Water Quality of Selected Rivers in the New England Coastal Basins in Maine, Massachusetts, New Hampshire, and Rhode Island, 1998-2000

By Kimberly W. Campo, Sarah M. Flanagan, *and* Keith W. Robinson

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 03-4210

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Pembroke, New Hampshire
2003

U.S. DEPARTMENT OF THE INTERIOR
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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. (http://www.usgs.gov/). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. (http://water.usgs.gov/nawqa/). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. (http://water.usgs.gov/nawqa/nawqamap.html). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings. (http://water.usgs.gov/nawqa/natsyn.html).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Associate Director for Water

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CONVERSION FACTORS, DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
inch (in.)	0.000254	micrometer (µm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.0283217	cubic meter per second (m^3/s)

Concentrations of chemical constituents in water are given in microsiemens per centimeter (µs/cm) at 25 degrees Celsius; milligram per liter (mg/L); microgram per liter (µg/L); nutrient loads are in kilogram per day (kg/d), and kilogram per day per square mile ($kg/d/mi^2$).

Horizontal Datum: Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Other abbreviations:

CCREM	Canadian Council of Resources and Environmental Ministers
cis-DCE	*cis*-1,2- dichloroethylene
DO	Dissolved Oxygen
LINJ	Long Island-New Jersey study unit
LRL	Laboratory Reporting Level
MTBE	Methyl *tert*-butyl ether
MCL	Maximum Contaminant Level
NAWQA	National Water-Quality Assessment Program
NECB	New England Coastal Basins study unit
PCE	Tetrachloroethylene
TCE	Trichloroethylene
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound

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ABSTRACT

Nine rivers were monitored routinely for a variety of field conditions, dissolved ions, and nutrients during 1998-2000 as part of the New England Coastal Basins (NECB) study of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. The nine rivers, located primarily in the Boston metropolitan area, represented a gradient of increasing urbanization from 1 to 68 percent urban land use. Additional water samples were collected and analyzed for pesticides and volatile organic compounds at two of the nine rivers. Specific conductance data from all rivers were correlated with urban land use; specific conductance values increased during winter at some sites indicating the effect of road de-icing applications. In the more intensely urbanized basins, concentrations of sodium and chloride were high during winter and likely are attributed to road de-icing applications. Concentrations of total nitrogen and the various inorganic and organic nitrogen species were correlated with the percentage of urban land in the drainage basin. Total phosphorus concentrations also were correlated with urbanization in the drainage basin, but only for rivers draining less than 50 square miles. Preliminary U.S. Environmental Protection Agency total nitrogen and total phosphorus criteria for the rivers in the area were frequently exceeded at many of the rivers sampled.

At the two sites monitored for pesticides and volatile organic compounds, the Aberjona and Charles Rivers near Boston, greater detection frequencies of pesticides were in samples from the spring and summer when pesticide usage was greatest. At both sites, herbicides were detected more commonly than insecticides. The herbicides prometon and atrazine and the insecticide diazinon were detected in over 50 percent of all samples collected from both rivers. No water samples contained pesticide concentrations exceeding any U.S. Environmental Protection Agency drinking-water standard or criteria for protecting freshwater aquatic life. The volatile organic compounds trichloroethylene, tetrachloroethylene, and *cis*-1,2-dichloroethylene—all solvents and de-greasers—were detected in all water samples from both rivers. The gasoline oxygenate methyl *tert*-butyl ether (MTBE) and the disinfection by-product chloroform were detected in all but one water sample from the two rivers. Two water samples from the Charles River had trichloroethylene concentrations that exceeded the U.S. Environmental Protection Agency Maximum Contaminant Level of 5 micrograms per liter for drinking water.

