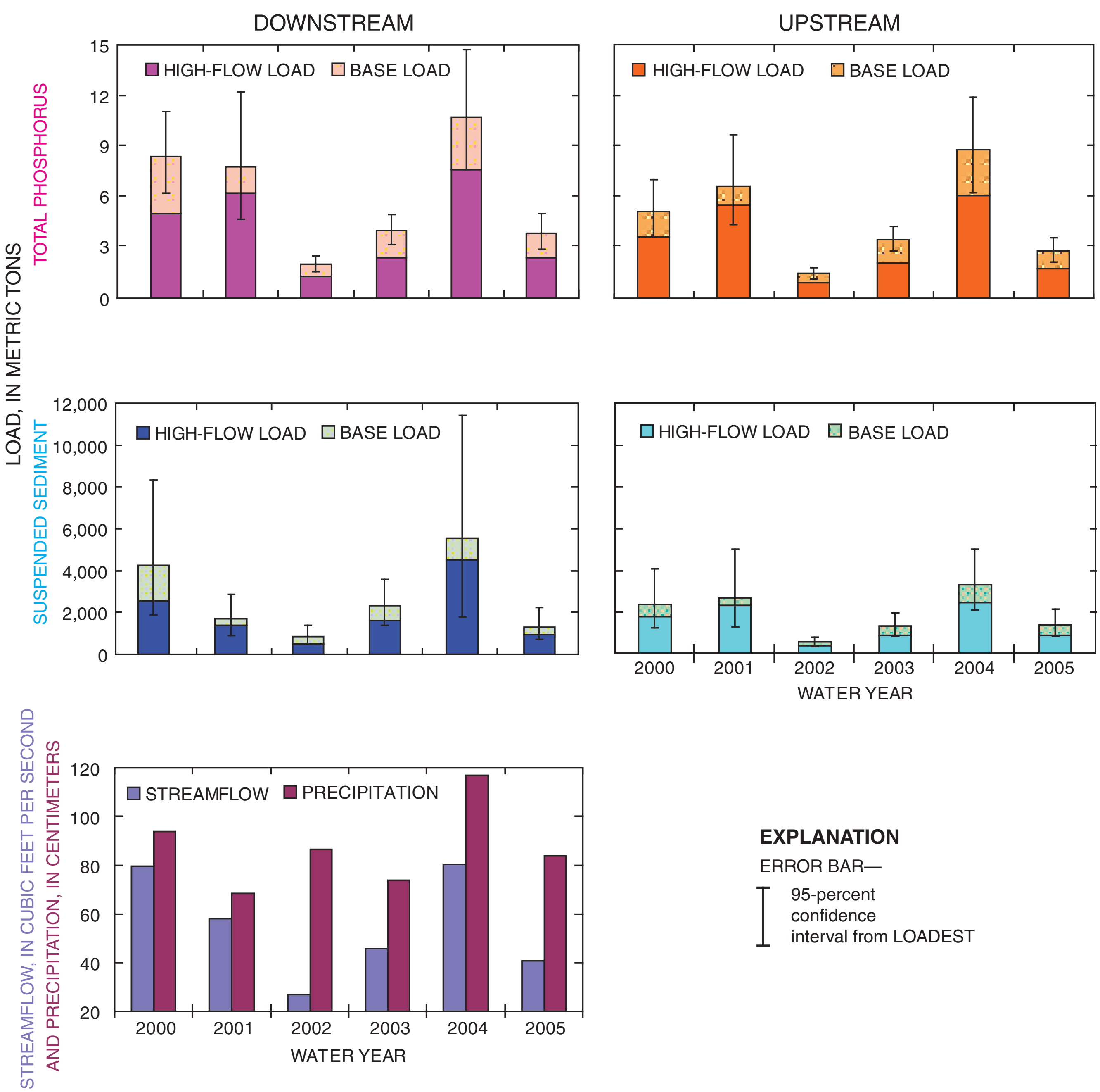

Figure 21. Annual loads of total phosphorus and suspended sediment from high-flow and base-flow contributions for upstream and downstream monitoring stations on Little Otter Creek, mean annual streamflow at USGS streamflow-gaging station 04282650, and total precipitation, water years 2000–2005. [Error bars show 95-percent confidence intervals from LOADEST output only and therefore, provide greater than 95-percent confidence in the annual estimates shown, due to supplementing LOADEST with results from GCLAS]

