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Monitoring to Assess Progress toward Meeting the Total Maximum Daily Load for Phosphorus in the Assabet River, Massachusetts—Phosphorus Loads, 2008 through 2010

Scientific Investigations Report 2013–5140

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

Front cover. Bent oak tree in autumn, reflected by Assabet River waters.
Back cover. Green heron (top) and great blue heron (bottom).
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SALLY JEWELL, Secretary

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

U.S. Geological Survey, Reston, Virginia: 2013

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Conversion Factors, Datum, and Abbreviations

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	0.003785	cubic meter (m^3)
gallon	3,785	milliliter (mL)
gallon	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Mesh diameters of filters are measured in microns (μm).

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

$$°F=(1.8×°C)+32$$

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

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83), unless otherwise indicated.

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).

Abbreviations

EWI	equal-width increment
MassDEP	Massachusetts Department of Environmental Protection
orthoP	orthophosphorus
PP	particulate phosphorus
RPD	relative percent difference
TMDL	total maximum daily load
TP	total phosphorus
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WWTP	wastewater-treatment plant

Monitoring to Assess Progress toward Meeting the Total Maximum Daily Load for Phosphorus in the Assabet River, Massachusetts—Phosphorus Loads, 2008 through 2010

By Marc J. Zimmerman and Jennifer G. Savoie

Abstract

Wastewater discharges to the Assabet River contribute substantial amounts of phosphorus, which support accumulations of nuisance aquatic plants that are most evident in the river's impounded reaches during the growing season. To restore the Assabet River's water quality and aesthetics, the U.S. Environmental Protection Agency required the major wastewater-treatment plants in the drainage basin to reduce the amount of phosphorus discharged to the river by 2012. From October 2008 to December 2010, the U.S. Geological Survey, in cooperation with the Massachusetts Department of Environmental Protection and in support of the requirements of the Total Maximum Daily Load for Phosphorus, collected weekly flow-proportional, composite samples for analysis of concentrations of total phosphorus and orthophosphorus upstream and downstream from each of the Assabet River's two largest impoundments: Hudson and Ben Smith. The purpose of this monitoring effort was to evaluate conditions in the river before enhanced treatment-plant technologies had effected reductions in phosphorus loads, thereby defining baseline conditions for comparison with conditions following the mandated load reductions. The locations of sampling sites with respect to the impoundments enabled examination of the impoundments' effects on phosphorus sequestration and on the transformation of phosphorus between particulate and dissolved forms. The study evaluated the differences between loads upstream and downstream from the impoundments throughout the sampling period and compared differences during two seasonal periods of relevance to aquatic plants: April 1 through October 31, the growing season, and November 1 through March 31, the nongrowing season, when existing permit limits allowed average monthly wastewater-treatment-plant-effluent concentrations of 0.75 milligram per liter (growing season) or 1.0 milligram per liter (nongrowing season) for total phosphorus. At the four sampling sites during the growing season, median weekly total phosphorus loads ranged from 110 to 190 kilograms (kg) and median weekly orthophosphorus loads ranged from 17 to 41 kg. During the nongrowing season, median weekly total phosphorus loads ranged from 240 to 280 kg and median weekly orthophosphorus loads ranged from 56 to 66 kg.

During periods of low and moderate streamflow, estimated loads of total phosphorus upstream from the Hudson impoundment generally exceeded those downstream during the same sampling periods throughout the study; orthophosphorus loads downstream from the impoundment were typically larger than those upstream. When storm runoff substantially increased the streamflow, loads of total phosphorus and orthophosphorus both tended to be larger downstream than upstream.

At the Ben Smith impoundment, both total phosphorus and orthophosphorus loads were generally larger downstream than upstream during low and moderate streamflow, but the differences were not as pronounced as they were at the Hudson impoundment. High flows were also associated with substantially larger total phosphorus and orthophosphorus loads downstream than those entering the impoundment from upstream.

In comparing periods of growing- and nongrowing-season loads, the same patterns of loads entering and leaving were observed at both impoundments. That is, at the Hudson impoundment, total phosphorus loads entering the impoundment were greater than those leaving it, and orthophosphorus loads leaving the impoundment were greater than those entering it. At the Ben Smith impoundment, both total phosphorus and orthophosphorus loads leaving the impoundment were greater than those entering it. However, the loads were greater during the nongrowing seasons than during the growing seasons, and the net differences between upstream and downstream loads were about the same.

The results indicate that some of the particulate fraction of the total phosphorus loads is sequestered in the Hudson impoundment, where particulate phosphorus probably undergoes some physical and biogeochemical transformations to the dissolved form orthophosphorus. The orthophosphorus may be taken up by aquatic plants or transported out of the impoundments. The results for the Ben Smith impoundment are less clear and suggest net export of total phosphorus and orthophosphorus. Differences between results from the two impoundments may be attributable in part to differences in

their sizes, morphology, unmonitored tributaries, riparian land use, and processes within the impoundments that have not been quantified for this study.

Introduction

The Assabet River in central Massachusetts is valued for its scenery, recreational access, biological diversity, and history. In 1999, the U.S. Congress designated reaches of the river's approximately 33-mile (mi) length as a National Wild and Scenic River (National Park Service, 2006). Before reaching its confluence with the Sudbury River in the town of Concord (fig. 1), the river passes through nine towns. Along the way, nine dams affect the river's flow and morphology.

The Assabet River Basin lies in a rapidly developing area of Massachusetts where water and wastewater demands have long strained water resources (McAdow, 1990). In 1998, the Assabet River was included on the Massachusetts 303d list as an impaired river with respect to nutrients, organic enrichment, and low dissolved oxygen (Commonwealth of Massachusetts, 2004). In particular, eutrophication caused by excessive concentrations of phosphorus and nitrogen in the river has led to nuisance growth of aquatic plants. Municipal wastewater-treatment plant (WWTP) discharges in Westborough, Marlborough, and Hudson release nutrient-containing wastewater directly to the Assabet River in the study area. During low-flow periods, treated wastewater discharges may constitute 80 percent of the river's flow (Commonwealth of Massachusetts, 2004). Water-supply withdrawals and transfers further contribute to the degradation of the river's water quality (DeSimone, 2004).

In 2004, the U.S. Environmental Protection Agency (USEPA) approved the "Assabet River Total Maximum Daily Load for Total Phosphorus" (Commonwealth of Massachusetts, 2004), referred to herein as the TMDL. The TMDL required the WWTPs to upgrade their facilities so as to decrease the loads of total phosphorus (TP) in WWTP effluents. The new regulatory requirements would go into effect as the facility improvements were completed. All of the upgrades were finished in the summer of 2012, after the completion of this study's monitoring period.

Prior to the TMDL implementation, the Massachusetts Department of Environmental Protection (MassDEP) required WWTPs to limit effluent concentrations of phosphorus to a maximum monthly average of 0.75 milligram per liter (mg/L) from April through October, and 1.0 mg/L from November through March (Alice M. Rojko, Massachusetts Department of Environmental Protection, written commun., 2011). The 2004 TMDL set new requirements for the November through March season at a maximum monthly average TP concentration of 1.0 mg/L; the April through October average TP concentration limit was set at 0.1 mg/L. If, upon investigation following TMDL implementation, the MassDEP determines that the limits were inadequate, then the permit limit concentrations could be lowered further.

Previous Studies of Phosphorus in the Assabet River

ENSR International (2001) presented the results of field and laboratory studies that were used to develop the TMDL for TP. The study involved collecting hydrological, water-quality, and biological information; sediment cores were collected from the river and sent to a laboratory which estimated potential phosphorus fluxes experimentally. The data from that study were used in a water-quality modeling study (ENSR International, 2005). The latter report yielded the quantitative results providing the basis for the TMDL that was approved by the USEPA for TP in the Assabet River (Commonwealth of Massachusetts, 2004). CDM[1] (2007) assessed the options of dredging and dam removal in conjunction with enhanced treatment by the WWTPs for reducing internal phosphorus loading—the ability of a water body to retain and release phosphorus from the sediment. CDM's results indicated that implementation of WWTP upgrades, dam removal, and WWTP limits on winter phosphorus releases that were lower than initially planned would have the most beneficial effects on water quality. Zimmerman and Sorenson (2005) reported on weekly changes in phosphorus concentrations in the Hudson impoundment during the summer of 2004; nutrient-cycling dynamics in impoundments are complex, and this study could not confirm a net phosphorus flux from the sediments that might contribute to internal loading.

Zimmerman and others (2011) presented data on the distribution and biomass of the floating aquatic macrophyte, *Lemna minor* (duckweed) and on fluxes of sediment phosphorus in the Hudson and Ben Smith impoundments and free-flowing reaches of the Assabet River. Their study of biomass and sediment flux reported that impounded, slow-flowing reaches of the river were characterized by larger amounts of *Lemna* and potentially greater sediment fluxes of phosphorus than in free-flowing reaches. Highest rates of induced phosphorus flux from the sediments under in situ experimental conditions were usually associated with warm summer periods and low-oxygen (hypoxic) conditions in the impoundments.

Conceptual Model

The Assabet River passes through two shallow impoundments, Hudson and Ben Smith, on which this study focuses. These impoundments do not stratify thermally during the summer and do not have anoxic hypolimnia—conditions that, if they occurred, could lead to the release of dissolved phosphorus from the sediments and its transport downstream. However, hypoxic conditions are sometimes present in the water column during warm summer periods in relatively stagnant parts of the impoundments. The previous studies cited above serve as a basis for a narrative conceptual model of the processes affecting the loads of TP and orthophosphorus (orthoP)

[1]In 2011, CDM (Camp, Dresser & McKee) acquired Wilbur Smith Associates to form CDM Smith.

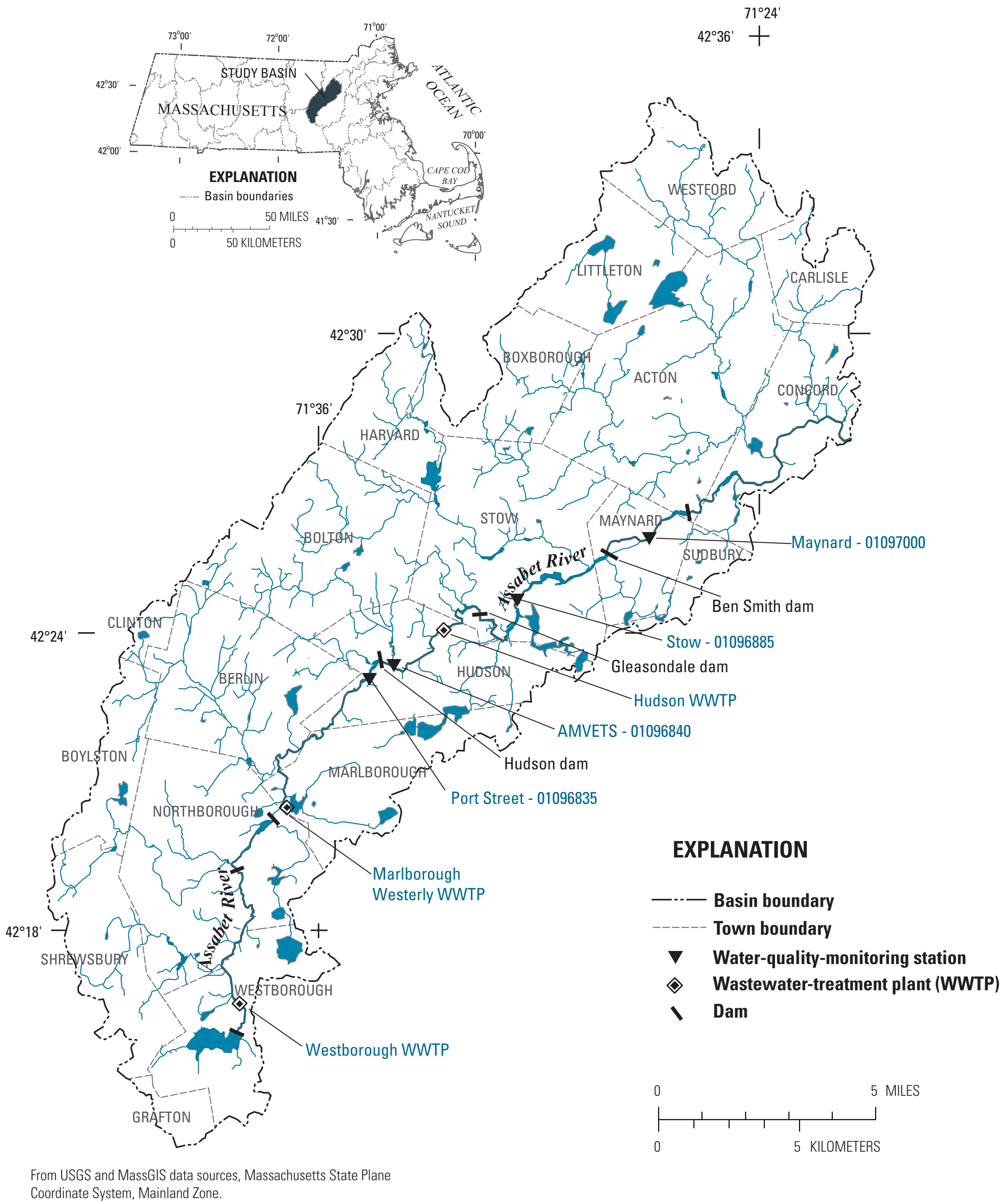

Figure 1. Locations of water-quality-monitoring stations, wastewater-treatment plants, and dams in the study area along the Assabet River Basin in central Massachusetts.

in the Assabet River study area which, in effect, runs from the Westborough WWTP to the U.S. Geological Survey (USGS) streamflow-monitoring station in Maynard.

Phosphorus occurs in dissolved, inorganic (orthoP) and particulate forms. Other phosphorus fractions in the form of dissolved organic phosphorus and dissolved inorganic phosphorus may occur as colloids; for example, in this study, any phosphorus fraction that passed through a 0.45-micron filter was considered part of the dissolved, orthoP fraction. OrthoP is readily available for uptake by aquatic plants that include the macrophytes and algae that may form nuisance growths in the study impoundments. The particulate form is subject to settling to the river bed at any point, including in the impoundments. After settling, particulate phosphorus (PP) may break down, releasing orthoP into the water column, which can then be transported downstream in the river, where it may be taken up by aquatic plants. The PP can also be resuspended by sufficiently high streamflow velocity. Thus, particulate and dissolved phosphorus may enter the impoundments and pass through, settle out, break down, or be absorbed. By observing the net differences between the loads of each of the various forms of phosphorus (TP, orthoP, and PP) that are monitored entering and leaving the impoundments, inferences can be drawn as to whether the impoundments sequester PP that may be converted, at least in part, to orthoP that can serve as a plant nutrient.

Purpose and Scope

In 2006, the USGS, in cooperation with the MassDEP, undertook studies to obtain baseline information needed to determine the eventual effectiveness of improvements in phosphorus removal by WWTPs in reducing phosphorus loads in the Assabet River. The study area of this report included about 22 mi (approximately two-thirds) of the river, starting at the WWTP in the town of Westborough, running through the towns of Northborough, Marlborough, Hudson, and Stow, and ending at the USGS streamgaging station in Maynard, Massachusetts (fig. 1). Although the Assabet River phosphorus TMDL applies to the entire length of the river, the study focused on the two largest impoundments, Hudson (in Hudson) and Ben Smith (in Stow and Maynard) that were created by old mill dams. The primary objectives of this study were to evaluate phosphorus loads in the Assabet River prior to implementation of WWTP phosphorus-removal improvements and during the seasonal periods (April through October and November through March) when permit limits at the WWTPs change and to consider the roles of the impoundments in the sequestration, transformation, and flux of phosphorus.