Selected water-quality data from two NCEB rivers in the Boston metropolitan area were compared to two similarly sized intensely urban rivers in another NAWQA study area in the New York City metropolitan area and to other urban rivers sampled as part of the NAWQA Program nationally. Nutrient total nitrogen and total

phosphorus concentrations and yields were less in the NECB study area than in the other study areas. In addition, the pesticides atrazine, carbaryl, diazinon, and prometon were detected less frequently and at lower concentrations in the two NECB rivers than in the New York City area streams or in the other urban NAWQA streams. Concentrations of the insecticides diazinon and carbaryl were detected more frequently and at higher concentrations in the NECB study area than in the other urban rivers sampled by NAWQA nationally. Detection frequency and concentrations of volatile organic compounds generally were higher in the two NECB streams than in the New York City area streams or in other urban NAWQA streams.

INTRODUCTION

The National Water-Quality Assessment (NAWQA) Program was implemented in 1991 by the U.S. Geological Survey (USGS) to assess the status and trends in water quality for a large part of the Nation's surface- and ground-water resources and to provide a better understanding of the factors that affect water quality (Gilliom and others, 1995). The New England Coastal Basins (NECB) study unit, 1 of 51 study units across the Nation, began in 1997 as part of the NAWQA Program (Ayotte and Robinson, 1997).

A primary goal of the NAWQA Program is to characterize water-quality conditions of rivers on a local scale by monitoring selected rivers in NAWQA study units. Monitoring is performed routinely at a group of river locations, which is called a fixed-site network (Gilliom and others, 1995). Because urbanization is important to local water-resource managers in the NECB study unit (termed study area throughout the remainder of the report) and the NAWQA Program (Ayotte and Robinson, 1997), the NECB study incorporated urbanization and its effects on stream-water quality in the design of the NECB fixed-site network. The NECB fixed-site network contained nine rivers; the selection of these rivers for inclusion in the fixed-site network was based primarily on the extent of urbanization in the drainage basin. Surface-water samples were collected monthly or more frequently from 1998 to 2000 to assess the spatial and temporal variability of chemical concentrations and loads in relation to hydrologic conditions and drainage-basin characteristics.

Purpose and Scope

This report summarizes the results of surface-water-quality monitoring conducted for the NECB fixed-site network from October 1998 to September 2000. Data from 27 to 76 water samples collected at each site for field measurements, dissolved ions, nutrients, pesticides, and volatile organic compounds (VOCs) are included. The effects of urbanization on measurements, concentrations, loads, and yields of selected constituents are described, as are seasonal and hydrologic trends. Finally, water-quality data from two urban rivers in the study area are compared to water-quality data from two urban basins in another NAWQA study unit in the New York City area, and to water-quality data from urban basins nationwide.

Description of the New England Coastal Basins Study Area

The NECB study area encompasses 23,000 mi^2 in western and central Maine, central and eastern New Hampshire, eastern Massachusetts, most of Rhode Island, and a small part of eastern Connecticut (fig. 1). The study area includes the major drainage basins of the Kennebec, Merrimack, Androscoggin, Saco, Charles, and Blackstone Rivers, as well as many small coastal drainage basins between these major basins. The study area had an estimated population of 8.3 million persons in 2000, an increase of 6.8 percent since 1990 (Kerie Hitt, U.S. Geological Survey, written commun., 2002). The highest population densities were in the southern and coastal regions of the study area. Major metropolitan areas include Boston, Mass., and Providence, R.I. The study area includes parts of four U.S. Environmental Protection Agency (USEPA) ecoregions: the Atlantic Coastal Pine Barrens, Laurentian Plains and Hills, Northeastern Coastal Zone, and the Northeastern Highlands (Omernick, 1987) (fig. 1). Land use in the 1990s (Vogelmann and others, 2001) was estimated to be 75-percent forested, 11-percent urban, 6-percent agriculture, 5-percent