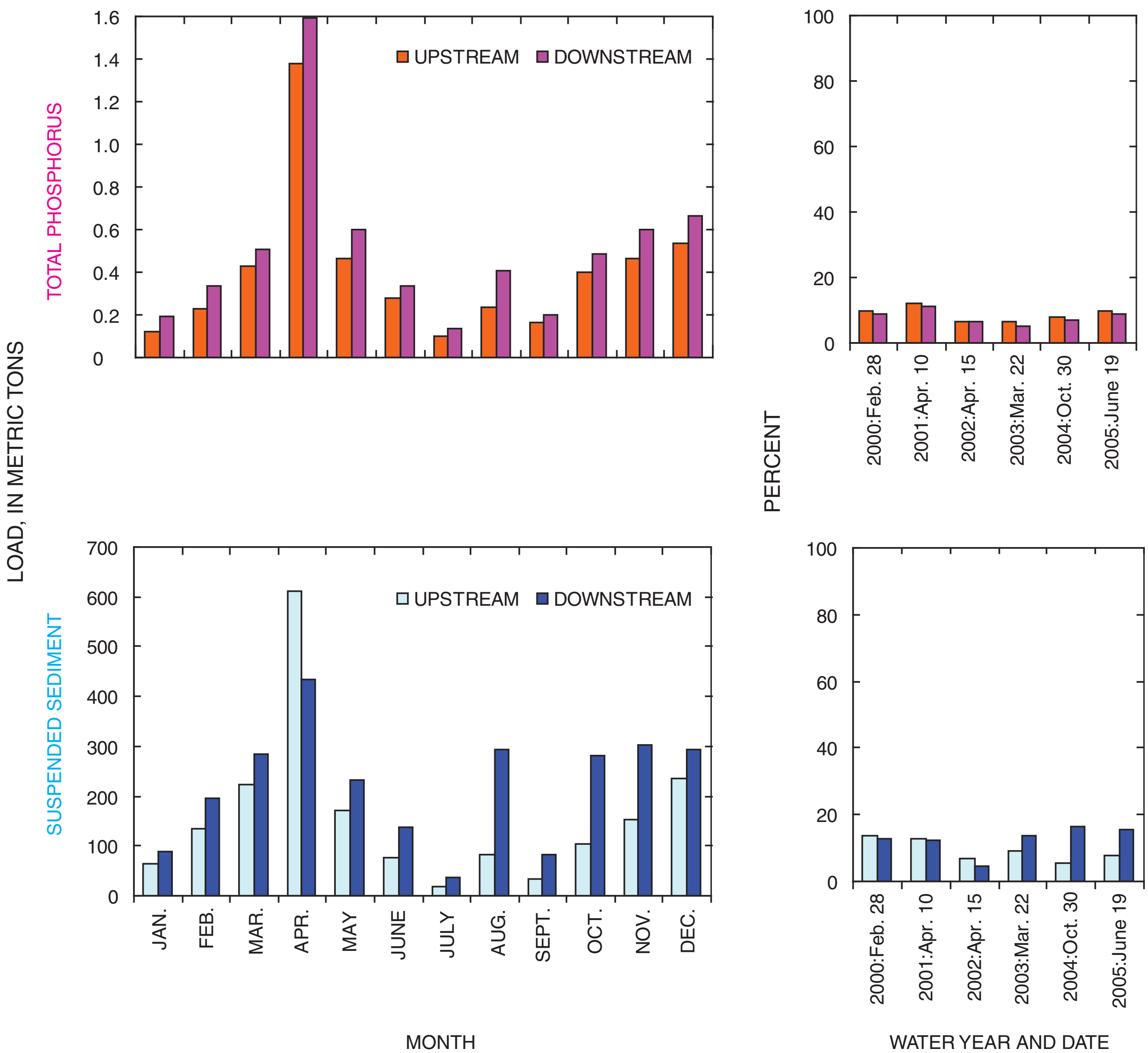

Figure 22. Mean loads by month for total phosphorus and suspended sediment at upstream and downstream monitoring stations on Little Otter Creek, water years 2000–2005. Right-side graphs show percentage that the largest single days' load contributed to the respective annual load.

Table 7. Differences in annual loads between downstream and upstream monitoring stations at Little Otter Creek, 2000–2005.