This report, the second of two describing conditions in the Assabet River prior to the implementation of the TMDL-mandated WWTP upgrades (see Zimmerman and others, 2011), presents the water-quality and streamflow data, estimated loads of phosphorus from treatment-plant effluent, and estimated loads of phosphorus downstream from the WWTPs. These baseline load estimates of loads will help determine the effectiveness of the treatment-plant upgrades in reducing phosphorus loads in the Assabet River.

Methods for Estimating Phosphorus Loads in the Assabet River

Typically, monitoring water quality for load estimation involves the collection of individual, equal-width-increment (EWI) samples on a fixed schedule—for example, quarterly, monthly, or weekly. Clearly, the more frequently water-quality samples are collected, the more likely the resulting data will represent the variability in stream concentrations that must be accurately characterized to estimate constituent loads. Robertson and Roerish (1999) found that, for 1-year studies, routine monthly sampling, supplemented by storm sampling, yielded the best results for estimating loads; for studies of 2 or more years, they found that semimonthly sampling was most effective, but they did not consider continuous, flow-proportional sampling. Because storms and other high-discharge events may carry substantial fractions of annual loads, collecting individual samples frequently following the storm hydrograph would be an obvious solution; however, frequent manual sampling could prove extremely expensive when the costs of sample collection and analysis are considered. Schleppi and others (2006) found that flow-proportional sampling gave more accurate and precise flux estimates than other methods. Streamflow-data collection at the time of water-quality sampling is essential for all approaches to constituent-load estimation.

Water-quality-samples that constitute the basis for this report were collected from October 2008 to December 2010 at four monitoring stations in the towns of Hudson (two sites), Stow, and Maynard (fig. 1). Field reconnaissance determined that these sampling stations were the best available locations for continuous monitoring of flows at sites bracketing the Hudson and Ben Smith impoundments. A major concern for the evaluation of the TMDL's effectiveness in controlling nutrient-induced eutrophication is the determination of the portion of the TP loads that may accumulate in the impoundments; PP retained in the impoundments may be transformed to a dissolved form that may become available to support undesirable (nuisance) aquatic-plant growth. This study used weekly flow-proportional, composite sampling as a cost-effective means to acquire data for estimating loads entering and leaving the impoundments.

Streamflow Measurements

Streamflow is calculated as the product of stream velocity and stream cross-section area and is typically measured in cubic feet per second. Because loads are estimated by multiplying constituent concentration by streamflow volume, accurate measurements of streamflow are essential. Hydrographers measure streamflow in the field by using a variety of techniques (Turnipseed and Sauer, 2010) and over a range of streamflow conditions. From these measurements, a rating curve is developed that relates streamflow to stage (elevation).

For this study, submersible pressure transducers were housed in protective tubing to monitor water levels, which were used to estimate flow based on a stage-discharge relation. Stream stage was measured nearly continuously (at 15-minute intervals) so that streamflow could be calculated from stage measurements on the many days when field measurements were not made. Outside-reference staff gages were installed for use in calibrating the continuous stage measurements.

To ensure accurate stage-discharge relations, streamflows at the four Assabet River sampling stations were measured routinely (every 6–8 weeks) either by wading or by acoustic Doppler technology (Turnipseed and Sauer, 2010). Rating-curve data were entered into the program stored in a datalogger housed in each monitoring shelter. Each datalogger was linked to the pressure transducer, which provided nearly continuous stage readings and calculated streamflow. Data stored in the datalogger were transmitted to a database in the USGS office in Northborough, Mass., and were subsequently used to compute the daily mean streamflow used in load estimation.

Monitoring Sites

Weekly flow-proportional composite samples were collected by automated sampling equipment installed in four monitoring shelters along the Assabet River: (1) Assabet River at Port Street at Hudson, Mass. (short name “Port Street”); (2) Assabet River 200 feet (ft) below Rte. 85 at Hudson, Mass. (short name “AMVETS”); (3) Assabet River at Sudbury Rd. near Stow, Mass. (short name “Stow”); and (4) Assabet River at Maynard, Mass. (short name “Maynard”) (fig. 1; table 1; appendix 1). The Port Street and AMVETS sites are located upstream and downstream, respectively, from the Hudson impoundment (fig. 2), and the Stow and Maynard sites are located upstream and downstream, respectively, from the Ben Smith impoundment (fig. 3). A third impoundment, Gleasondale, into which the Hudson WWTP discharges, is located between the AMVETS and Stow monitoring sites, but it is not a subject of this study. The impoundments are located several miles downstream from the largest WWTP (in Westborough, fig. 1). The Hudson and Ben Smith impoundments are approximately 6 mi apart (table 2).

Three of the shelters that contain the monitoring and sampling equipment were new 4-ft by 6-ft by 10-ft plywood sheds, and the fourth (at Maynard) was a long-term concrete streamgaging station (fig. 4); all were heated. Automated samplers (fig. 5) drew in water-quality samples through ½-inch (in.) copper sample tubing, which was protected by a 2-in. heavy-duty plastic pipe extending from each shelter to the center of flow in the river. The copper tubing was wrapped with electrical heating tape to prevent water from freezing in the tubing during the winter. The intake was fitted with a plastic strainer to prevent debris from clogging the sample tubing.

Automated Sample Collection

Composite, flow-proportional samples were collected with a portable automatic sampler outfitted with a four-bottle rack and controlled by a datalogger. The weekly composite target was 32 subsamples (the approximate number of 100-milliliter (mL) samples that the sample bottle could hold). Every week, the average daily streamflow for the upcoming week was estimated; the estimate was used to calculate a threshold volume that would trigger the automated sampler. If the streamflow volumes were greater on some days than others, then samples were collected more frequently on the days with greater streamflows; this is what is meant by “flow-proportional sampling.”

Table 1. Location coordinates, drainage-basin areas, and annual mean daily streamflow for water-quality- and streamflow-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, water years 2008 to 2010.

[Locations of monitoring stations are shown in figures 1 to 3. Latitude and longitude are given in degrees (°), minutes (′), and seconds (″) relative to the North American Datum of 1983 (NAD 83), except for station number 01097000, whose coordinates are relative to NAD 27; USGS, U.S. Geological Survey; mi^2, square mile; ft^3/s, cubic foot per second; --, no data; ft, foot]

USGS station name	Short name	USGS station number	Latitude	Longitude	Drainage basin area (mi^2)	Annual mean daily streamflow (ft^3/s)		
						2008	2009	2010
Assabet River at Port Street at Hudson	Port Street	01096835	42°23′07″	71°34′40″	60.5	--	162	163
Assabet River 200 ft below Route 85 at Hudson	AMVETS	01096840	42°23′24″	71°34′11″	64.2	--	171	172
Assabet River at Sudbury Road near Stow	Stow	01096885	42°24′42″	71°30′29″	88.0	--	202	219
Assabet River at Maynard	Maynard	01097000	42°25′55″	71°27′01″	116	247	266	275

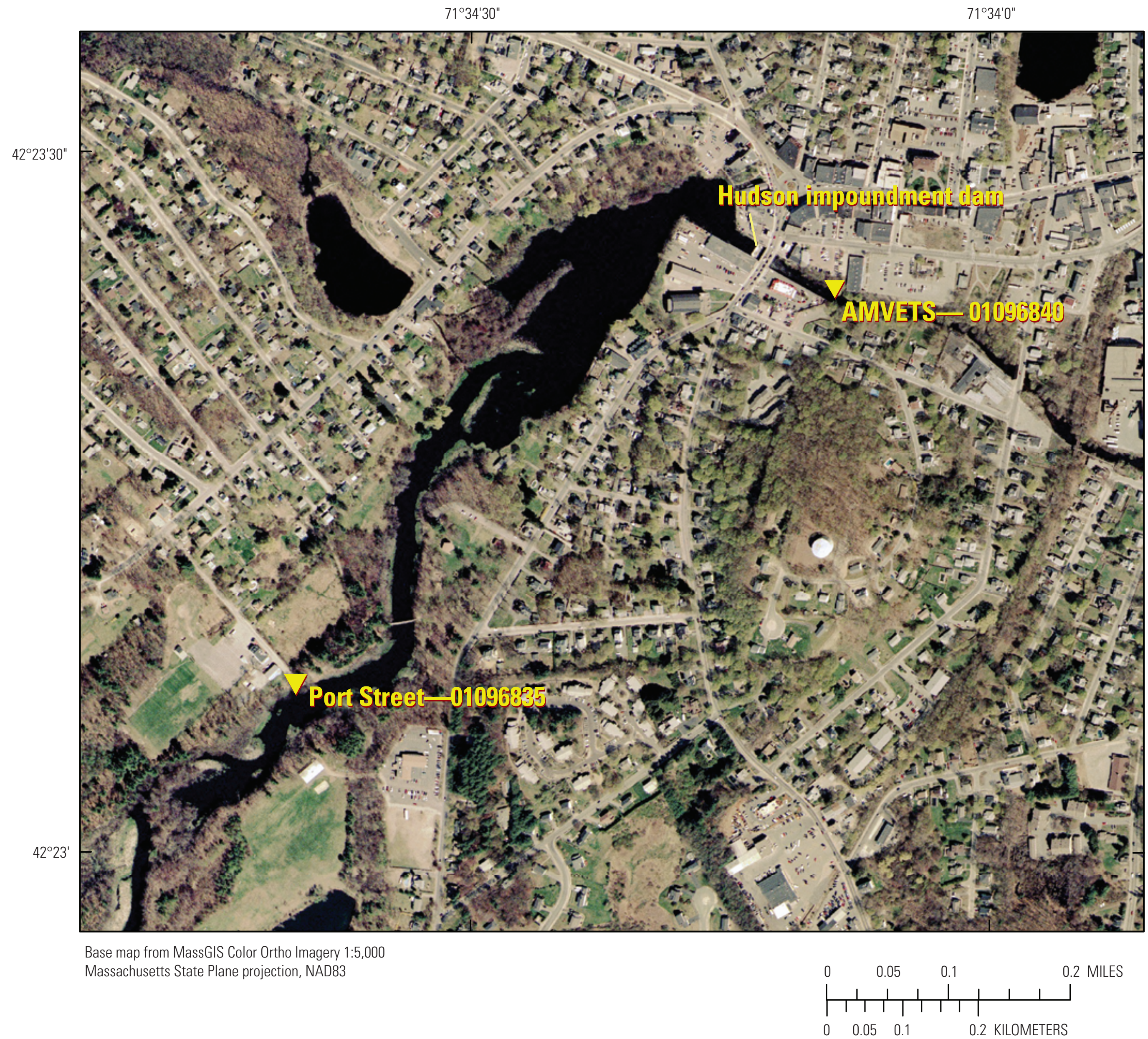

Figure 2. The locations of the U.S. Geological Survey water-quality-monitoring stations 01096835 (Port Street) and 01096840 (AMVETS) upstream and downstream from the Hudson impoundment.

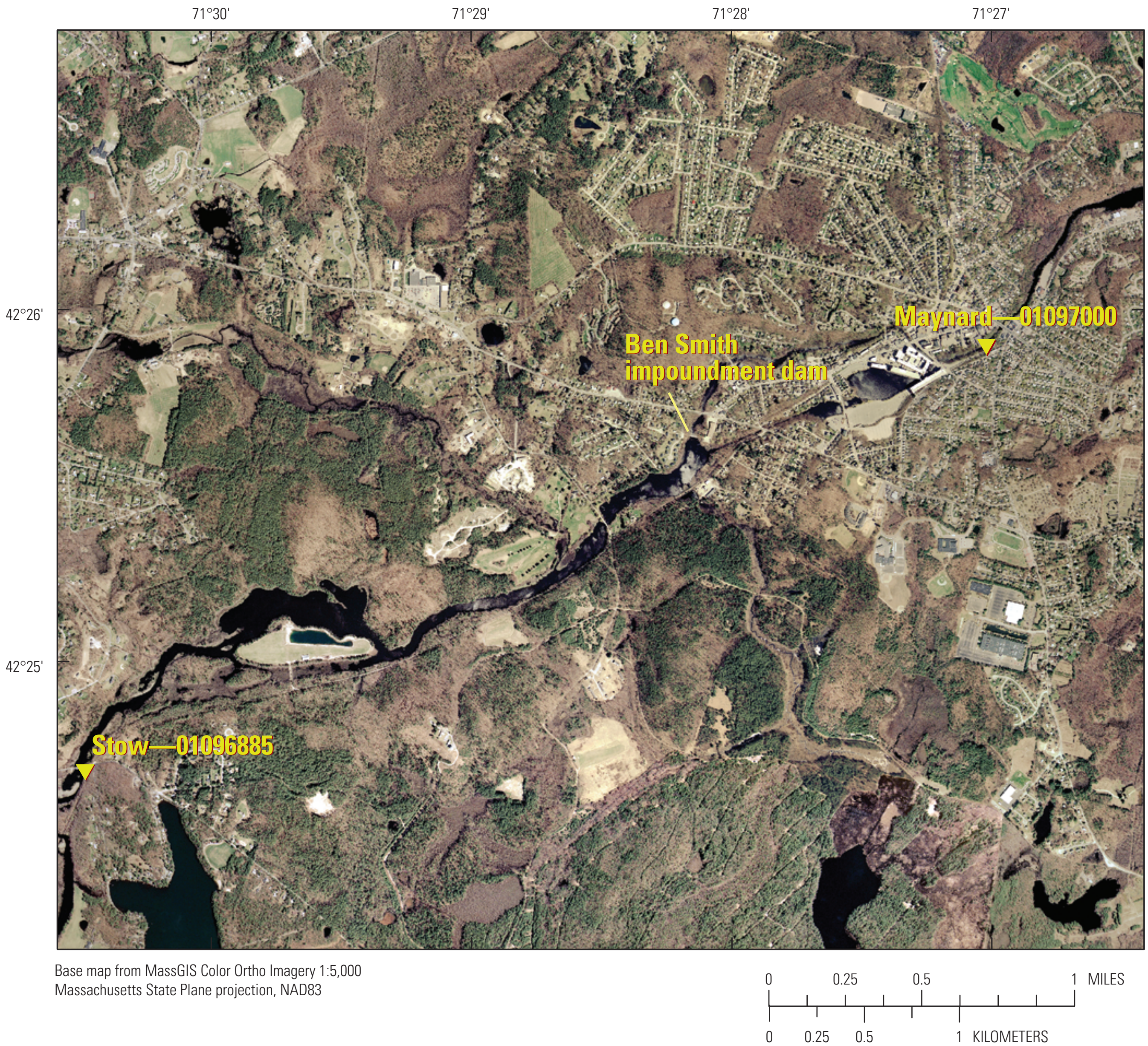

Figure 3. The locations of U.S. Geological Survey water-quality-monitoring stations 01096885 (Stow) and 01097000 (Maynard) upstream and downstream from the Ben Smith impoundment.

Table 2. Distances downstream from the Westborough wastewater-treatment plant (WWTP) to other WWTPs, impoundment dams, and water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts.