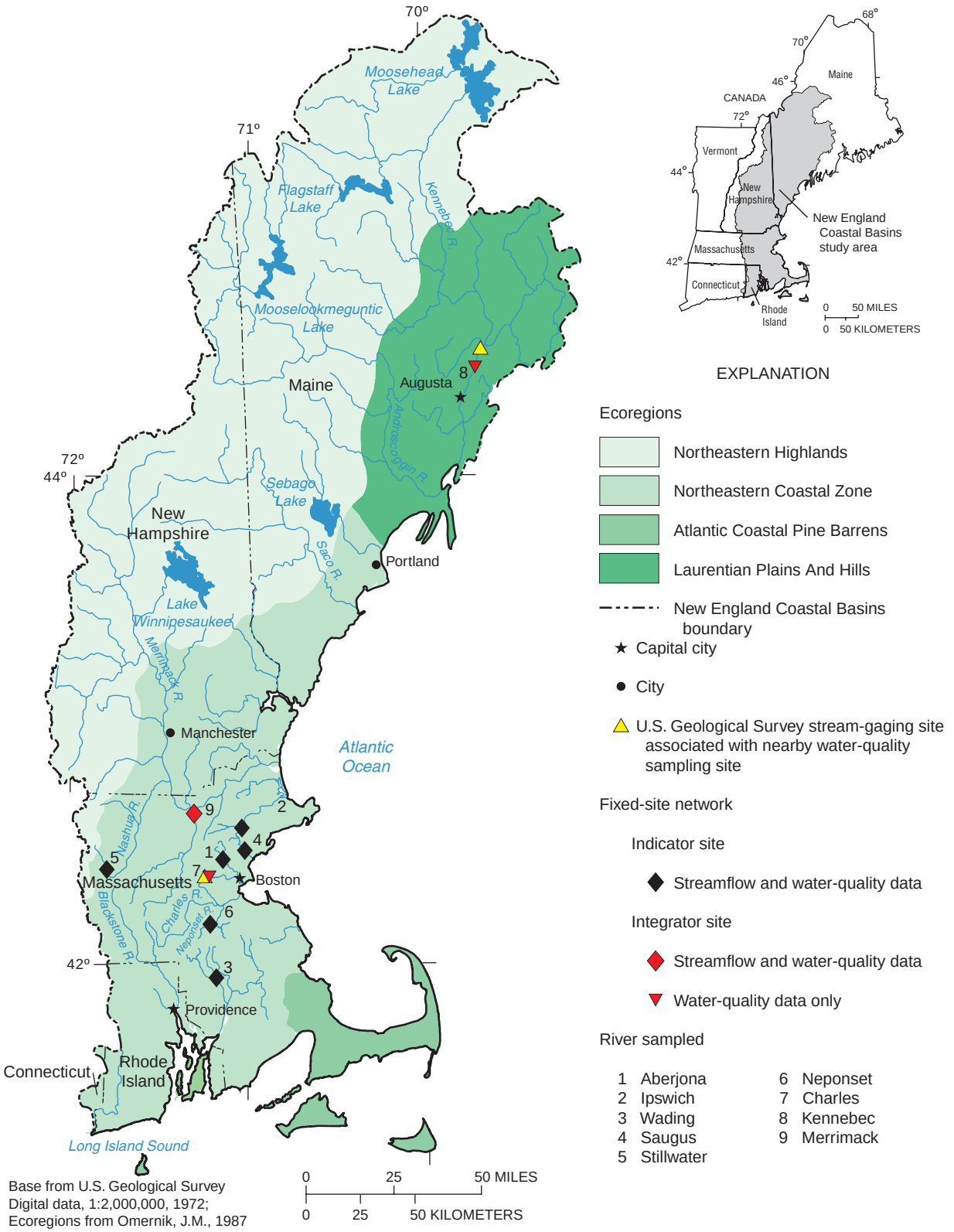


Figure 1. Ecoregions and location of surface-water sampling sites, New England Coastal Basins study area.

surface-water bodies, and 3-percent other land uses (Vogelmann and others, 2001); (Flanagan and others, 1999) (fig. 2).