[Numbers in parentheses ( ) indicate that the load at the upstream monitoring station is greater than the load at the downstream monitoring station]

	2000	2001	2002	2003	2004	2005	Average
	Difference in annual load between downstream and upstream monitoring stations, in metric tons						
	Total phosphorus						
Estimation of load based on method described in report	3.1	1.0	0.3	0.3	1.9	0.9	1.3
Estimation of load based on drainage-area differential	.2	.2	.0	.1	.2	.1	.1
	Suspended sediment						
Estimation of load based on method described in report	1,916	(970)	351	1,021	2,245	(46)	753
Estimation of load based on drainage-area differential	97	39	20	53	126	30	61

Evaluation of the Effect of Barnyard BMPs in the Water Quality of Little Otter Creek

For the agricultural component of this study, BMPs were expected to include a suite of on-farm practices typical in the Lake Champlain Basin: barnyard improvements such as roof gutters and redirection of milkhouse wastes to a manure pit, a comprehensive nutrient-management plan, and streambank fencing with one or several stabilized cow crossings. After the barnyard improvements were made, the rest of the planned BMPs were not implemented. Nevertheless, pairs of concentrations of phosphorus and monthly loads of phosphorus and suspended sediment from upstream and downstream monitoring stations were analyzed for periods before (calibration) and after (treatment) barnyard BMP construction to determine whether any water-quality changes due to those BMPs could be detected.

Regression statistics for paired concentrations of phosphorus and monthly loads of phosphorus and suspended sediment from the two monitoring stations for calibration and treatment periods showed that all relations were significant (table 8). Results of the ANCOVA for phosphorus concentrations at the downstream monitoring station, using phosphorus concentrations at the upstream station as covariates, showed that the differences between the y-intercept and slope of the treatment-period regression line were not significant compared to the y-intercept and slope of the calibration period (table 9, fig. 23). This was, however, a marginal result, given that the p-values for the difference in y-intercept, 0.075, and the difference in slope, 0.052, were just slightly above the significance level 0.05. That the calibration- and treatment-period regression lines crossed (fig. 23), with the treatment period having a steeper slope, indicated a possible worsening of conditions after treatment. The steeper slope meant that phosphorus concentrations at the downstream monitoring station during large storms, which was when higher concentrations generally were seen, were higher in the treatment period relative to the calibration period. This result, although insignificant, was contrary to the reduction in phosphorus concentrations that was anticipated.

ANCOVA results for monthly loads of phosphorus and suspended sediment showed that the only significant difference between the calibration and treatment periods was in y-intercept for monthly loads of phosphorus. Because the difference in slope was not significant for the ANCOVA of phosphorus load (p-value = 0.12), a reduced regression model was used with the interaction term omitted. However, the calculated magnitude of the phosphorus-load reduction was the same 21 percent (in original load units) whether the interaction term remained or was left out. This reduction in loads of phosphorus for the treatment period is illustrated by the parallel and slightly offset regression lines in the middle graph of figure 23. Regression lines for loads of suspended sediment are indistinguishable, indicating that there was no change between the calibration and treatment periods. Restated, there was no effect due to the barnyard BMP in the relation between loads of suspended sediment at the upstream and downstream monitoring stations. However, it is important to reiterate that the barnyard BMP was never intended to be the sole improvement to the farm and, by itself, was not expected to result in a noticeable reduction in loads of phosphorus or suspended sediment to Little Otter Creek.

Table 8. Regression statistics for relations between concentrations of total phosphorus and monthly loads of total phosphorus and suspended sediment from upstream and downstream monitoring stations at Little Otter Creek, for calibration (before BMP) and treatment (after BMP) periods.

[BMP, best-management practice; <, less than]

	Phosphorus concentration	Phosphorus load	Suspended-sediment load
R^2 calibration period	0.64	0.99	0.80
R^2 treatment period	.82	.99	.71
F-statistic calibration period	52	4,199	103
F-statistic treatment period	295	4,008	105
Significance of F-statistic calibration period	<.0001	<.0001	<.0001
Significance of F-statistic treatment period	<.0001	<.0001	<.0001
Mean square error calibration period	1.18	13.32	13.33
Mean square error treatment period	4.85	14.13	12.42

Table 9. Results of ANCOVA comparing concentrations of total phosphorus and monthly loads of total phosphorus and suspended sediment from upstream and downstream monitoring stations at Little Otter Creek, Vermont, for calibration (before BMP) and treatment (after BMP) periods.