[Monitoring station and number, wastewater-treatment plants (WWTPs) and dams are shown in figure 1]

Location	Distance (miles)
Westborough WWTP	0
Marlborough-Westerly WWTP	6
Port Street - 01096835	11.1
Hudson dam	11.8
AMVETS - 01096840	11.9
Hudson WWTP	14.1
Gleasondale dam	15.6
Stow - 01096885	18
Ben Smith dam	30.6
Maynard - 01097000	31.9

When the threshold was exceeded, a signal was transmitted to the automated sampler, causing it to purge the suction line and collect two 100-mL aliquots of water. The first aliquot, the TP sample, was pumped into a 3.8-liter (L) polyethylene bottle previously acidified with 10 mL of sulfuric acid. The second aliquot, the orthoP sample, was pumped into a second bottle, which was modified so that the water sample could be completely pumped into a refrigerator by a peristaltic pump. Inside the refrigerator, the tubing connected to an inline polysulfone capsule filter (Pall AquaPrep 4270) with a pore size of 0.45 micron, polyester reinforcement, and an effective filtration area of 20 square centimeters (cm^2). After passing through the filter, the sample entered a 9-L polyethylene storage bottle.

In the event that the week's streamflow was underestimated, and more than 32 TP samples were needed, a second 3.8-L acidified bottle collected any additional TP samples. The 9-L storage bottle had ample excess capacity for additional orthoP samples. If the total weekly streamflow was overestimated, fewer than 32 TP and orthoP samples were collected, but the sample numbers were nevertheless collected proportionally to flow.

Grab-Sample Collection

Based on cross-sectional conductance data and scientific judgment prior to the start of sampling, the sampling intake locations were regarded as representing well-mixed zones of the river. For quality control to confirm that the automated sampling system collected representative samples, outside grab samples were collected from bridges near the stations by using a weighted-bottle sampler at approximately the same time as an inside grab sample was collected by the automated sampler. The phosphorus concentrations in the outside grab samples that were collected manually from the river were compared with phosphorus concentrations in individual samples collected by the automated sampler.

Sample Processing and Chemical Analysis

Samples were processed at the USGS Massachusetts-Rhode Island Water Science Center laboratory in Northborough, Mass. The weekly composite samples were retrieved from the shelters every 7 days. Sample bottles were replaced with clean ones, and new filters were installed at each site. In addition to collecting samples, USGS personnel recorded measurements of river stage, battery voltage, streamflow, and refrigerator temperature. The collection bottle for TP, preacidified with 10 mL of sulfuric acid, usually needed additional acid to preserve the sample to a pH less than 2. The volume of additional acid was calculated based on the weight of the sample. Samples were chilled and stored prior to shipping to the USGS National Water Quality Laboratory for analysis (Fishman, M.J., 1993; U.S. Environmental Protection Agency, 1993).

Water-Quality Data

Weekly flow-proportional composite samples collected in 2008 to 2010 from four monitoring stations along the Assabet River were analyzed for TP and orthoP (table 3, in back of report). Occasional equipment failures—for example, power failures and frozen and disconnected sample tubing—led to missing data. The WWTPs provided additional phosphorus data for treated effluent discharged to the Assabet River.

In addition to the environmental phosphorus samples collected from the stream by the automated sampler, blanks, grab samples, replicate (split-composite) samples, and EWI samples were collected. Phosphorus and orthoP were not detected in the blanks. Concurrent grab samples were collected 25 times, replicates were collected for about 10 percent of the total number of environmental samples, and blanks were collected 7 times (table 4, in back of report). Concentrations of phosphorus in grab samples collected manually from the river correlated well with concentrations in grab samples collected by the automated sampler. Relative percent differences[2] (RPD) for the grab samples averaged about 6.6 percent for TP and 3.8 percent for orthoP, with medians of 2.7 and 3.0 percent, respectively. EWI samples were collected concurrently with inside grab samples (see appendix 2, part A); the average RPD

[2]Relative percent difference is the absolute difference between two numbers divided by the average of the two numbers and multiplied by 100 percent. Measurement-performance criteria for TP and orthoP were RPDs less than 20 percent.

Figure 4. Water-quality-monitoring stations along the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts.

values for TP and orthoP samples were 8.2 and 5.6 percent, respectively. These quality-control-sampling results indicated that the automated samplers were collecting representative samples from these well-mixed sections of the river. RPDs for the replicate samples averaged about 1.6 percent for TP and 5.1 percent for orthoP, with medians of 1.1 and 0.0 percent, respectively. These replicate quality-control data demonstrated that sample processing yielded consistent results.

In a test to determine whether one week's holding time led to adsorption of phosphorus to the sides of the sampling containers, acidified and filtered samples collected at each monitoring station were retained in their containers for an additional week after initial processing for analysis. At the end of the week, a second set of samples was collected for analysis. Decreasing concentrations would indicate that the containers adsorbed some phosphorus. Concentrations increased slightly during the week for all but one sample (see appendix 2, part B). The maximum RPD was about 10 percent, and the minimum was about 1 percent.

The value of composite-sample concentrations is in their use in load-estimate calculations. Weekly TP loads (table 5, in back of report) were calculated at the four stations by multiplying the composite sample concentrations (table 3, in back of report) by the total weekly flow derived from mean daily streamflows (appendix 3). When loads were calculated, no attempts were made to estimate the weekly loads when water-quality data were missing or when sampling was incomplete because of equipment problems. Weekly TP loads during the study ranged from 16 to 950 kilograms (kg) at Port Street (median 220 kg), 17 to 1,100 kg at AMVETS (median

Figure 5. Equipment installed in water-quality-monitoring stations along the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts.

170 kg), 8.3 to 1,500 kg at Stow (median 214 kg), and 16 to 2,000 kg at Maynard (median 240 kg). OrthoP loads ranged from 2.5 to 170 kg at Port Street (median 25 kg), 2.1 to 270 kg at AMVETS (median 36 kg), 1.0 to 310 kg at Stow (median 44 kg), and 2.9 to 280 kg at Maynard (median 53 kg).

WWTP operators are required to provide basic information about their operations to the USEPA and the MassDEP. Of particular relevance to this study are the requirements to provide water-quality data. At least once a week, WWTP staffs analyze plant effluents for phosphorus and nitrogen. These data are tabulated monthly and, along with discharge volume and precipitation data, are reported to the USEPA and the MassDEP. The USGS obtained TP data either directly from individual WWTPs or from the MassDEP. Because the WWTPs do not provide daily phosphorus data, the loads for each week were estimates that used the average TP sample concentrations during the same one-week period as the USGS composite samples, regardless of the number of days on which concentrations were reported (generally, only once per week). This average concentration was multiplied by the reported total weekly effluent discharge volume to yield an estimated weekly load (table 6, in back of report). These data should be viewed with caution because a single WWTP phosphorus sample may not accurately represent the concentrations of weekly effluent discharges in the same manner that flow-proportional, composite samples represent the stream concentrations.

Phosphorus Concentrations and Loads

The USGS phosphorus-load estimates were based on the concentrations of total phosphorus and of orthoP analyzed from weekly, flow-proportional, composite samples. Loads were calculated by multiplying sample concentrations by the flow volume for the sampling week. The net effects of the impoundments on the phosphorus loads were determined by comparing the differences in loads upstream and downstream from each impoundment. The particulate component of TP can settle in the impoundments and elsewhere along the river; in situ, phosphorus can desorb from the sediments, and dissolved phosphorus can move downstream or be taken up by aquatic macrophytes and contribute to nuisance growth of plants that are associated with eutrophication.

Evaluating the analytically based estimates of TP loads alone can lead to misunderstandings or misinterpretations of the load estimates. TP loads and orthoP loads constitute the basic results presented in this report, and the TMDL primarily addresses TP loads. However, TP consists of PP and dissolved (orthoP) fractions, which have different properties, interactions, cycles, and pathways in the aquatic environment. Focusing on TP does not account for the varying proportions of these two components among samples. Thus, evaluating the particulate fraction may clarify the overall effects of the impoundments on the distribution and deposition of phosphorus loads. In this study, ratios of orthoP to TP were calculated for all weekly load estimates. Maxima for these ratios ranged between 0.30 and 0.39; the minima ranged from 0.04 to 0.09; medians ranged between 0.12 and 0.23; and means ranged between 0.14 and 0.22 (table 7). These ratios are based on sampling dates for which both orthoP and TP data were available. These results show that, on the average, about 80 percent of the estimated TP loads consisted of PP, and 20 percent was in the dissolved form; under some conditions, however, the ratios varied considerably.

Phosphorus Loads Upstream and Downstream from Impoundments

A simple means of comparison between loads upstream and downstream from each impoundment is subtraction. This report uses graphs of the loads and the differences between upstream and downstream loads at various times to enhance visualization of the study's results.

Hudson Impoundment

Estimated TP loads entering the Hudson impoundment near the Port Street sampling station frequently exceeded loads leaving the impoundment during sampling periods from 2008 to 2010 (fig. 6A). Subtracting the downstream loads from the upstream loads demonstrates that upstream loads exceeded downstream loads during most of the study's sampling periods (fig. 7A). The larger upstream loads are most apparent when loads were moderate (250 to 500 kg); fig. 6A). In association with short-lived streamflow peaks in December 2008, July 2009, and March 2010, the downstream loads exceeded upstream loads, with peak loads at the downstream AMVETS station in excess of 600 kg. During periods marked by low flows in September to October 2009 and July to September 2010, the upstream and downstream phosphorus loads were about equal and less than 200 kg.

Table 7. Summary statistics for the ratios of orthophosphorus concentrations to total phosphorus concentrations in weekly composite samples collected at the Port Street, AMVETS, Stow, and Maynard water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.

	Port Street 01096835	AMVETS 01096840	Stow 01096885	Maynard 01097000
Maximum	0.30	0.39	0.42	0.39
Minimum	0.04	0.07	0.04	0.09
Median	0.12	0.23	0.20	0.22
Mean	0.14	0.22	0.19	0.22

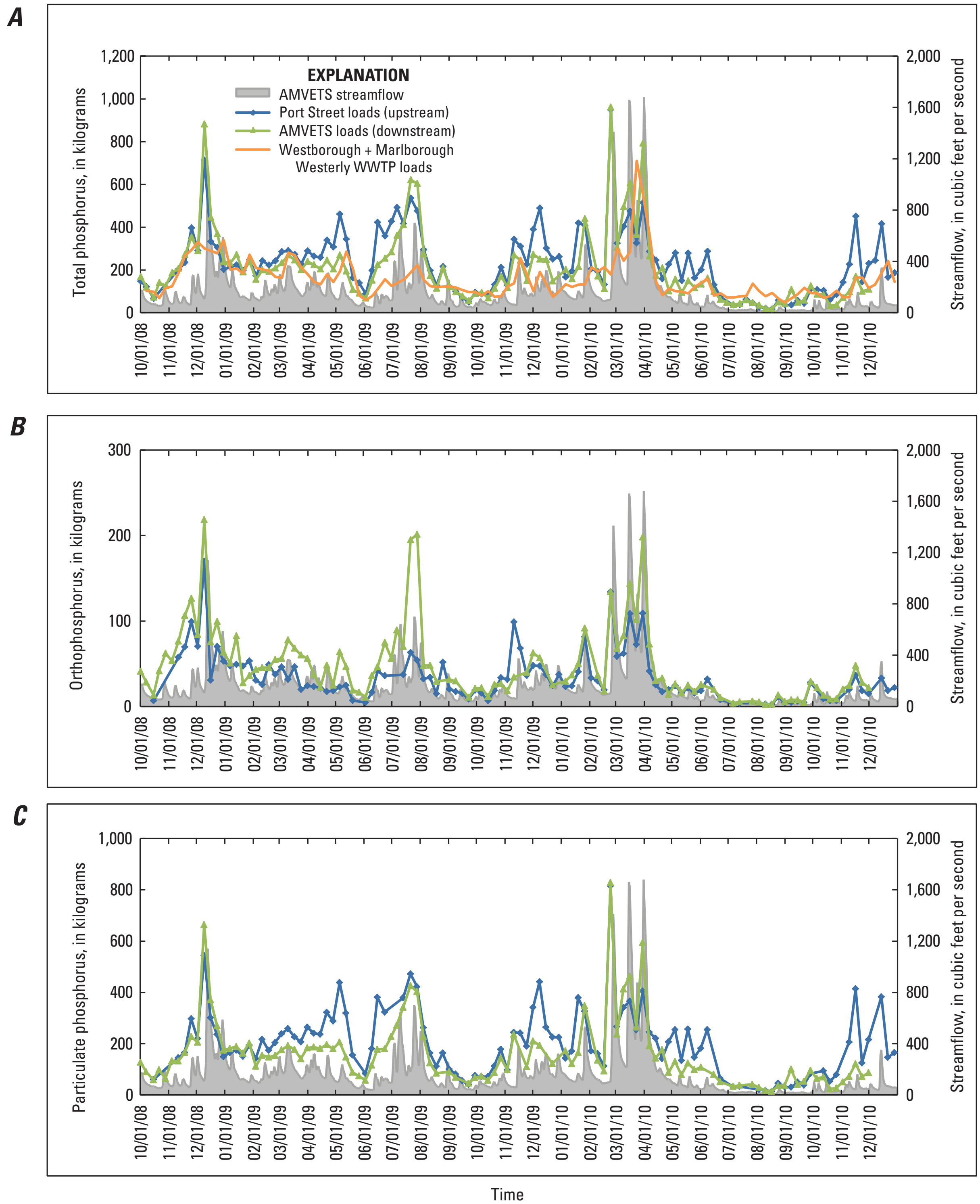

Figure 6. Streamflow and estimated weekly loads upstream and downstream from the Hudson impoundment of *A,* total phosphorus and the sum of total phosphorus loads from the upstream Westborough and Marlborough Westerly wastewater-treatment plants; *B,* orthophosphorus; and *C,* particulate phosphorus, October 2008 through December 2010.