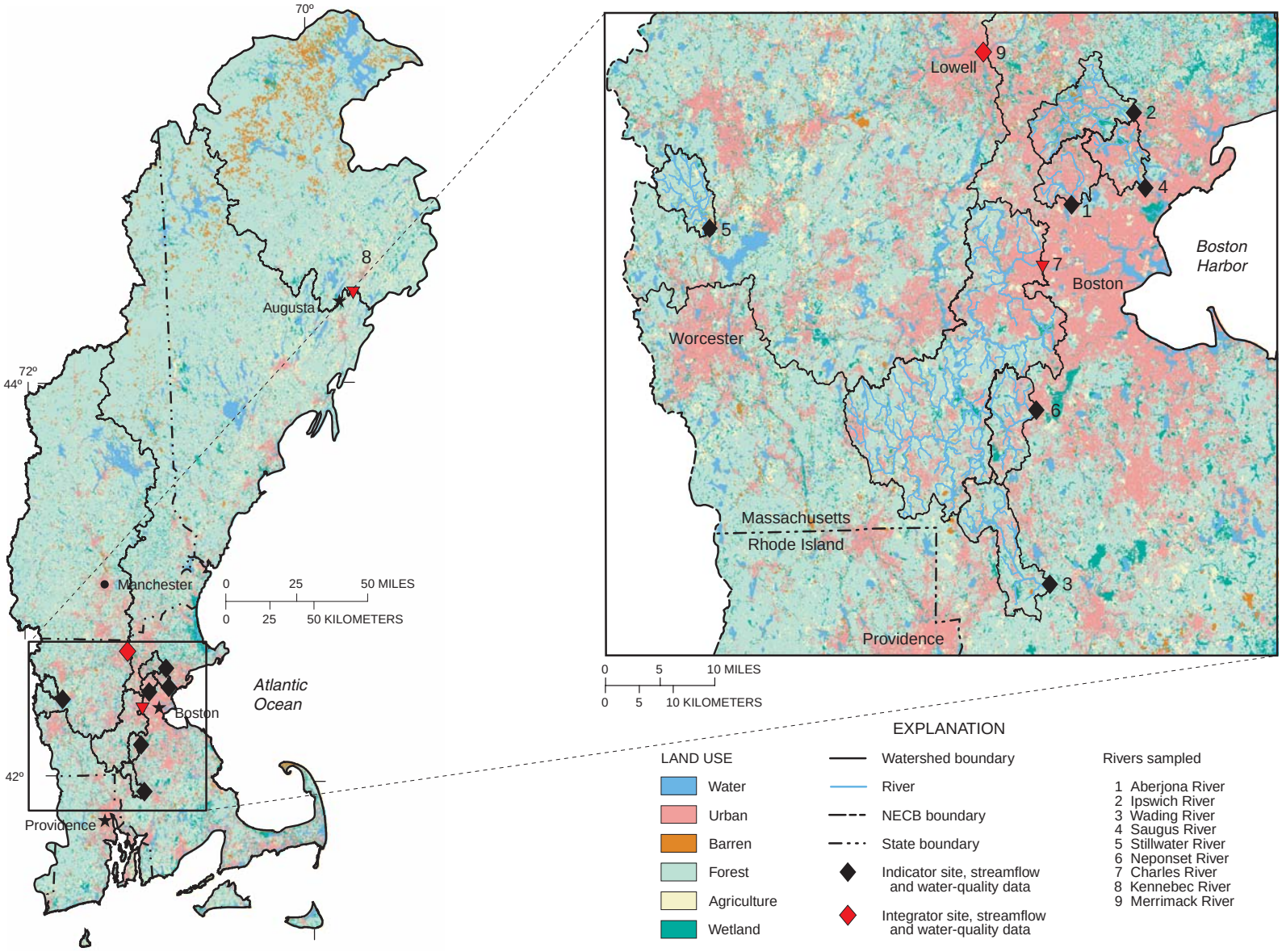
Most of the NECB study area is underlain by near-surface bedrock, which controls the natural surface-water quality. Weather-resistant igneous and metamorphic rock plus thin, compact soils result in surface waters that naturally contain low concentrations of nutrients, dissolved and suspended solids, and are highly susceptible to acidification by precipitation. A more detailed description of the NECB study area and the environmental settings are presented in Flanagan and others (1999).