[ANCOVA, analysis of covariance; BMP, best-management practice; df, degrees of freedom; MS, mean square; F, F-statistic; <, less than; **bold** value indicates significant result at $\alpha = 0.05$]

	Phosphorus concentration				Phosphorus load				Suspended-sediment load			
Source	df	MS	F	p-value	df	MS	F	p-value	df	MS	F	p-value
Model	3	2.04	111.08	**<0.001**	3	9.19	2,706.38	**<0.001**	3	8.78	71.80	**<0.001**
Error	96	.02	--	--	68	.00	--	--	68	.12	--	--
Difference in y-intercept between calibration and treatment periods	1	6.06	.04	.075	1	27.56	.04	**<0.001**	1	26.34	0.00	.96
Difference in slope between calibration and treatment periods	1	.07	3.94	.052	1	.01	2.56	.12	1	.00	.02	.91

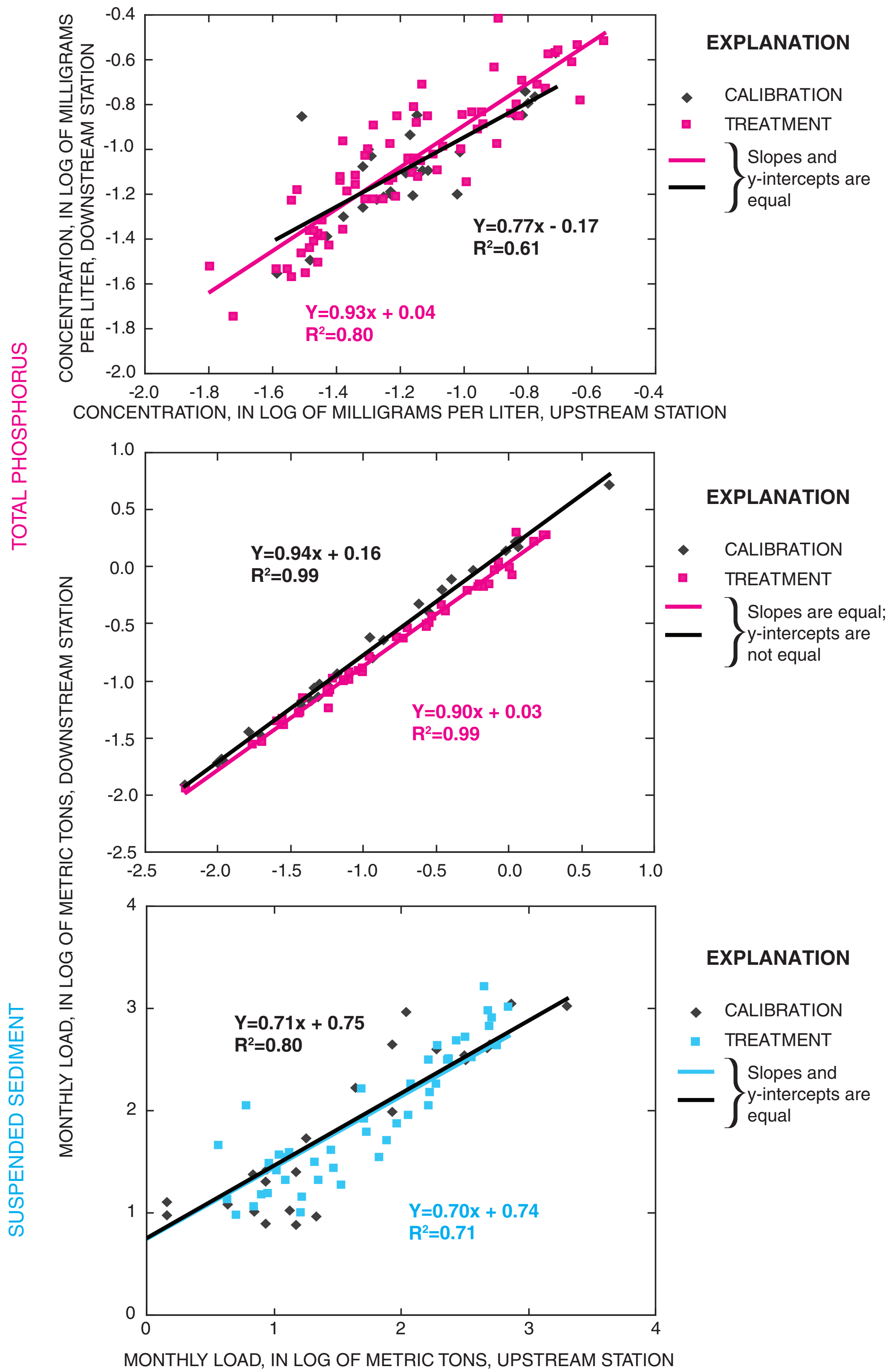

Figure 23. Scatterplots and regression equations comparing calibration and treatment periods from paired watershed ANCOVA for concentrations of phosphorus and monthly loads of phosphorus and suspended sediment from upstream and downstream monitoring stations at Little Otter Creek. [ANCOVA, analysis of covariance; BMP, best-management practice]

Effect of Land Use on Phosphorus Yields in the Lake Champlain Basin

Ranges of phosphorus yields for major tributary subbasins of the Lake Champlain Basin (excluding the Pike River in Canada) as well as for the stations sampled for this study on Little Otter Creek and Englesby Brook are shown in figure 24. Data on phosphorus concentrations are from the Lake Champlain long-term water quality and biological monitoring project (Vermont Department of Environmental Conservation, 2006). The two other factors used in these yield calculations, mean daily streamflow for every sampled date from each sampling station and drainage areas, were determined at USGS streamflow-gaging stations (Butch and others, 2003, 2004, 2005; Coakley and others, 2001, 2002; Kiah and others, 2003, 2006; Keirstead and others, 2004, 2005). None of the 17 subbasins other than Englesby Brook have urban land use greater than 4 percent. The five subbasins with the lowest median yields of phosphorus, Ausable, Bouquet, Little Ausable, Putnam, and Saranac, have among the highest forested land-use percentages (close to or above 80 percent). The median phosphorus yield at Englesby Brook, 0.16 t per year per square kilometer (t/yr/km^2), was the same as that for the Missisquoi Basin, which is the only Lake Champlain subbasin that has a unique Phosphorus Reduction Task Force and International Agreement for carrying out phosphorus-reduction strategies. For all areas of the Lake Champlain Basin, agricultural land use is predominantly in the lowlands near the lake. Consequently, even though the percentage of agricultural land use appears low compared to forested land use, for most of the subbasins, water-quality samples were collected at locations dominated by agricultural land.