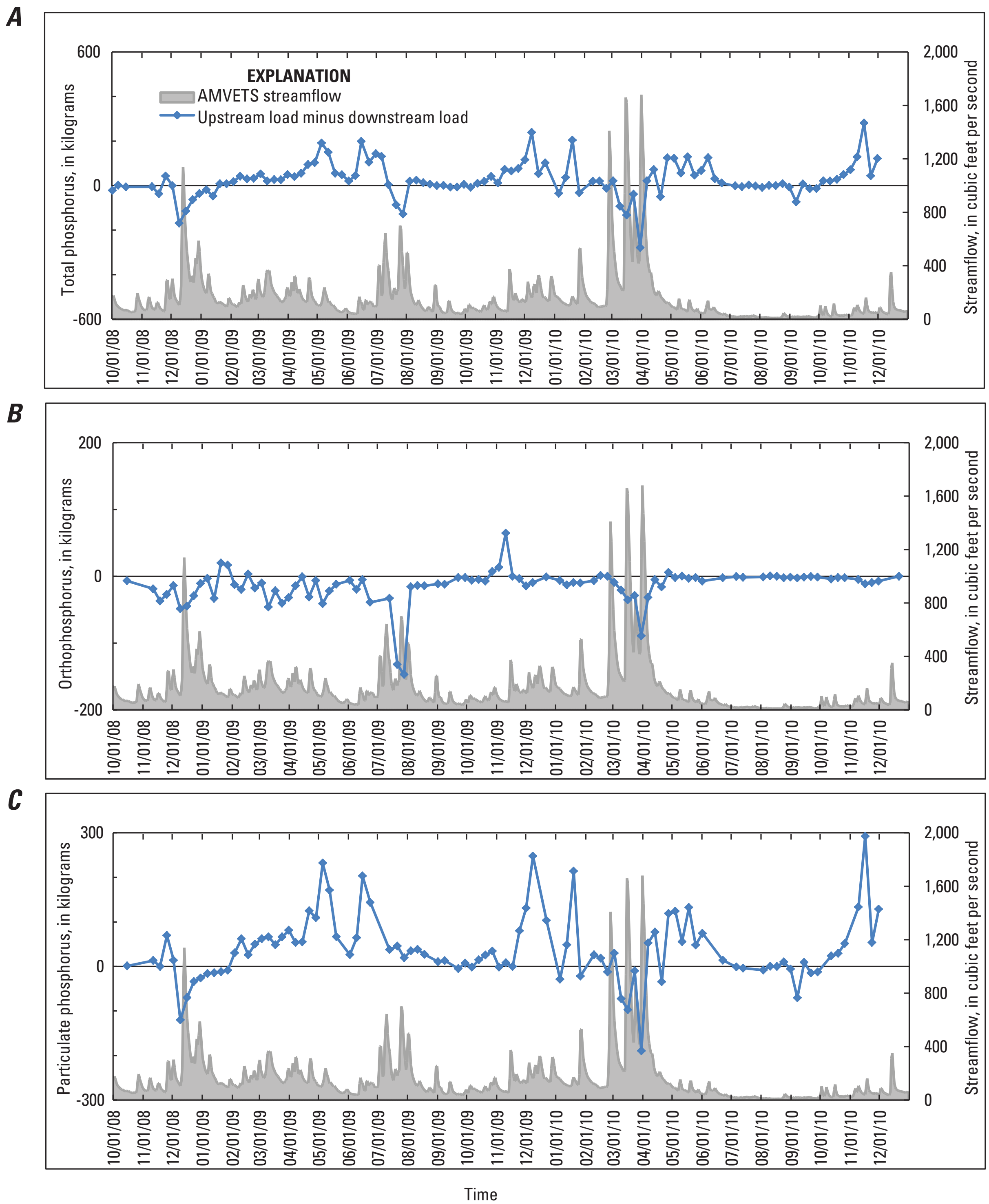

Figure 7. Streamflow and differences between estimated weekly loads of *A,* total phosphorus; *B,* orthophosphorus; and *C,* particulate phosphorus upstream and downstream (AMVETS monitoring site) from the Hudson impoundment October 2008 through December 2010.

The sums of the weekly estimated TP loads discharged by the upstream WWTPs in Westborough and Marlborough were about 250 to 300 kg in late 2008 through mid-2009 (fig. 6A; table 6, in back of report). During late 2009 through early 2010, TP loads decreased to less than 200 kg. From July through October 2010, the loads were less than 100 kg. Occasionally, spikes in the loads (notably, March and April 2010) substantially exceeded 300 kg. These spikes may be artifacts of the calculation method, which generally relied on a single concentration to represent an entire week (an unusually high concentration could lead to a substantial overestimation of a load), or they could reflect increased effluent discharge in association with a major storm. For example, in March 2010, the Westborough WWTP discharged atypically large volumes of effluent (more than 8 million gallons per day (Mgal/d)) during a period when more than 12 in. (30 centimeters (cm)) of precipitation resulted in the fifth-largest streamflow of record at Maynard (for the period of record, 1941 to present). In December 2010, the high load was associated with a relatively high concentration of TP (almost 4 mg/L) in the sample used to represent the load.

During the first half of the 2009 water year[3], wastewater loads equaled 50 to 100 percent of the estimated TP loads entering and leaving the Hudson impoundment (fig. 6A). During the summer of 2009, the wastewater loads remained the same, but their fraction of the total stream loads decreased substantially because the total stream loads increased in association with relatively high streamflows. During the winter and spring of 2010, the WWTP cumulative loads steadily increased before decreasing sharply following the high streamflows in March and April. The WWTP loads remained relatively small until they peaked again in late 2010 at approximately the same time that loads at Port Street were peaking.

Estimated orthoP loads at the Hudson impoundment sampling sites did not demonstrate the same dynamics as the TP loads. OrthoP loads at the upstream Port Street sampling station rarely exceeded those at the downstream AMVETS station (fig. 6B); the calculated differences in the loads further support that observation (fig. 7B). However, in a manner similar to that of TP loads under high-flow conditions associated with storms and substantial runoff, such as in the summer of 2009 and the spring of 2010, the orthoP loads at the downstream AMVETS station increased substantially relative to the loads at the upstream Port Street station (figs. 6B, 7B), indicating that orthoP had been transported downstream out of the impoundment during storms.

Results of the application of the Wilcoxon signed-rank test further support the interpretation that loads upstream and downstream from the Hudson impoundment were significantly different (p less than 0.001 for both TP and orthoP). Upstream loads of TP were most often larger than downstream loads, and downstream loads of orthoP were most often larger than upstream loads (figs. 7A, B).

[3]A water year is a continuous period from October 1 through September 30 and is designated by the year in which it ends.

Because TP is the sum of particulate and dissolved phosphorus fractions, further examination of this relation can clarify the effects of impoundments on stream phosphorus loads. Ratios of orthoP to TP varied considerably among samples, with the ratios for the AMVETS station almost always exceeding the ratios at the Port Street station (table 7). That is, orthoP generally represented a higher proportion of the TP load at the downstream AMVETs station than at the upstream Port Street station. Subtraction of the orthoP loads from the TP loads to obtain weekly PP loads shows that the differences between upstream and downstream TP loads resulted from PP sequestration in the Hudson impoundment (figs. 6C and 7C). That is, in a pattern similar to that of the TP loads, the PP loads at the upstream Port Street station generally exceeded the loads at the downstream AMVETS station (fig. 7C), indicating retention in the impoundment.

Ben Smith Impoundment

Estimated TP and orthoP loads at the Ben Smith impoundment did not show the same pronounced upstream versus downstream relations as demonstrated for the Hudson impoundment. Starting in July 2009, TP and orthoP loads were more often greater at the downstream (Maynard) sampling site than at the upstream (Stow) sampling site; the differences are rarely large (figs. 8A, B and 9A, B). From October 2008 until July 2009, TP loads were usually larger at Stow than at Maynard; however, after that period, the loads were either greater at Stow or approximately equal at the two stations. OrthoP loads at Stow also tended to be larger than those at Maynard from October 2008 through March 2009, with loads after that period either greater at Maynard or approximately equal at both stations. The greatest downstream loads were generally associated with high flows, as in the summer of 2009 and spring of 2010. In August and September 2010, the river stage and its associated flow in the Assabet River at Maynard were so low that the water level did not reach the sampling intake, and no samples were collected. In a pattern similar to that observed in the Hudson-impoundment load estimates, TP and orthoP loads at the corresponding upstream and downstream sampling stations were not greatly different when streamflow was low or moderate. Results of the application of the Wilcoxon signed-rank test indicate that the downstream loads at Maynard were significantly greater than those upstream (p less than 0.001 for TP and orthoP.)

In general, the estimated TP loads at the Stow and Maynard sampling sites closely tracked the estimated TP loads from upstream WWTPs during periods of low and moderate flow, such as summer 2010, when wastewater discharges frequently were in excess of 90 percent of the total streamflow entering the impoundment. During summer 2009, however, there was a disparity between the estimated loads at the sampling sites and the WWTP loads; the WWTP TP loads remained low, at about 200 kg, while the loads at Stow and Maynard increased substantially, reaching more than 1,000 kg during a period of increased streamflow. By contrast, in winter 2010, both estimated stream loads and WWTP TP loads increased with increasing streamflow.

Considering the differences in estimated upstream and downstream loads of PP at the Ben Smith impoundment further supports the interpretation associated with the TP loads. During most of the 2009 water year, estimated PP loads entering the Ben Smith impoundment at the Stow sampling station were usually greater than particulate loads downstream from the impoundment, indicating retention in the impoundment (figs. 8C and 9C). From July 2009 through December 2010, by contrast, estimated PP loads downstream were generally greater than or approximately equal to the loads upstream at the Stow sampling station. The flooding in March and April 2010 undoubtedly transported great amounts of suspended materials downstream and redistributed PP throughout the basin. These interpretations demonstrate why it is important to evaluate the loads of PP when considering the TP loads that are sequestered in the impoundment, where the phosphorus may remain, may be transformed to a dissolved form, and may be mobilized and transported downstream during extreme events, such as the floods in March and April 2010.

Seasonal Differences between Upstream and Downstream Loads, October 2008 through December 2010

From April 1 through October 31 in 2009 and 2010, the WWTPs' permit limits for TP were monthly average concentrations of 0.75 mg/L; the April 1 through October 31 period roughly corresponded to the growing season for aquatic plants. From November 1 through March 31 (the nongrowing season), when aquatic plant growth was minimal because of low temperatures and short daily photosynthesis periods, the permit limit for TP at the WWTPs was a monthly average concentration of 1.0 mg/L. Phosphorus loads at the WWTPs and at the sampling stations were compared for differences between the two seasons (median values for two years, table 8A). As expected, because of the seasonal differences in permit limits, study-period median and average estimated TP and orthoP loads at all treatment plants and at the sampling stations were larger during the nongrowing season than during the growing season. Maximum discharge-load values were larger at all WWTPs during the nongrowing season than during the growing season and, except for some orthoP loads, all minimum values were larger, too. With the exception of Maynard, the medians at the sampling stations were roughly 75 to 150 percent larger during the nongrowing season than during the growing season. At Maynard, median TP and orthoP loads were only about 42 and 54 percent larger, respectively, during the nongrowing season than during the growing season.

Summary statistics for seasonal PP loads do not reveal the same magnitudes of differences as for TP and orthoP loads (table 8B). During the nongrowing season, the median (2-year) difference between the PP weekly loads at the Port Street and AMVETS stations (Hudson impoundment) was 26 kg; during the growing season, the difference was 28 kg. The median differences between the PP weekly loads at Stow and Maynard (Ben Smith impoundment) during the nongrowing and growing seasons are -8 and -18 kg, respectively (negative values indicate that median downstream loads are greater than median upstream loads). Although these PP load estimates may not show substantial differences between the seasons at each impoundment, they still reflect previous observations that PP is sequestered in the Hudson impoundment, and that there are relatively small net losses of PP from the Ben Smith impoundment.

Understanding the Effects of Impoundments on Phosphorus Loads in the Assabet River, October 2008 through December 2010

The data interpretations presented here focus on the effects of the Hudson and Ben Smith impoundments on TP, orthoP, and PP loads in the Assabet River. The central questions are (1) "Do the impoundments sequester TP?" (2) "Do the forms of phosphorus change in the impoundments?" and (3) "Are there seasonal changes in the net effects of the impoundments on the proportions of particulate and orthoP in stream loads?"

Load estimates indicate that the phosphorus dynamics in the two impoundments differ. For the Hudson impoundment, TP loads entering the impoundment exceed the loads leaving it, and orthoP loads leaving the impoundment exceed the loads entering; in the Hudson impoundment, some of the PP is retained, and orthoP is produced. These differences are generally associated with moderate streamflow. The simplest interpretation for these observations is that PP deposited in the impoundment is subjected to physical and (or) biogeochemical processes that transform a fraction of the particulate matter into orthoP. The particulate fraction is likely to be quite heterogeneous with some of its constituents more or less labile (likely to change) than others; those (labile) constituents would be converted to orthoP at different rates. The internally produced orthoP is added to the inflowing orthoP, resulting in a net gain measured downstream from the impoundment. During the growing season, substantial amounts of orthoP may be recycled in the impoundments and either sequestered as living biomass or converted into PP. The magnitude of orthoP uptake, transformation, and release in the impoundments cannot be determined without a sampling program that would be substantially more complex (and expensive) than the existing one and would be designed to evaluate phosphorus cycling and impoundment hydrodynamics.

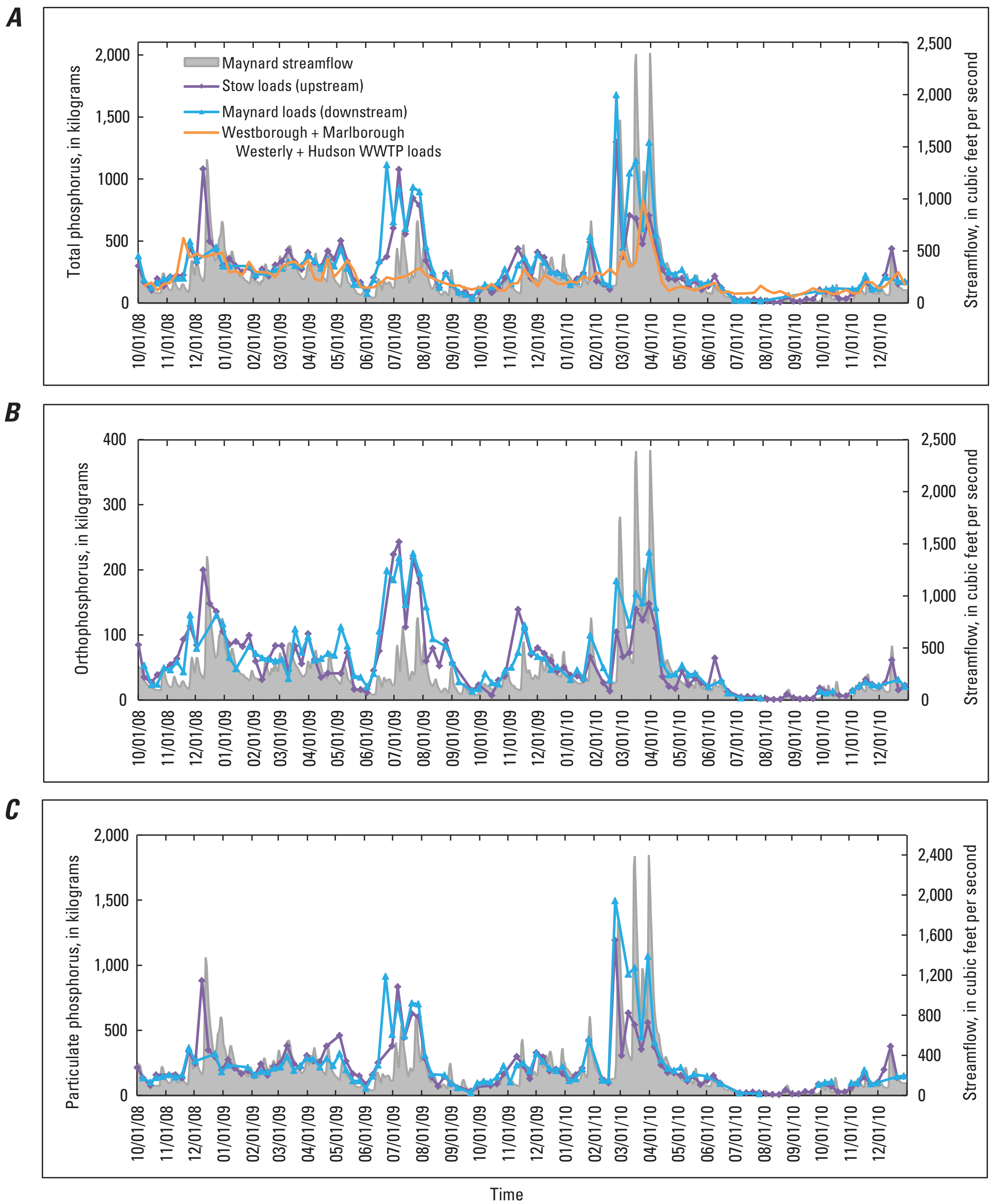

Figure 8. Streamflow and estimated weekly loads of *A,* total phosphorus and the sum of total phosphorus loads from the upstream Westborough, Marlborough Westerly, and Hudson wastewater-treatment plants; *B,* orthophosphorus; and *C,* particulate phosphorus upstream and downstream from the Ben Smith impoundment, October 2008 through December 2010.