Human activities have effected surface-water quality in the study area. For more than 200 years, the damming of rivers and the disposal of untreated wastes from pulp and paper mills, lumber mills, textile and tanning factories, and urban populations made some rivers in New England among the most contaminated in the United States (Flanagan and others, 1999). Surface-water quality in New England began improving in the 1970s with the passage of the Clean Water Act of 1972 (U.S. Environmental Protection Agency, 2002a). As a result of the Clean Water Act, increased Federal, State, and local funds were spent to construct municipal wastewater-treatment plants. Many private industries also constructed facilities to treat their waste by-products. Consequently, many rivers that were once severely contaminated may now be clean enough for swimming and fishing.

Despite improvements described above, a number of water-quality issues remain. In its 2000 State of the New England Environment Report, the USEPA has identified high nutrient loads as the biggest water-quality issue for many New England waterways in the 1990s (U.S. Environmental Protection Agency, 2000a). The USEPA considers excessive amounts of phosphorus to be the leading cause of eutrophication in most New England lakes and streams, and excessive amounts of nitrogen to be the leading cause of eutrophication in estuaries and coastal areas such as Long Island Sound. Bottom sediments in many surface-water bodies continue to show contamination from nutrients, polychlorinated biphenyls (PCBs), mercury, and other heavy metals deposited from past and present human activities (Chalmers, 2002). The expansion of urban and suburban development throughout the study area is resulting in additional urban stormwater discharges. Acidic atmospheric deposition, composed of sulfur dioxide and nitrogen oxide, negatively affects lakes and forests, particularly in northern New England (Flanagan and others, 1999). Other major causes of water-quality impairment in New England waters in the 1990s were from waterborne pathogens, mercury contamination of freshwater fishes, and low dissolved oxygen (U.S. Environmental Protection Agency, 2000a).

Flow alteration has affected some small drainage basins, where water withdrawals from surface and ground waters for drinking-water use or irrigation have resulted in reduced streamflows during parts of the year (Flanagan and others, 1999). For example, during those periods of extreme low-flow conditions, nutrient-rich wastewater effluent can be most of the streamflow in small river basins if municipal wastewater-treatment facilities are present.

Excessive algae growth, shown as a plume forming behind a dam on the Nashua River, Mass., commonly is the result of high nutrient loads in surface waters.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972;
U.S. Environmental Protection Agency satellite imagery,
30-meter-pixel resolution, National land cover dataset, 1992

Figure 2. Land uses in the drainage basins of surface-water sampling sites in the New England Coastal Basins study area.

Acknowledgments

Special thanks to Karen Beaulieu and Britt Stock of the U.S. Geological Survey for the long hours they spent collecting and processing samples. James Coles and Marc Zimmerman of the U.S. Geological Survey were instrumental in planning and designing the NECB fixed-site network.

STUDY DESIGN

The nine rivers monitored for water quality represent a mixture of small (indicator) and large (integrator) basins and different land uses (table 1). Indicator basins are less than 100 mi^2 in size and are selected on the basis of a particular land use or environmental setting (Gilliom and others, 1995). Integrator basins are greater than 250 mi^2 in size and are selected to document water-quality conditions in heterogeneous large drainage basins that are affected by different land uses and environmental settings.

Site-selection criteria for all rivers include the presence of a continuous-recording, streamflow-gaging station maintained by the USGS at or near the water-quality sampling site (fig. 3). Site-selection criteria for indicator basins included

- The location of the stream in one similar ecoregion as defined by Omernik (1987) to minimize the effects of natural factors (such as climate, topography, vegetation, and soils) on water quality. All six selected indicator drainage basins are in the Northeastern Coastal Zone ecoregion (fig. 1).
- The physical characteristics of the sampling reach had to meet NAWQA criteria for the biological assessments of habitat, fish, algae, and macroinvertebrates (Gilliom and others, 1995). These criteria require the presence of riffle, run, and pool habitats in the sampling reach.
- Minimal effects on water quality and streamflow from known point sources of wastewater (permitted municipal and industrial wastewater-treatment facility discharges).

Figure 3. Cross-sectional view of the Neponset River, in Massachusetts, showing the water-quality sampling reach and the adjacent U.S. Geological Survey streamflow-gaging station on the right streambank.