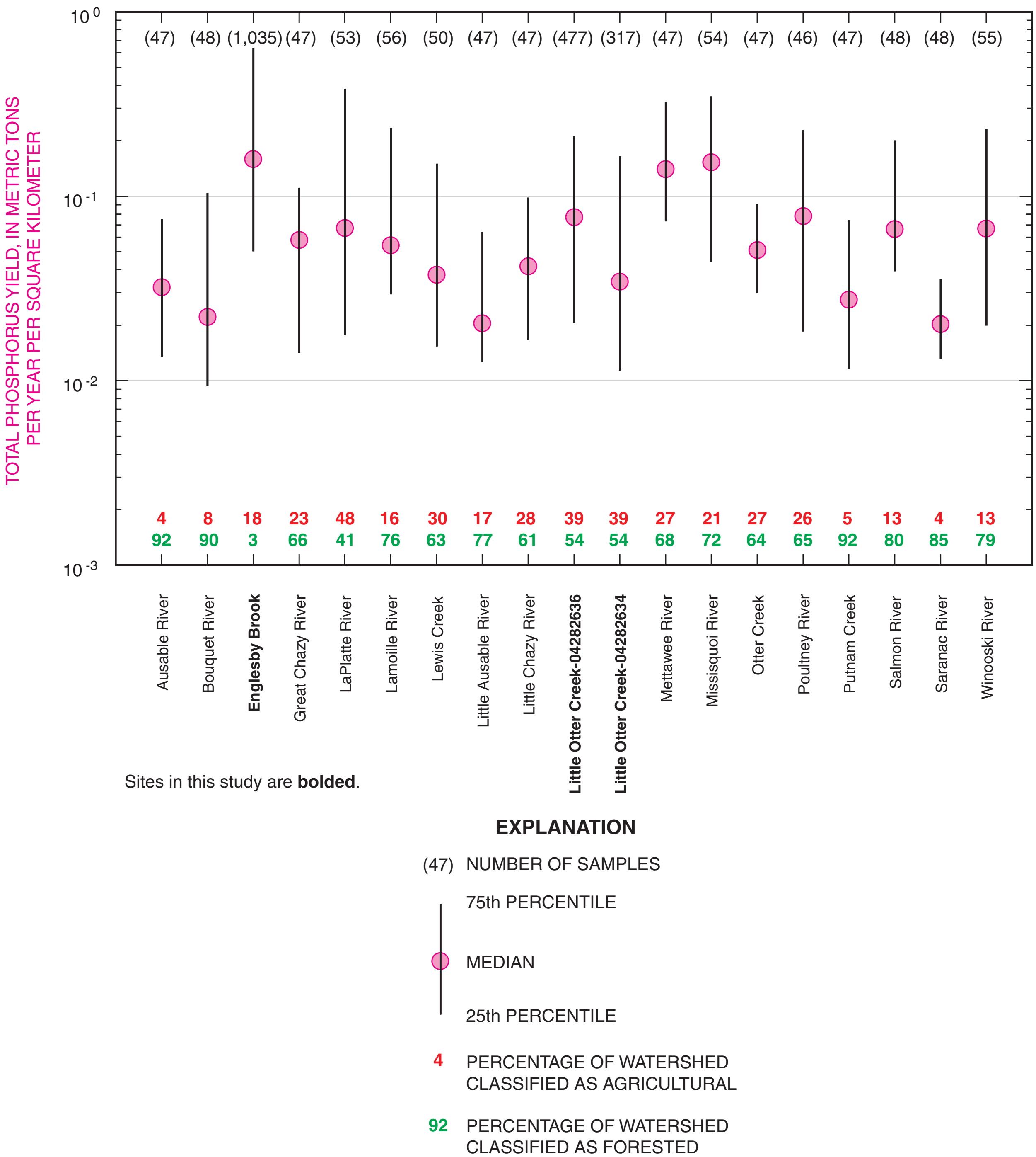

Figure 24. Quartiles and median yields of total phosphorus from major subbasins in the Lake Champlain Basin (excluding the Pike River subbasin in Canada), Vermont and New York, water years 2002–2004. [Concentration data for rivers other than Englesby Brook and Little Otter Creek 04282636 and 04282634 are from Vermont Department of Environmental Conservation, 2006; refer to text for other citations]

Summary and Conclusions

The U.S. Geological Survey (USGS), in cooperation with the Vermont Department of Environmental Conservation, the City of Burlington, and the Lake Champlain Basin Program, collected data from 2000 to 2005 on concentrations and loads of nutrients and suspended sediment in two watersheds in northern Vermont to investigate the effectiveness of best-management practices (BMPs) in improving water quality in tributaries to Lake Champlain. The selected watersheds have predominantly different land uses—Englesby Brook in Burlington, is an urban watershed, and Little Otter Creek in Ferrisburg, is an agricultural watershed. Data on nitrogen, phosphorus, and suspended sediment were collected for Englesby Brook; data on phosphorus and suspended sediment were collected for Little Otter Creek. During the monitoring period, a golf-course pond (one of three planned structural BMPs) was retrofitted with BMPs in the urban watershed, and a set of barnyard BMPs was installed at the agricultural site. Other planned BMPs in the agricultural watershed, including streambank fencing and nutrient management, were not implemented.

Base-flow concentrations at Englesby Brook from water years 2000 to 2005 ranged from 0.5 to 1.91 milligrams per liter (mg/L) for nitrogen; from 0.024 to 0.3 mg/L for phosphorus; and from 3 to 189 mg/L for suspended sediment. High-flow concentrations ranged from 0.4 to 3.43 mg/L for nitrogen; from 0.032 to 11.8 mg/L for phosphorus; and from 5 to 6,880 mg/L for suspended sediment. Annual loads of nitrogen at Englesby Brook ranged from 0.5 metric tons (t) in 2002 and 2003 to 1.3 t in 2004; loads of phosphorus ranged from 0.1 t in 2001, 2002, 2003, and 2005 to 0.3 t in 2004; and loads of suspended sediment ranged from 28 t in 2003 to 236 t in 2004.