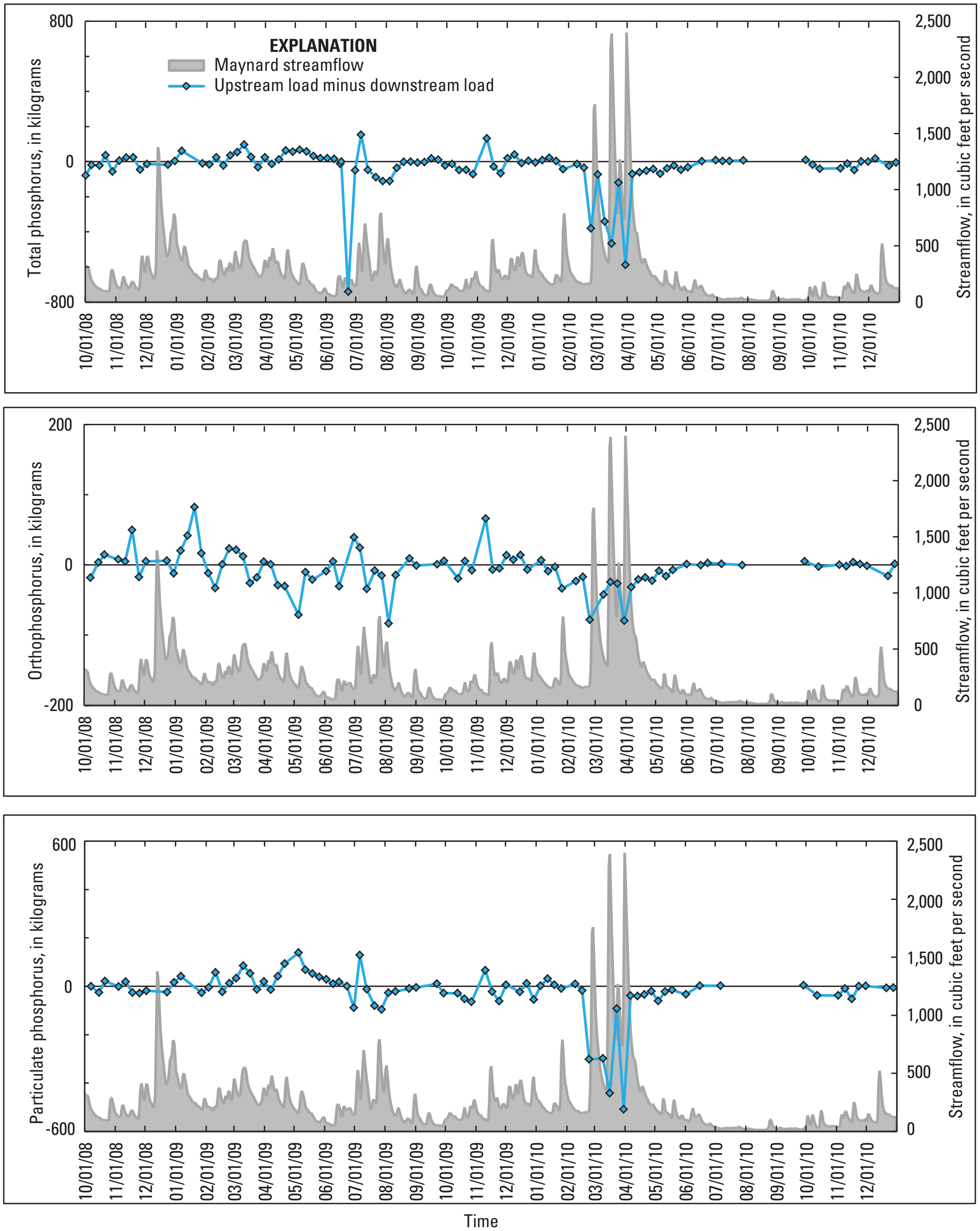

Figure 9. Streamflow and differences between estimated weekly loads of *A,* total phosphorus; *B,* orthophosphorus; and *C,* particulate phosphorus upstream and downstream from the Ben Smith impoundment, and streamflow, October 2008 through December 2010.

Table 8. *A,* Summary statistics for nongrowing-season and growing-season loads of total phosphorus and orthophosphorus, in kilograms, in wastewater-treatment-plant effluent and at water-quality-monitoring stations on the Assabet River, October 2008 through December 2010; and *B,* summary statistics for differences between particulate phosphorus loads at upstream and downstream water-quality-monitoring stations at the Hudson and Ben Smith impoundments on the Assabet River, October 2008 through December 2010.

[Locations of monitoring stations are shown in figures 1–3. All data are rounded to two significant figures. Values in part B were derived by using the differences in loads from individual weekly sampling periods. Negative values indicate that the downstream-load value was larger than the upstream-load value. WWTP, wastewater-treatment plant; TP, total phosphorus; OrthoP, orthophosphorus; --, no data]

A. Total phosphorus and orthophosphorus, in kilograms

	Westborough WWTP		Marlborough Westerly WWTP		Hudson WWTP		Port Street 01096835		AMVETS 01096840		Stow 01096885		Maynard 01097000	
	TP	OrthoP	TP	OrthoP	TP	OrthoP	TP	OrthoP	TP	OrthoP	TP	OrthoP	TP	OrthoP
Nongrowing season (November 1 through March 31)														
Maximum	500	360	530	160	260	57	960	220	1,300	200	1,400	250	1,700	230
Minimum	23	24	10	1.4	2.3	3.0	71	18	74	14	74	14	110	14
Median	98	87	50	23	44	16	240	56	280	66	280	66	270	63
Mean	120	95	78	39	49	19	280	66	340	72	340	73	360	73
Growing season (April 1 through October 31)														
Maximum	260	200	160	81	180	--	540	63	620	200	1,100	240	1,100	230
Minimum	6.9	28	7.9	1.8	1.9	--	16	2.5	17	2.1	8.3	1.0	16	2.9
Median	73	67	24	9.0	16	--	140	17	110	25	140	27	190	41
Mean	78	75	28	14	30	--	180	19	150	33	210	45	280	66

B. Particulate phosphorus

	Hudson impoundment	Ben Smith impoundment
Nongrowing season (November 1 through March 31)		
Maximum	290	85
Minimum	-190	-510
Median	26	-8.0
Mean	28	-40
Growing season (April 1 through October 31)		
Maximum	230	140
Minimum	-71	-96
Median	28	-18
Mean	45	-7

Under conditions associated with large increases in streamflow through the Hudson impoundment, there are marked net decreases of both PP and orthoP loads in the impoundments during sampling periods, probably as a result of scouring caused by the increased stream velocities: PP that may have settled in the impoundment is resuspended, and dissolved orthoP that may have accumulated in elevated concentrations in isolated parts of the impoundment is exported. More orthoP would likely be entrained from relatively stagnant areas of the impoundments under high flow conditions than under a normal flow regime.

Interpretation of the phosphorus dynamics is less clear for the Ben Smith impoundment than for the Hudson impoundment. TP and orthoP loads are usually larger downstream from the Ben Smith impoundment than upstream. In a manner similar to that observed in the Hudson impoundment, however, under high-flow conditions, both TP and orthoP loads downstream from the Ben Smith impoundment increase substantially over the upstream loads, indicating that storm-related streamflows play an important role in the distribution of riverine phosphorus loads, including the redistribution of loads previously retained in impoundments.

Differences in net loading patterns (retention versus loss) between the two impoundments may be explained, at least in part, by physical characteristics: (1) the Hudson impoundment has only one small tributary; (2) the Ben Smith impoundment has several tributaries; among them, the largest drains about 20 square miles (mi^2) and another drains about 4.6 mi^2; (3) retention times for the two impoundments would be expected to differ given their differences in size and morphology; and (4) the Assabet River downstream from the Ben Smith impoundment flows through the town of Maynard before reaching the downstream monitoring station. Runoff from the unmonitored tributaries and from downtown Maynard may transport nonpoint-source phosphorus loads into the river that contribute to the downstream increases in TP and orthoP loads determined from samples collected at the downstream monitoring station (Maynard).

A large proportion of the TP load in the river, roughly 80 percent, is in the form of PP. The PP may settle out of the water column to the river bed in free-flowing and impounded reaches. When stream velocities at the river bed in free-flowing reaches become fast enough, the particles may be resuspended and transported farther downstream. To mobilize or scour particulates in the deeper areas of the river, primarily in its impoundments, stream velocities there would also have to increase.

Although orthoP is not subject to settling, it may be absorbed by aquatic plants and thus removed from the water column. During the warm parts of the growing season, when conditions are optimal for growth and accumulation of floating macrophytes, substantial amounts of dissolved phosphorus may be rapidly recycled in the impoundments and either sequestered as living biomass or converted into PP. These warm periods may be characterized by extremely low streamflow dominated by WWTP discharges that may support large amounts nuisance-plant growth and accumulation. Without additional sampling, the magnitudes of orthoP uptake, transformation, and release in the impoundments and along the free-flowing reaches of the river can only be hypothesized.

Finally, for the two nongrowing seasons that were part of this study, seasonal changes in loadings from the WWTPs did not seem to affect the patterns of loads entering and leaving the two impoundments. During both of the nongrowing seasons, the loads of TP entering the Hudson impoundment were usually greater than the loads leaving it, and the orthoP loads leaving the impoundment were usually greater than those entering. At the Ben Smith impoundment, TP and orthoP loads leaving the impoundment were slightly greater than loads entering the impoundment during both the nongrowing and growing seasons. However, at both impoundments during the nongrowing seasons, the loads themselves are larger, especially the maximum loads, than in the growing season, but the net differences do not change very much between seasons.

Regarding the questions posed at the beginning of this section, it is likely that the impoundments do sequester phosphorus, but the size and complexity of the Ben Smith impoundment and its watershed in conjunction with multiple potential instances of settling and resuspension of PP make such an interpretation that impoundment difficult on the basis of existing data. Similarly, it is also likely that phosphorus forms change in the impoundments, as exemplified by the data from the Hudson impoundment. Seasonally, no net change in the patterns of sequestration or transformation could be determined for the two impoundments studied. These questions could be reevaluated after the effects of changes in phosphorus loadings associated with the upgraded WWTPs are monitored and interpreted. Implications of the findings from the current study point to the importance of the impoundments in affecting the transport, retention, and transformation of phosphorus loads in the Assabet River.

Summary

Although the Assabet River has, in part, been designated as a National Wild and Scenic River, the Massachusetts Department of Environmental Protection (MassDEP) has also assessed the Assabet River as having impaired water quality—an effect of excessive nutrient-containing effluents from municipal wastewater-treatment plants in the towns of Westborough, Marlborough, Hudson, and Maynard, Massachusetts. In 2004, the U.S. Environmental Protection Agency approved the “Assabet River Total Maximum Daily Load for Total Phosphorus” developed by the MassDEP, which required that the wastewater-treatment plants decrease the loads of phosphorus in their discharges to the river, and the Department set the limits for those phosphorus discharges.

To document baseline phosphorus loads prior to the implementation of the restrictions and to determine if impoundments affected the phosphorus concentrations and loads in the river, the U.S. Geological Survey, in cooperation with the MassDEP, measured streamflow and collected flow-proportional total phosphorus and orthophosphorus samples, composited for one-week periods, at four locations along the Assabet River in the towns of Hudson, Stow, and Maynard from October 2008 to December 2010. The sampling sites were located upstream and downstream from each of two impoundments, and the differences in total phosphorus and orthophosphorus loads upstream and downstream from each impoundment were assessed.

For most of the study period, the results for the comparatively small upstream impoundment (Hudson) indicated that median estimated weekly loads of total phosphorus entering the impoundment (220 kilograms (kg)) were larger than loads leaving it (170 kg); median weekly estimated orthophosphorus loads leaving the impoundment were larger (36 kg) than those entering it (25 kg). At the larger downstream impoundment (Ben Smith), the differences were not as substantial relative to those of the smaller Hudson impoundment, and median weekly total phosphorus and orthophosphorus loads leaving the impoundment (240 and 53 kg, respectively) usually were larger than those entering (214 and 44 kg, respectively). At both impoundments, under high flow conditions, total phosphorus and orthophosphorus loads leaving the impoundments were greater than upstream loads.

During nongrowing-season periods when limits on treatment-plant-discharge concentrations were higher than growing-season limits, median loads at the Hudson impoundment were roughly double those during growing-season periods, but the net differences in upstream and downstream loads did not change substantially between those seasons. At the Ben Smith impoundment, the median loads at the upstream Stow monitoring station during the nongrowing seasons were also double the median loads during growing seasons. At the downstream Maynard monitoring station, the differences in median total phosphorus and orthophosphorus loads between nongrowing and growing seasons were smaller, but nongrowing-season loads were still larger than growing-season loads for both total phosphorus and orthophosphorus.

The differences in loads upstream and downstream from the Hudson impoundment provided evidence that particulate phosphorus was sequestered in the impoundment during most of the sampling period. Dissolved orthophosphorus was produced in the impoundment by physical and (or) biogeochemical processes and, in combination with orthophosphorus transported into and out of the impoundment, created a net export of orthophosphorus from the impoundment. The small differences between inflowing and outflowing loads at the comparatively large downstream impoundment (Ben Smith) suggest that additional factors may have had effects on the observed load at that location. Such factors could include a possible longer retention time at the Ben Smith impoundment than at the Hudson impoundment, loads from unmonitored tributaries, and possible nonpoint sources of phosphorus in the town of Maynard, which is downstream from the impoundment and upstream from the monitoring station.

This project has provided baseline information on total phosphorus, orthophosphorus, and particulate phosphorus loads for comparison with future assessments of phosphorus loads in the Assabet River under new, lower concentration limits for total phosphorus. In addition, the study has demonstrated the value of using flow-proportional, composite monitoring in evaluating nutrient loads in rivers. Phosphorus dynamics within impoundments on the Assabet River, including the effects of complex physical, hydrologic, chemical, and biological factors, play an important—but variable—role in affecting the form, timing, and magnitude of phosphorus loads in the river.

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Tables 3–6

Table 3. Concentrations of total phosphorus and orthophosphorus in weekly composite samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.