The nine sites were sampled monthly. Additional samples were collected during low and high flows. Two sites, one indicator and one integrator, were selected for intensive sampling, which involved more frequent sample collection at weekly or bi-weekly intervals. The intensive sampling strategy was designed to assess the occurrence and seasonal patterns in concentrations of pesticides and VOCs. The most urban indicator and integrator sites, the Aberjona and Charles Rivers, respectively, were selected for intensive sampling.

Indicator Basins

The primary objective of sampling in the six indicator basins was to describe how water quality varies along a gradient of urban intensity. The six indicator basins, the Aberjona, Ipswich, Neponset, Saugus, Stillwater, and Wading Rivers, are all in eastern Massachusetts and were selected to assess the affects of urbanization on the water quality of similar-sized drainage basins in the Northeastern Coastal Zone ecoregion (figs. 1 and 2, table 1). Urban land use ranges from 4 percent in the Stillwater River Basin to 68 percent in the Aberjona River Basin. Drainage areas range from 23 to 45 mi^2 (table 1). Each indicator basin was classified either as minimally urbanized (urban land use comprised less than 5 percent of the drainage basin), moderately urbanized (urban land use greater than 5 and less than 50 percent), or intensely urbanized

Table 1. Characterization of fixed sampling sites in the New England Coastal Basins study area

[No., number; fig., figure; STAID, Station identifier number; mi^2, square miles; Urb, urban; Ag, agriculture; For, Forest; Wet, wetlands; Wat, water; °, degree, ′, minute, ″, second; INT, intensive fixed site; BAS, basic fixed site]

Site No. (fig. 1)	Site name	STAID	Latitude	Longitude	Sample type	Basin size (mi^2)	Land use/Land cover (percent of total)					[1]2000 Population density (people/mi^2)	Level of urbanization
							Urb	Ag	For	Wet	Wat		
Indicator sites													
1	Aberjona River at Winchester, Mass.	01102500	42° 26′ 50″	71° 08′ 22″	INT	25	68	2	24	4	2	2,973	Intensely urbanized
2	Ipswich River at South Middleton, Mass.	01101500	42° 34′ 10″	71° 01' 39″	BAS	45	38	4	40	16	2	1,191	Moderately urbanized
3	Neponset River at Norwood, Mass.	01105000	42° 10′ 39″	71° 12′ 05″	BAS	35	30	6	53	10	1	1,093	Moderately urbanized
4	Saugus River at Saugus Iron Works at Saugus, Mass.	01102345	42° 28′ 10″	71° 00′ 28″	BAS	23	56	4	27	9	4	2,340	Intensely urbanized
5	Stillwater River near Sterling, Mass.	01095220	42° 24′ 39″	71° 47′ 30″	BAS	32	4	10	76	8	2	203	Minimally urbanized
6	Wading River near Norton, Mass.	01109000	41° 56′ 51″	71° 10′ 38″	BAS	43	18	7	64	10	1	597	Moderately urbanized
Integrator sites													
7	Charles River above Watertown Dam at Watertown, Mass.	01104615	42° 21′ 54″	71° 11′ 26″	INT	268	30	7	53	7	3	1,460	Moderately urbanized
8	Kennebec River at North Sidney, Maine	01049265	44° 28′ 25″	69° 41′ 08″	BAS	5,403	1	6	83	4	6	26	Minimally urbanized
9	Merrimack River below Concord River at Lowell, Mass.	01100000	42° 38′ 45″	71° 17′ 56″	BAS	4,635	9	8	74	5	4	308	Moderately urbanized

[1]Data from Kerie Hitt, U.S. Geological Survey, written commun., 2003.

(urban land use greater than 50 percent) (table 1). Major water-quality issues in each of the indicator basins are summarized in table 2.