Annual and monthly loads were estimated by using one of two USGS computer programs: Graphical Constituent Loads Analysis System (GCLAS)—the integration approach for when high-flow data coverage was dense, or Load Estimator (LOADEST)—the rating-curve approach for when high-flow data coverage was sparse or not available, and for other unsampled days such as during base-flow conditions. Annual load patterns of nitrogen, phosphorus and suspended sediment at Englesby Brook were almost identical to the annual streamflow pattern, with largest loads in 2004 and smallest loads in 2002. Wide error bars for the 2004 loads of phosphorus and suspended sediment were probably due to high variability in concentrations and hysteresis. Export from individual storms accounted for large percentages of annual export. Median nutrient yields at Englesby Brook were within ranges observed at other New England urban streams, although the spread of yields was greater at Englesby Brook.

Results indicated that construction of the golf-course pond BMP in the Englesby Brook watershed (1) did not reduce concentrations of phosphorus or suspended sediment during base flow or small storms, (2) reduced concentrations of phosphorus and suspended sediment during events with average streamflow greater than 3 cubic feet per second, (3) did not reduce loads of phosphorus or suspended sediment during storms, and (4) possibly reduced loads overall. Measurements of the water-quality parameters, made near the mouth of Englesby Brook, were an attempt to evaluate the effectiveness of the golf-course pond BMP that was constructed in the upper third of the watershed, with at least 1.7 kilometers of straight distance between the activity being evaluated and the measurement point. Because impairment of the Englesby Brook watershed and the stream corridor was generally along the entire breadth and length, construction of the golf-course pond BMP was expected to be the initial step in a more substantial suite of restoration work.

In the Little Otter Creek watershed, data were collected from two water-quality monitoring stations—one upstream from a 77-hectare dairy farm, and one downstream from the farm. At the upstream monitoring station, base-flow concentrations ranged from 0.016 to 0.141 mg/L for phosphorus and from 2 to 13 mg/L for suspended sediment. High-flow concentrations ranged from 0.019 to 0.565 mg/L for phosphorus and from 1 to 473 mg/L for suspended sediment. At the downstream monitoring station, base-flow concentrations ranged from 0.018 to 0.233 mg/L for phosphorus and from 10 to 132 mg/L for suspended sediment. High-flow concentrations ranged from 0.019 to 1.95 mg/L for phosphorus and from 8 to 1,190 mg/L for suspended sediment. Higher concentrations of phosphorus during base flow were observed at the downstream than at the upstream monitoring station. Base-flow concentrations of suspended sediment at the downstream monitoring station were more variable than the upstream monitoring station, with the highest and the lowest concentrations observed during the summer. For most storms, concentrations of phosphorus at the downstream monitoring station on Little Otter Creek were higher than concentrations at the upstream monitoring station, whereas concentrations of suspended sediment were similar for the two stations. Annual loads of phosphorus and suspended sediment, and streamflow were smallest in 2002 and largest in 2004. Concentrations and loads of phosphorus at Little Otter Creek were closely related to concentrations and loads of suspended sediment. Although individual events contributed large percentages to annual loads, the contributing percentages were larger at Englesby Brook than at Little Otter Creek.

An estimate of export attributable to the dairy farm on Little Otter Creek indicated that annual loads of phosphorus at the downstream monitoring station were always larger than loads at the upstream monitoring station and annual loads of suspended sediment at the downstream monitoring station were larger than loads at the upstream monitoring station for 4 out of 6 years. On a monthly basis, loads of phosphorus and suspended sediment at the downstream monitoring station were significantly larger than loads at the upstream monitoring station. For monthly loads averaged over 6 years, the loads of phosphorus and suspended sediment during April were much larger than during any other month, primarily because the estimated 2001 loads were based on the largest streamflow recorded during the study period.

The paired watershed study design was used to test changes in regression relations for paired data from the upstream monitoring station (independent covariate) and the downstream monitoring station (dependent covariate) between calibration (before BMP) and treatment (after BMP) periods. Results for phosphorus concentrations showed that the differences between the y-intercept and slope of the treatment period regression line were not significant compared to the y-intercept and slope of the calibration period. Results for monthly loads of phosphorus and suspended sediment showed that the only significant difference between the calibration and treatment periods was in y-intercept for monthly phosphorus loads, where the relation of loads between the downstream and upstream monitoring stations after treatment was less than the relation during the calibration period. This was the single promising outcome of the Little Otter Creek part of the study. It should be emphasized that construction of the set of barnyard BMPs was not expected, in the absence of the full suite of BMPs that was originally planned, to result in a perceptible reduction in concentrations or loads of phosphorus or suspended sediment to Little Otter Creek.

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