[Locations of monitoring stations are shown in figures 1 to 3. mg/L, milligrams per liter; P, phosphorus; --, no data; E, estimated concentration at or less than method detection level; <, less than value shown]

Weekly start date	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)	Weekly start date	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
Port Street - 01096835			Port Street - 01096835—Continued		
10/01/08	0.077	--	07/21/09	0.085	0.010
10/07/08	0.086	--	07/28/09	0.088	0.010
10/15/08	0.080	E 0.008	08/04/09	0.110	0.012
11/11/08	0.134	0.038	08/11/09	0.104	0.018
11/18/08	0.189	0.056	08/18/09	0.102	0.012
11/25/08	0.116	0.029	08/25/09	0.104	0.025
12/02/08	0.099	0.024	09/01/09	0.084	0.014
12/09/08	0.084	0.020	09/08/09	0.079	0.014
12/16/08	0.054	E 0.005	09/15/09	0.070	0.015
12/23/08	0.048	0.011	09/22/09	0.069	0.012
12/30/08	0.042	0.011	09/29/09	0.074	0.015
01/06/09	0.054	0.012	10/06/09	0.067	0.012
01/13/09	0.100	0.022	10/13/09	0.070	E 0.006
01/20/09	0.105	0.025	10/20/09	0.085	0.012
01/27/09	0.121	0.026	10/27/09	0.101	0.016
02/03/09	0.101	0.018	11/03/09	0.110	0.027
02/10/09	0.085	0.009	11/10/09	0.194	0.056
02/17/09	0.082	0.018	11/17/09	0.109	0.024
02/24/09	0.071	0.011	11/24/09	0.100	0.016
03/03/09	0.080	0.013	12/01/09	0.122	0.015
03/10/09	0.064	E 0.007	12/08/09	0.134	0.013
03/17/09	0.100	0.017	12/15/09	0.081	0.010
03/24/09	0.092	E 0.008	12/22/09	0.083	E 0.008
03/31/09	0.084	0.007	12/29/09	0.077	0.011
04/07/09	0.068	E 0.006	01/05/10	0.079	0.011
04/14/09	0.108	0.009	01/12/10	0.106	0.013
04/21/09	0.098	E 0.005	01/19/10	0.176	0.017
04/28/09	0.167	0.010	01/26/10	0.070	0.014
05/05/09	0.163	E 0.008	02/02/10	0.086	0.014
05/12/09	0.182	0.013	02/09/10	0.109	0.017
05/19/09	0.162	E 0.007	02/16/10	0.082	0.012
05/26/09	0.140	--	02/23/10	0.085	0.012
06/02/09	0.135	E 0.007	03/02/10	0.050	0.009
06/09/09	0.156	0.013	03/09/10	0.052	0.008
06/15/09	0.205	0.020	03/16/10	0.035	0.008
06/23/09	0.190	0.019	03/23/10	0.036	0.008
06/30/09	0.155	--	03/30/10	0.033	E 0.007
07/06/09	0.088	--	04/06/10	0.053	E 0.008
07/13/09	0.101	0.009	04/13/10	0.077	E 0.008

Table 3. Concentrations of total phosphorus and orthophosphorus in weekly composite samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.—Continued

[Locations of monitoring stations are shown in figures 1 to 3. mg/L, milligrams per liter; P, phosphorus; --, no data; E, estimated concentration at or less than method detection level; <, less than value shown]

Weekly start date	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
Port Street - 01096835—Continued		
04/20/10	0.069	E 0.007
04/27/10	0.129	0.011
05/04/10	0.168	0.015
05/11/10	0.126	0.013
05/18/10	0.183	0.014
05/25/10	0.166	0.016
06/01/10	0.196	0.018
06/08/10	0.207	0.023
06/15/10	0.154	--
06/22/10	0.131	0.014
07/06/10	0.119	0.012
07/13/10	0.110	0.011
07/20/10	0.163	--
07/27/10	0.198	--
08/03/10	0.126	0.021
08/10/10	0.138	0.018
08/17/10	0.107	0.016
08/24/10	0.128	0.025
08/31/10	0.127	0.015
09/07/10	0.127	0.018
09/14/10	0.176	0.020
09/21/10	0.189	0.020
09/28/10	0.165	0.041
10/05/10	0.138	--
10/12/10	0.125	0.011
10/19/10	0.133	0.015
10/26/10	0.180	0.014
11/02/10	0.166	--
11/09/10	0.208	0.018
11/16/10	0.321	0.026
11/23/10	0.180	0.023
11/30/10	0.224	0.014
12/07/10	0.187	--
12/14/10	0.176	0.014
12/21/10	0.160	--
12/28/10	0.179	0.021
AMVETS - 01096840		
10/01/08	0.082	0.020
10/07/08	0.079	0.019

Weekly start date	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
AMVETS - 01096840—Continued		
10/15/08	0.081	0.015
10/21/08	0.091	0.027
10/28/08	0.071	0.021
11/04/08	0.098	0.028
11/11/08	0.131	0.048
11/18/08	0.171	0.067
11/25/08	0.098	0.035
12/02/08	0.093	0.027
12/09/08	0.105	0.026
12/16/08	0.065	0.011
12/23/08	0.052	0.014
12/30/08	0.045	0.012
01/06/09	0.055	0.012
01/13/09	0.115	0.035
01/20/09	0.097	0.014
01/27/09	0.112	0.017
02/03/09	0.086	0.024
02/10/09	0.066	0.015
02/17/09	0.068	0.016
02/24/09	0.057	0.015
03/03/09	0.062	0.015
03/10/09	0.052	0.015
03/17/09	0.083	0.023
03/24/09	0.077	0.023
03/31/09	0.064	0.015
04/07/09	0.054	0.009
04/14/09	0.082	0.009
04/21/09	0.066	0.013
04/28/09	0.107	0.013
05/05/09	0.089	0.021
05/12/09	0.100	0.024
05/19/09	0.096	0.017
05/26/09	0.082	0.015
06/02/09	0.089	0.014
06/09/09	0.114	0.027
06/15/09	0.121	0.025
06/23/09	0.129	0.038
06/30/09	0.142	0.028
07/06/09	0.109	0.027

Table 3. Concentrations of total phosphorus and orthophosphorus in weekly composite samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010. —Continued

[Locations of monitoring stations are shown in figures 1 to 3. mg/L, milligrams per liter; P, phosphorus; --, no data; E, estimated concentration at or less than method detection level; <, less than value shown]

Weekly start date	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
AMVETS - 01096840—Continued		
07/13/09	0.094	0.016
07/21/09	0.086	0.027
07/28/09	0.096	0.032
08/04/09	0.098	0.017
08/11/09	0.090	0.025
08/18/09	0.090	0.023
08/25/09	0.095	--
09/01/09	0.081	0.021
09/08/09	0.076	0.023
09/15/09	0.076	--
09/22/09	0.075	0.014
09/29/09	0.067	0.016
10/06/09	0.070	0.016
10/13/09	0.059	0.010
10/20/09	0.070	0.016
10/27/09	0.077	0.012
11/03/09	0.096	0.015
11/10/09	0.142	0.018
11/17/09	0.082	--
11/24/09	0.064	0.017
12/01/09	0.083	0.019
12/08/09	0.066	0.015
12/15/09	0.063	--
12/22/09	0.047	0.008
01/05/10	0.089	0.013
01/12/10	0.082	0.019
01/19/10	0.086	0.020
01/26/10	0.072	0.015
02/09/10	0.094	0.020
02/16/10	0.068	0.011
02/23/10	0.086	0.012
03/02/10	0.045	0.010
03/09/10	0.054	0.009
03/16/10	0.038	0.009
03/23/10	0.036	0.010
03/30/10	0.044	0.011
04/06/10	0.043	0.012
04/13/10	0.052	0.009
04/20/10	0.085	0.013

Weekly start date	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
AMVETS - 01096840—Continued		
04/27/10	0.055	E 0.008
05/04/10	0.091	0.015
05/11/10	0.076	0.013
05/18/10	0.093	0.016
05/25/10	0.113	0.017
06/01/10	0.124	0.024
06/08/10	0.110	--
06/15/10	0.111	0.022
06/22/10	0.105	0.018
06/29/10	0.123	--
07/06/10	0.120	0.013
07/13/10	0.121	0.015
07/20/10	0.149	--
07/27/10	0.191	0.025
08/03/10	0.162	0.024
08/10/10	0.125	0.014
08/17/10	0.100	0.016
08/24/10	0.098	0.026
08/31/10	0.146	0.019
09/07/10	0.369	0.026
09/14/10	0.150	0.024
09/21/10	0.249	0.021
09/28/10	0.169	0.040
10/05/10	0.101	0.026
10/12/10	0.092	0.014
10/19/10	0.067	0.018
10/26/10	0.073	0.018
11/02/10	0.078	0.022
11/09/10	0.085	0.022
11/16/10	0.115	0.032
11/23/10	0.118	0.033
11/30/10	0.101	0.020
Stow - 01096885		
10/01/08	0.092	0.026
10/07/08	0.073	0.015
10/15/08	0.080	0.021
10/21/08	0.080	--
10/28/08	0.074	0.020
11/04/08	0.094	0.024

Table 3. Concentrations of total phosphorus and orthophosphorus in weekly composite samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.—Continued

[Locations of monitoring stations are shown in figures 1 to 3. mg/L, milligrams per liter; P, phosphorus; --, no data; E, estimated concentration at or less than method detection level; <, less than value shown]

Weekly start date	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
Stow - 01096885—Continued		
11/11/08	0.112	0.032
11/18/08	0.135	0.056
11/25/08	0.107	0.027
12/02/08	0.086	0.022
12/09/08	0.119	0.022
12/16/08	0.057	0.017
12/23/08	0.054	0.017
12/30/08	0.043	0.015
01/06/09	0.063	0.015
01/13/09	0.080	0.024
01/20/09	0.082	0.027
01/27/09	0.093	0.032
02/03/09	0.078	0.022
02/10/09	0.069	<0.008
02/17/09	0.062	0.018
02/24/09	0.066	0.018
03/03/09	0.068	0.017
03/10/09	0.066	E 0.007
03/17/09	0.087	0.022
03/24/09	0.083	0.017
03/31/09	0.084	0.021
04/07/09	0.063	0.012
04/14/09	0.093	0.011
04/21/09	0.092	0.009
04/28/09	0.149	--
05/05/09	0.147	0.012
05/12/09	0.153	0.033
05/19/09	0.132	0.012
05/26/09	0.125	0.012
06/02/09	0.114	0.014
06/09/09	0.130	0.029
06/15/09	0.156	0.036
06/23/09	0.176	--
06/30/09	0.186	0.069
07/06/09	0.142	0.032
07/13/09	0.114	0.023
07/21/09	0.109	0.028
07/28/09	0.118	0.027
08/04/09	0.115	0.020
08/11/09	0.106	0.038
08/18/09	0.092	0.039
08/25/09	0.099	0.038
09/01/09	0.076	0.030
09/08/09	0.059	--
09/15/09	0.067	--
09/22/09	0.059	0.018
09/29/09	0.054	0.014
10/06/09	0.074	--
10/13/09	0.058	E 0.005
10/20/09	0.063	0.016
10/27/09	0.076	0.014
11/10/09	0.126	0.040
11/17/09	0.084	0.027
11/24/09	0.074	0.026
12/01/09	0.107	E 0.021
12/08/09	0.082	0.016
12/15/09	0.057	0.014
12/22/09	0.067	0.012
12/29/09	0.048	0.011
01/05/10	0.053	0.013
01/12/10	0.079	0.015
01/19/10	0.085	0.011
01/26/10	0.067	0.009
02/02/10	0.060	0.014
02/09/10	0.075	0.013
02/16/10	0.064	0.008
02/23/10	0.099	0.008
03/02/10	0.045	0.008
03/09/10	0.068	E 0.007
03/16/10	0.039	0.008
03/23/10	0.035	0.009
03/30/10	0.043	0.009
04/06/10	0.054	0.012
04/13/10	0.056	E 0.007
04/20/10	0.058	E 0.006
04/27/10	0.079	E 0.007
05/04/10	0.093	0.021
05/11/10	0.074	0.013

Table 3. Concentrations of total phosphorus and orthophosphorus in weekly composite samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.—Continued

[Locations of monitoring stations are shown in figures 1 to 3. mg/L, milligrams per liter; P, phosphorus; --, no data; E, estimated concentration at or less than method detection level; <, less than value shown]

Weekly start date	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
Stow - 01096885—Continued		
05/18/10	0.082	0.015
05/25/10	0.070	0.017
06/01/10	0.097	0.015
06/08/10	0.117	0.035
06/15/10	0.105	0.025
06/22/10	--	0.016
06/29/10	0.070	--
07/06/10	0.068	0.013
07/13/10	0.063	0.012
07/20/10	0.062	0.009
07/27/10	0.086	0.009
08/03/10	0.068	E 0.006
08/10/10	0.050	E 0.006
08/17/10	0.043	E 0.007
08/24/10	0.059	0.010
08/31/10	0.041	0.010
09/07/10	0.045	E 0.005
09/14/10	0.089	< 0.008
09/21/10	0.109	0.009
09/28/10	0.113	0.020
10/05/10	0.083	--
10/12/10	0.074	0.010
10/19/10	0.054	0.011
10/26/10	0.057	0.011
11/02/10	0.064	0.013
11/09/10	0.066	0.012
11/16/10	0.086	0.016
11/23/10	0.087	0.019
11/30/10	0.074	0.013
12/07/10	0.112	0.013
12/14/10	0.105	0.015
12/21/10	0.098	0.010
12/28/10	0.105	0.014
Maynard - 01097000		
10/02/08	0.090	--
10/07/08	0.064	0.018
10/15/08	0.080	0.015
10/21/08	0.067	0.010
10/28/08	0.059	0.015
Maynard - 01097000—Continued		
11/04/08	0.071	0.016
11/11/08	0.078	0.023
11/18/08	0.088	0.019
11/25/08	0.091	0.024
12/02/08	0.065	0.015
12/23/08	0.045	0.013
12/30/08	0.033	0.013
01/06/09	0.041	0.009
01/13/09	--	0.010
01/27/09	0.076	0.021
02/03/09	0.067	0.021
02/10/09	0.050	0.013
02/17/09	0.050	0.013
02/24/09	0.045	0.010
03/03/09	0.045	0.010
03/10/09	0.040	E 0.004
03/17/09	0.058	E 0.021
03/24/09	0.070	0.017
03/31/09	0.063	0.016
04/07/09	0.050	0.009
04/14/09	0.066	0.015
04/21/09	0.060	0.012
04/28/09	0.091	0.021
05/05/09	0.093	0.024
05/12/09	0.091	0.027
05/19/09	0.084	0.021
05/26/09	0.088	0.021
06/02/09	0.070	0.019
06/09/09	0.102	0.022
06/15/09	0.109	0.034
06/23/09	0.358	0.064
06/30/09	0.138	0.039
07/06/09	0.110	0.026
07/13/09	0.107	0.026
07/21/09	0.112	0.027
07/28/09	0.115	0.025
08/04/09	0.114	0.036
08/11/09	0.096	0.035
08/18/09	0.078	--

Table 3. Concentrations of total phosphorus and orthophosphorus in weekly composite samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010. —Continued

[Locations of monitoring stations are shown in figures 1 to 3. mg/L, milligrams per liter; P, phosphorus; --, no data; E, estimated concentration at or less than method detection level; <, less than value shown]

Weekly start date	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
Maynard - 01097000—Continued		
08/25/09	0.090	0.031
09/01/09	0.065	0.025
09/08/09	0.056	0.018
09/15/09	0.049	--
09/22/09	0.043	0.016
09/29/09	0.058	0.009
10/06/09	0.066	0.018
10/13/09	0.069	0.014
10/20/09	0.060	0.009
10/27/09	0.073	0.012
11/03/09	0.070	0.023
11/10/09	0.109	0.026
11/17/09	0.070	0.022
11/24/09	0.071	0.020
12/01/09	0.076	0.013
12/08/09	0.056	0.011
12/15/09	0.044	0.008
12/22/09	0.052	0.011
12/29/09	0.041	--
01/05/10	0.042	0.009
01/12/10	0.060	0.016
01/19/10	0.063	0.009
01/26/10	0.059	0.011
02/09/10	0.057	0.017
02/16/10	0.052	0.011
02/23/10	0.110	0.012
03/02/10	0.039	--
03/09/10	0.082	0.009
03/16/10	0.049	E 0.007

Weekly start date	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
Maynard - 01097000—Continued		
03/23/10	0.036	0.009
03/30/10	0.057	0.010
04/06/10	0.049	0.013
04/13/10	0.051	0.009
04/20/10	0.052	0.008
04/27/10	0.065	0.011
05/04/10	0.081	0.016
05/11/10	0.065	0.015
05/18/10	0.065	0.013
05/25/10	0.077	--
06/01/10	0.091	0.011
06/15/10	0.080	0.019
06/22/10	--	0.011
06/29/10	0.046	--
07/06/10	0.052	E 0.008
07/13/10	0.048	--
07/27/10	0.045	<0.008
09/28/10	0.086	0.012
10/05/10	0.078	0.007
10/12/10	0.077	0.009
11/02/10	0.073	0.009
11/09/10	0.055	0.010
11/16/10	0.082	0.010
11/23/10	0.069	0.014
11/30/10	0.061	0.011
12/07/10	0.092	--
12/21/10	0.074	0.013
12/28/10	0.076	0.009

Table 4. Concentrations of total phosphorus and orthophosphorus in blank samples, point samples, and replicate samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.

[Locations of monitoring stations are shown in figures 1 to 3. Relative percent differences compare concentrations in automated grab samples with concentrations in corresponding manually collected grab samples and in split-replicate composite samples. Time is given as military (24-hour) time. Sample type: OGS, outside grab sample; IGS, inside grab sample; C, composite sample; R, replicate (split composite sample); mg/L, milligrams per liter; P, phosphorus; --, no data; <, less than value shown]

Date	Time	Sample type	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
11/04/08	1549	Blank	<0.008	--
01/06/09	1134	Blank	<0.008	<0.006
03/10/09	1139	Blank	<0.008	<0.008
06/15/09	1304	Blank	<0.008	<0.008
08/11/09	1349	Blank	<0.008	<0.008
03/02/10	1214	Blank	<0.008	--
06/15/10	1229	Blank	<0.008	<0.008
Port Street - 01096835				
10/01/08	930	IGS	0.083	0.046
10/01/08	940	OGS	0.078	0.041
Relative percent difference			6.2	11.5
10/15/08	1055	IGS	0.081	0.031
10/15/08	1100	OGS	0.083	0.034
Relative percent difference			2.4	9.2
11/26/08	1325	IGS	0.144	0.070
11/26/08	1335	OGS	0.143	0.069
Relative percent difference			0.7	1.4
12/09/08	1040	IGS	0.134	0.094
12/09/08	1050	OGS	0.140	0.102
Relative percent difference			4.4	8.2
03/31/09	1135	IGS	0.083	0.040
03/31/09	1145	OGS	0.085	0.044
Relative percent difference			2.4	9.5
04/28/09	1130	IGS	0.103	0.037
04/28/09	1140	OGS	0.087	0.040
Relative percent difference			16.8	7.8
11/11/08	1040	C	0.134	0.038
11/11/08	1041	R	0.133	0.038
Relative percent difference			0.7	0
12/09/08	1035	C	0.084	0.020
12/09/08	1036	R	0.085	0.020
Relative percent difference			1.2	0
Port Street - 01096835—Continued				
01/27/09	1030	C	0.121	0.026
01/27/09	1031	R	0.121	0.026
Relative percent difference			0	0
05/12/09	1055	C	0.182	0.013
05/12/09	1056	R	0.172	0.013
Relative percent difference			5.6	0
06/23/09	1145	C	0.190	0.019
06/23/09	1146	R	0.194	0.018
Relative percent difference			2.1	5.4
07/13/09	1505	C	0.101	0.009
07/13/09	1506	R	0.100	0.009
Relative percent difference			1.0	0
08/04/09	925	C	0.110	0.012
08/04/09	926	R	0.109	0.011
Relative percent difference			0.9	8.7
09/15/09	1020	C	0.070	0.015
09/15/09	1021	R	0.072	0.016
Relative percent difference			2.8	6.5
04/27/10	1045	C	0.129	0.011
04/27/10	1046	R	0.126	0.011
Relative percent difference			2.4	0
08/03/10	1130	C	0.126	0.021
08/03/10	1131	R	0.124	0.021
Relative percent difference			1.6	0
08/24/10	950	C	0.128	0.025
08/24/10	951	R	0.128	0.023
Relative percent difference			0	8.3
11/16/10	945	C	0.321	0.026
11/16/10	946	R	0.320	0.026
Relative percent difference			0.3	0

Table 4. Concentrations of total phosphorus and orthophosphorus in blank samples, point samples, and replicate samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.—Continued

[Locations of monitoring stations are shown in figures 1 to 3. Relative percent differences compare concentrations in automated grab samples with concentrations in corresponding manually collected grab samples and in split-replicate composite samples. Time is given as military (24-hour) time. Sample type: OGS, outside grab sample; IGS, inside grab sample; C, composite sample; R, replicate (split composite sample); mg/L, milligrams per liter; P, phosphorus; --, no data; <, less than value shown]

Date	Time	Sample type	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
AMVETS - 01096840				
10/01/08	1020	IGS	0.085	0.046
10/01/08	1010	OGS	0.095	0.049
Relative percent difference			11.1	6.3
10/15/08	1130	IGS	0.089	--
10/15/08	1120	OGS	0.096	0.036
Relative percent difference			7.6	--
11/04/08	1615	IGS	0.071	0.035
11/04/08	1610	OGS	0.071	0.037
Relative percent difference			0	5.6
11/04/08	1616	IGS-R	0.072	0.037
11/04/08	1611	OGS-R	0.072	0.036
Relative percent difference			0	2.7
11/26/08	1305	IGS	0.132	0.070
11/26/08	1255	OGS	0.143	0.069
Relative percent difference			8.0	1.4
03/31/09	1210	IGS	0.076	0.040
03/31/09	1200	OGS	0.077	0.042
Relative percent difference			1.3	4.9
04/28/09	1210	IGS	0.096	0.040
04/28/09	1200	OGS	0.092	0.040
Relative percent difference			4.3	0
10/07/08	1110	C	0.079	0.019
10/07/08	1111	R	0.078	0.018
Relative percent difference			1.3	5.4
10/21/08	1425	C	0.091	0.027
10/21/08	1426	R	0.090	0.026
Relative percent difference			1.1	3.8
11/18/08	1000	C	0.171	0.067
11/18/08	1001	R	0.170	0.068
Relative percent difference			0.6	1.5
AMVETS - 01096840—Continued				
12/23/08	1135	C	0.052	0.014
12/23/08	1136	R	0.053	0.014
Relative percent difference			1.9	0
03/17/09	1155	C	0.083	0.023
03/17/09	1156	R	0.083	0.023
Relative percent difference			0	0
05/26/09	1345	C	0.082	0.015
05/26/09	1346	R	0.082	0.014
Relative percent difference			0	6.9
07/06/09	1230	C	0.109	0.027
07/06/09	1231	R	0.108	0.029
Relative percent difference			0.9	7.1
08/11/09	1300	C	0.090	0.025
08/11/09	1301	R	0.090	0.025
Relative percent difference			0	0
07/13/10	1005	C	0.121	0.015
07/13/10	1006	R	0.126	0.016
Relative percent difference			4.0	6.5
10/12/10	1010	C	0.092	0.014
10/12/10	1011	R	0.093	0.014
Relative percent difference			1.1	0
10/26/10	1005	C	0.073	0.018
10/26/10	1006	R	0.073	0.018
Relative percent difference			0	0
Stow - 01096885				
10/01/08	1050	IGS	0.106	0.051
10/01/08	1053	OGS	0.107	0.053
Relative percent difference			0.9	3.8
10/15/08	1240	IGS	0.081	0.039
10/15/08	1245	OGS	0.081	0.037
Relative percent difference			0	5.3

Table 4. Concentrations of total phosphorus and orthophosphorus in blank samples, point samples, and replicate samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.—Continued

[Locations of monitoring stations are shown in figures 1 to 3. Relative percent differences compare concentrations in automated grab samples with concentrations in corresponding manually collected grab samples and in split-replicate composite samples. Time is given as military (24-hour) time. Sample type: OGS, outside grab sample; IGS, inside grab sample; C, composite sample; R, replicate (split composite sample); mg/L, milligrams per liter; P, phosphorus; --, no data; <, less than value shown]

Date	Time	Sample type	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
Stow - 01096885—Continued				
11/04/08	1530	IGS	0.074	0.037
11/04/08	1535	OGS	0.072	0.037
Relative percent difference			2.7	0
11/26/08	1110	IGS	0.148	0.063
11/26/08	1120	OGS	0.144	0.062
Relative percent difference			2.7	1.6
11/26/08	1111	IGS-R	0.142	0.062
11/26/08	1121	OGS-R	0.147	0.061
Relative percent difference			2.1	1.6
12/16/08	1115	IGS	0.070	0.026
12/16/08	1125	OGS	0.058	0.026
Relative percent difference			18.8	0
03/31/09	1235	IGS	0.088	0.032
03/31/09	1245	OGS	0.075	0.032
Relative percent difference			16.0	0
03/31/09	1236	IGS-R	0.073	0.032
03/31/09	1246	OGS-R	0.072	0.032
Relative percent difference			1.4	0
10/07/08	1140	C	0.073	0.015
10/07/08	1141	R	0.075	0.015
Relative percent difference			2.7	0
10/29/08	925	C	0.074	0.020
10/29/08	926	R	0.073	0.020
Relative percent difference			1.4	0
11/25/08	1340	C	0.107	0.027
11/25/08	1341	R	0.109	0.033
Relative percent difference			1.9	20.0
01/13/09	1410	C	0.080	0.024
01/13/09	1411	R	0.082	0.023
Relative percent difference			2.5	4.3
Stow - 01096885—Continued				
03/31/09	1230	C	0.084	0.021
03/31/09	1231	R	0.084	0.021
Relative percent difference			0	0
04/14/09	1120	C	0.093	0.011
04/14/09	1121	R	0.093	0.011
Relative percent difference			0	0
06/15/09	1400	C	0.156	0.036
06/15/09	1401	R	0.156	0.035
Relative percent difference			0	2.8
07/21/09	1140	C	0.109	0.028
07/21/09	1141	R	0.108	0.029
Relative percent difference			0.9	3.5
08/25/09	1135	C	0.099	0.038
08/25/09	1136	R	0.097	0.038
Relative percent difference			2.0	0
03/02/10	1305	C	0.045	0.008
03/02/10	1306	R	0.045	0.009
Relative percent difference			0	11.8
06/15/10	1200	C	0.105	0.025
06/15/10	1201	R	0.105	0.026
Relative percent difference			0	3.9
09/07/10	1135	C	0.045	E .005
09/07/10	1136	R	0.044	E .004
Relative percent difference			2.2	--
12/07/10	1005	C	0.112	0.013
12/07/10	1006	R	0.111	0.014
Relative percent difference			0.9	7.4
12/14/10	1100	C	0.105	0.015
12/14/10	1101	R	0.104	0.014
Relative percent difference			1.0	6.9

Table 4. Concentrations of total phosphorus and orthophosphorus in blank samples, point samples, and replicate samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.—Continued

[Locations of monitoring stations are shown in figures 1 to 3. Relative percent differences compare concentrations in automated grab samples with concentrations in corresponding manually collected grab samples and in split-replicate composite samples. Time is given as military (24-hour) time. Sample type: OGS, outside grab sample; IGS, inside grab sample; C, composite sample; R, replicate (split composite sample); mg/L, milligrams per liter; P, phosphorus; --, no data; <, less than value shown]

Date	Time	Sample type	Total phosphorus (mg/L)	Orthophosphorus (mg/L as P)
Maynard - 01097000				
10/01/08	1028	IGS	0.125	0.037
10/01/08	1035	OGS	0.087	0.038
Relative percent difference			35.8	2.7
10/15/08	1310	IGS	0.066	0.029
10/15/08	1315	OGS	0.074	0.029
Relative percent difference			11.4	0
11/04/08	1530	IGS	0.058	0.025
11/04/08	1435	OGS	0.057	0.025
Relative percent difference			1.7	0
11/26/08	1145	IGS	0.135	0.060
11/26/08	1155	OGS	0.141	0.062
Relative percent difference			4.3	3.3
03/31/09	1310	IGS	0.060	0.025
03/31/09	1320	OGS	0.059	0.024
Relative percent difference			1.7	4.1
05/12/09	1225	IGS	0.094	0.040
05/12/09	1235	OGS	0.096	0.039
Relative percent difference			2.1	2.5
10/15/08	1320	C	0.080	0.015
10/15/08	1311	R	0.082	0.015
Relative percent difference			2.5	0
11/04/08	1500	C	0.071	0.016
11/04/08	1501	R	0.072	0.015
Relative percent difference			1.4	6.5
12/02/08	1325	C	0.065	0.015
12/02/08	1326	R	0.064	0.015
Relative percent difference			1.6	0
Maynard - 01097000—Continued				
02/10/09	1335	C	0.050	0.013
02/10/09	1336	R	0.054	0.013
Relative percent difference			7.7	0
05/19/09	1230	C	0.084	0.021
05/19/09	1231	R	0.084	0.022
Relative percent difference			0	4.7
06/30/09	1315	C	0.138	0.039
06/30/09	1316	R	0.141	0.039
Relative percent difference			2.2	0
07/28/09	1210	C	0.115	0.025
07/28/09	1211	R	0.111	0.040
Relative percent difference			3.5	46.2
09/28/10	1130	C	0.086	0.012
09/28/10	1131	R	0.086	--
Relative percent difference			0	--
11/09/10	1110	C	0.055	0.010
11/09/10	1111	R	0.056	0.010
Relative percent difference			1.8	0
12/21/10	1110	C	0.074	0.013
12/21/10	1111	R	0.082	0.022
Relative percent difference			10.3	51.4

Table 5. Estimated weekly total phosphorus and orthophosphorus loads, in kilograms, and summary statistics based on weekly composite samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.

[Locations of monitoring stations are shown in figures 1 to 3; --, no data; summary statistics, rounded to two significant figures, are at the bottom of the table]

Weekly start date	Port Street - 01096835		AMVETS - 01096840		Stow - 01096885		Maynard - 01097000	
	Total phosphorus	Ortho-phosphorus	Total phosphorus	Ortho-phosphorus	Total phosphorus	Ortho-phosphorus	Total phosphorus	Ortho-phosphorus
10/1/2008	146	--	168[1]	41[1]	299[1]	85[1]	379[1]	--
10/7/2008	121[1]	--	119[1]	29[1]	170[1]	35[1]	189[1]	53[1]
10/15/2008	67[1]	7[1]	72[1]	13[1]	103[1]	27[1]	125[1]	23[1]
10/21/2008	--	--	140	42	197	39	161	24
10/28/2008	--	--	126	62	176	--	193	49
11/4/2008	--	--	187	53	212	54	206	46
11/11/2008	203	57	208	76	222	63	199	59
11/18/2008	234	69	272	106	224	93	200	43
11/25/2008	397	99	354	126	450	113	496	131
12/2/2008	290	70	290	84	329	84	343	79
12/9/2008	713	170	882[1]	218[1]	1,081[1]	200[1]	--	--
12/16/2008	332	31	447	76	496	148	--	--
12/23/2008	306	70	369	99	432	136	450	130
12/30/2008	202	53	238	64	301	105	297	117
1/6/2009	213	47	232	51	359	86	298	65
1/13/2009	224	49	271	83	300	90	--	48
1/20/2009	198	47	190	27	250	82	--	--
1/27/2009	247	53	239	36	288	99	299	83
2/3/2009	173	31	155	43	212	60	228	71
2/10/2009	242	26	200	45	273	32	249	65
2/17/2009	223	49	193	45	218	63	241	63
2/24/2009	241	37	209	55	306	83	270	60
3/3/2009	285	46	233	56	334	84	280	62
3/10/2009	290	32	270	78	426	45	329	33
3/17/2009	273	46	246	68	327	83	300	109
3/24/2009	227	20	201	60	271	56	303	74
3/31/2009	289	24	239	56	407	102	383	97
4/7/2009	264	23	224	37	326	62	340	61
4/14/2009	258	21	203	22	293	35	281	64
4/21/2009	339	17	245	48	420	41	357	71
4/28/2009	307	18	204	25	354	--	297	69
5/5/2009	461	23	270	64	502	41	434	112
5/12/2009	344	25	194	47	336	72	279	83
5/19/2009	163	7	108	19	182	17	150	38
5/26/2009	139	--	90	17	166	16	147	35
6/2/2009	88	5	68	11	95	12	76	21
6/9/2009	197[1]	16[1]	152[1]	36[1]	204[1]	45[1]	188[1]	41[1]
6/15/2009	422	41	224	46	327	75	339	106
6/23/2009	359	36	254	75	373	--	1,114	199
6/30/2009	427[1]	--	284[1]	56[1]	603[1]	224[1]	653[1]	184[1]
7/6/2009	492[1]	--	361[1]	89[1]	1,078	243	924	218
7/13/2009	416[1]	37[1]	412[1]	70[1]	556[1]	112[1]	603[1]	146[1]

Table 5. Estimated weekly total phosphorus and orthophosphorus loads, in kilograms, and summary statistics based on weekly composite samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.—Continued

[Locations of monitoring stations are shown in figures 1 to 3; --, no data; summary statistics, rounded to two significant figures, are at the bottom of the table]

Weekly start date	Port Street - 01096835		AMVETS - 01096840		Stow - 01096885		Maynard - 01097000	
	Total phosphorus	Ortho-phosphorus	Total phosphorus	Ortho-phosphorus	Total phosphorus	Ortho-phosphorus	Total phosphorus	Ortho-phosphorus
7/21/2009	535	63	621	195	845	217	934	225
7/28/2009	476	54	604	201	786	180	897	195
8/4/2009	295	32	276	48	342	60	453	143
8/11/2009	197	34	173	48	221	79	258	94
8/18/2009	127	15	114	29	124	52	126	--
8/25/2009	215	52	209	--	238	91	238	82
9/1/2009	121	20	122	32	145	57	151	58
9/8/2009	99	18	98	30	84	--	87	28
9/15/2009	71	15	78	--	87	--	68	--
9/22/2009	49	9	56	11	48	15	37	14
9/29/2009	95	19	89	21	90	23	113	17
10/6/2009	87	16	95	22	135	--	149	41
10/13/2009	78	7	68	12	82	7	131	27
10/20/2009	132	19	114	26	119	30	166	25
10/27/2009	212	34	171	27	201	37	273	45
11/3/2009	129	32	117	18	--	--	153	50
11/10/2009	343[1]	99[1]	270[1]	34[1]	438	139	306[1]	73[1]
11/17/2009	310	68	245	--	336	108	365	115
11/24/2009	226	36	150	40	199	70	265	75
12/1/2009	389	48	273	62	409	80	389	67
12/8/2009	489	47	250	57	367	72	326	64
12/15/2009	301	37	248	--	247	61	256	47
12/22/2009	250	24	148	25	245	44	240	51
12/29/2009	262	37	--	--	218	50	223	--
1/5/2010	167	23	202	29	155	38	146	31
1/12/2010	195	24	159	37	195	37	173	46
1/19/2010	419	41	215	50	240	31	237	34
1/26/2010	407	81	440	92	491	66	534	100
2/2/2010	205	33	--	--	176	41	--	--
2/9/2010	191	30	171	36	152	26	166	49
2/16/2010	132	19	112	18	111	14	146	31
2/23/2010	949	134	962[1]	134[1]	1,297[1]	105[1]	1,677[1]	183[1]
3/2/2010	325	59	304	68	373	66	446	--
3/9/2010	403	62	496	83	706	73	1,047	115
3/16/2010	474	108	607	144	679[1]	139[1]	1,146[1]	164[1]
3/23/2010	326	72	365	101	477	123	597	149
3/30/2010	514	109	793[1]	198[1]	706[1]	148[1]	1,294[1]	227[1]
4/6/2010	286	41	265	73	480	110	550	142
4/13/2010	246	25	174	30	270	36	331	57
4/20/2010	159	17	209	33	196	21	248	39
4/27/2010	226	20	102	14	190	18	232	40
5/4/2010	279	24	157	26	200	45	269	53

Table 5. Estimated weekly total phosphorus and orthophosphorus loads, in kilograms, and summary statistics based on weekly composite samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.—Continued

[Locations of monitoring stations are shown in figures 1 to 3; --, no data; summary statistics, rounded to two significant figures, are at the bottom of the table]

Weekly start date	Port Street - 01096835		AMVETS - 01096840		Stow - 01096885		Maynard - 01097000	
	Total phosphorus	Ortho-phosphorus	Total phosphorus	Ortho-phosphorus	Total phosphorus	Ortho-phosphorus	Total phosphorus	Ortho-phosphorus
5/11/2010	150	16	95	16	133	23	171	39
5/18/2010	279	22	149	25	180	34	203	41
5/25/2010	162	16	116	18	108	26	155	--
6/1/2010	200	18	133	26	136	22	168	21
6/8/2010	287	32	162	--	216	65	--	--
6/15/2010	130	--	100	20	123	29	121	29
6/22/2010	73	8	62	10	--	13	--	11
6/29/2010	--	--	47	--	34	--	26	--
7/6/2010	36	3	37	4	25	5	22	3
7/13/2010	37	4	43	5	27	5	23	--
7/20/2010	62	--	59	--	30	4	--	--
7/27/2010	45	--	47	6	24	3	16	3
8/3/2010	25	4	34	5	17	1	--	--
8/10/2010	20	3	20	2	9	1	--	--
8/17/2010	16	3	17	3	8	1	--	--
8/24/2010	57	11	49	13	51	9	--	--
8/31/2010	36	4	43	6	15	4	--	--
9/7/2010	35	5	109	8	14	1	--	--
9/14/2010	56	6	48	8	34	3	--	--
9/21/2010	43	5	58	5	28	2	--	--
9/28/2010	111	28	125	29	106	18	96	13
10/5/2010	107	--	86	22	93	--	110	11
10/12/2010	103	9	83	13	80	11	120	14
10/19/2010	60	7	32	9	33	7	--	--
10/26/2010	85	7	36	9	34	6	--	--
11/2/2010	142	--	71	20	74	15	112	14
11/9/2010	226	20	97	25	109	20	120	22
11/16/2010	451	37	170	48	173	31	222	27
11/23/2010	144	18	100	28	113	24	112	23
11/30/2010	230	15	109	22	120	21	120	22
12/7/2010	244	--	--	--	224	26	206	--
12/14/2010	416	33	--	--	439	61	--	--
12/21/2010	165	19	--	--	153	16	177	31
12/28/2010	187	22	--	--	167	22	171	21
Maximum	950	170	1,100	270	1,500	310	2,000	280
Minimum	20	2.5	17	2.1	8.3	1.0	16	2.9
Median	220	25	170	36	210	44	240	53
Mean	240	35	210	50	270	60	320	71

[1]Weekly composite is greater or less than 7 days; see appendix 2.

Table 6. Estimated weekly total phosphorus loads, in kilograms, in discharges from wastewater-treatment plants on the Assabet River in Westborough, Marlborough, and Hudson, Massachusetts, October 2008 through December 2010.

[Locations of monitoring stations are shown in figures 1 to 3. --, missing data, load not calculated; WWTP, wastewater-treatment plant]

Date	Total phosphorus loads, in kilograms				
	Westborough WWTP	Marlborough Westerly WWTP	Hudson WWTP	Sum of phosphorus loads from Westborough and Marlborough Westerly WWTP	Sum of all total phosphorus loads
10/07/08	89	13	39	102	141
10/15/08	66	31	68	98	165
10/21/08	46	22	35	68	103
10/28/08	97	18	38	115	153
11/04/08	91	32	40	123	163
11/11/08	112	75	56	188	244
11/18/08	118	149	257	267	524
11/25/08	137	156	74	294	368
12/02/08	135	194	68	330	398
12/09/08	95	206	71	300	371
12/16/08	--	265	31	--	--
12/23/08	108	169	118	278	395
12/30/08	160	179	67	339	405
01/06/09	87	116	46	203	248
01/13/09	101	105	51	206	258
01/20/09	86	96	43	182	225
01/27/09	162	108	61	271	332
02/03/09	98	111	44	209	253
02/10/09	--	101	48	--	--
02/17/09	84	112	48	196	244
02/24/09	75	93	41	168	209
03/03/09	85	77	133	163	295
03/10/09	188	93	41	281	322
03/17/09	156	113	66	269	335
03/24/09	117	95	76	212	288
03/31/09	133	47	165	180	345
04/07/09	100	43	52	143	195
04/14/09	103	30	44	132	177
04/21/09	147	32	179	179	358
04/28/09	105	38	67	143	211
05/05/09	162	31	80	193	273
05/12/09	260	25	58	286	344
05/19/09	183	24	55	207	261
05/26/09	57	24	48	81	128
06/02/09	38	21	65	59	124
06/09/09	38	40	50	77	127
06/15/09	89	26	45	115	161
06/23/09	138	18	52	156	208
06/30/09	102	23	68	125	194

Table 6. Estimated weekly total phosphorus loads, in kilograms, in discharges from wastewater-treatment plants on the Assabet River in Westborough, Marlborough, and Hudson, Massachusetts, October 2008 through December 2010.—Continued

[Locations of monitoring stations are shown in figures 1 to 3. --, missing data, load not calculated; WWTP, wastewater-treatment plant]

Date	Total phosphorus loads, in kilograms				
	Westborough WWTP	Marlborough Westerly WWTP	Hudson WWTP	Sum of phosphorus loads from Westborough and Marlborough Westerly WWTP	Sum of all total phosphorus loads
07/06/09	128	--	--	--	--
07/13/09	142	14	63	156	219
07/21/09	80	--	--	--	--
07/28/09	193	30	61	223	284
08/04/09	112	41	69	153	222
08/11/09	91	34	76	124	201
08/18/09	107	13	57	120	177
08/25/09	--	11	29	--	--
09/01/09	110	14	16	124	140
09/08/09	81	36	25	118	143
09/15/09	85	21	15	105	121
09/22/09	84	12	13	96	109
09/29/09	76	21	26	97	123
10/06/09	69	10	35	79	114
10/13/09	82	19	53	101	154
10/20/09	57	17	31	74	105
10/27/09	49	29	22	78	100
11/03/09	98	24	30	122	152
11/10/09	74	63	26	137	163
11/17/09	93	161	16	254	270
11/24/09	--	49	37	--	--
12/01/09	71	29	34	100	134
12/08/09	133	58	33	191	223
12/15/09	--	51	51	--	--
12/22/09	48	26	82	74	156
12/29/09	83	17	54	101	155
01/05/10	114	19	44	133	177
01/12/10	97	23	41	120	161
01/19/10	98	33	86	131	217
01/26/10	98	34	55	133	188
02/02/10	137	75	36	212	248
02/09/10	135	57	33	193	226
02/16/10	184	30	62	213	275
02/23/10	146	32	48	178	226
03/02/10	251	51	118	301	420
03/09/10	187	56	48	243	291
03/16/10	102	183	46	285	331
03/23/10	178	532	122	710	832
03/30/10	404	145	33	549	582

Table 6. Estimated weekly total phosphorus loads, in kilograms, in discharges from wastewater-treatment plants on the Assabet River in Westborough, Marlborough, and Hudson, Massachusetts, October 2008 through December 2010.—Continued

[Locations of monitoring stations are shown in figures 1 to 3. --, missing data, load not calculated; WWTP, wastewater-treatment plant]

Date	Total phosphorus loads, in kilograms				
	Westborough WWTP	Marlborough Westerly WWTP	Hudson WWTP	Sum of phosphorus loads from Westborough and Marlborough Westerly WWTP	Sum of all total phosphorus loads
04/06/10	174	165	27	338	365
04/13/10	--	36	16	--	--
04/20/10	70	54	16	124	140
04/27/10	43	41	9	83	93
05/04/10	67	42	31	109	140
05/11/10	85	18	19	104	123
05/18/10	56	51	12	107	119
05/25/10	48	29	4	76	80
06/01/10	--	26	7	--	--
06/08/10	11	20	4	31	35
06/15/10	29	30	3	59	62
06/22/10	--	15	3	--	--
06/29/10	7	13	4	20	24
07/06/10	17	8	5	24	30
07/13/10	27	16	4	43	46
07/20/10	15	12	5	27	32
07/27/10	20	45	3	65	68
08/03/10	21	59	2	80	82
08/10/10	44	9	4	54	57
08/17/10	14	9	4	23	27
08/24/10	9	10	5	19	24
08/31/10	11	11	4	22	25
09/07/10	--	12	3	--	--
09/14/10	31	12	3	43	47
09/21/10	20	25	3	45	48
09/28/10	51	29	4	80	84
10/05/10	40	12	4	52	56
10/12/10	35	26	3	61	64
10/19/10	31	20	4	51	55
10/26/10	--	14	3	--	--
11/02/10	36	11	8	46	54
11/09/10	23	16	7	39	46
11/16/10	31	20	4	51	56
11/23/10	35	22	2	57	60
11/30/10	34	22	3	56	59
12/07/10	500	35	5	535	540
12/14/10	--	32	6	--	--
12/21/10	247	32	6	279	285
12/28/10	231	30	5	261	267

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Appendix 1. Start and end dates and times for composite samples collected at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.

[Available separately at http://pubs.usgs.gov/sir/2013/5140/]

Appendix 2. *A,* Concentrations and relative percent differences of total phosphorus and orthophosphorus in concurrent equal-width-increment (EWI) and outside-gage grab samples (OGS); *B,* Concentrations and relative percent differences of total phosphorus and orthophosphorus on first and last days of seven-day holding time in sample containers.

[Available separately at http://pubs.usgs.gov/sir/2013/5140/]

Appendix 3. Daily mean streamflow in cubic feet per second at water-quality-monitoring stations on the Assabet River in the towns of Hudson, Stow, and Maynard, Massachusetts, October 2008 through December 2010.

[Available separately at http://pubs.usgs.gov/sir/2013/5140/]

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