Integrator Basins

The three integrator basins in the NECB fixed-site network include the Charles, Kennebec, and Merrimack Rivers (fig. 1, table 1). The Merrimack and Kennebec Rivers are the two largest rivers, covering 44 percent of the study area. These two rivers share a similar water-quality history. In both drainage basins, dams to generate hydropower were constructed in the 19th and early 20th centuries and soon were followed by settlement and industrialization (Davies and others, 1999). The rivers and their major tributaries became severely contaminated by the middle to late 1800s and remained that way for the next century. Currently (2003), after two centuries of extensive deforestation, forests are once again the predominant land cover in both drainage basins (table 1). The Merrimack River drains various large metropolitan cites, whereas the Kennebec River drains small cities. The Charles River

Table 2. Major water-quality issues of concern for the six indicator sites and three integrator sites in the New England Coastal Basins study area

[USEPA, U.S. Environmental Protection Agency; CSOs, combined sewer overflows; °C, degrees Celsius]

River name	Water-quality issue of concern reported to the USEPA as required in section 303(d) of the Clean Water Act[1]
	Indicator rivers
Aberjona	Elevated levels of waterborne pathogens, non-ionized ammonia, nutrient enrichment, and low dissolved oxygen.[2]
Ipswich	Nutrients, waterborne pathogens, organic enrichment, and low dissolved oxygen. Excessive withdrawals of ground water in upper parts of watershed results in extremely low streamflows during summer and fall months, which threatens aquatic life in the stream.[3, 4]
Neponset	Priority organics, metals, siltation, nutrient enrichment, low dissolved oxygen, waterborne pathogens, suspended solids, noxious aquatic plants, turbidity, and water temperatures exceeding 20 °C.[2]
Saugus	Nutrients, such as nitrogen-ammonia and total phosphorus, low dissolved oxygen, elevated levels of specific conductance, and water temperatures exceeding 20 °C.[3]
Stillwater	pH values below 6.5 and water temperatures exceeding 20 °C.[5] This river is one of two main tributaries to Wachusetts Reservoir, a source of public water supply.
Wading	Nutrient enrichment, low dissolved oxygen, and bacterial and viral pathogens. Effluent from two wastewater-treatment plants exceeded surface-water criteria for trace metals aluminum, copper, lead, and zinc.[6]
	Integrator rivers
Charles	Nutrient enrichment from wastewater discharges and stormwater runoff.[7] Streambed sediment quality in lower half of basin is severely degraded.[8]
Kennebec	Basin contains numerous eutrophic lakes and tributaries.[9] Discharges from CSOs, inadequate sewers, and aging wastewater-treatment facilities.[10] Streamflow is highly regulated.
Merrimack	Pathogens derived mostly from CSOs in cities and nutrient enrichment.[11] Streamflow is moderately to highly regulated.

[1] U.S. Environmental Protection Agency, 2002a.
[2] M.J. Weinstein, Massachusetts Department of Environmental Protection, Division of Watershed Management, written commun., 2002.
[3] DeCesare and others, 2000.
[4] Zarriello, 2002.
[5] Weinstein and others, 2001.
[6] Massachusetts Department of Environmental Protection, written commun., 1996.
[7] Fiorentino and others, 2000.
[8] Breault and others, 2000.
[9] Davies and others, 1999.
[10] Maine Department of Environmental Protection, 2000.
[11] Kennedy and others, 2001.

Basin is much smaller in size than the Merrimack and Kennebec River Basins, but was selected because it is the dominant drainage basin in the Boston metropolitan area in eastern Massachusetts. Major water-quality issues of concern in each of the integrator basins are summarized in table 2.

DATA COLLECTION AND ANALYSIS

All nine sites were monitored using NAWQA fixed-site sampling protocols that are consistent among all NAWQA sampling activities throughout the Nation. Various graphical and statistical methods were used to analyze water-quality data.

Data Collection

NAWQA protocols for fixed-site sampling are designed to assess the spatial and temporal distribution of water quality in relation to various streamflow conditions and consist of water-quality sample collection at each fixed site monthly or more frequently (Gilliom and others, 1995). Water samples collected at all fixed sites were analyzed for dissolved ions, nutrients, dissolved and suspended organic carbon, and suspended sediment (see appendix 1 for a complete list of all analyzed constituents). Field measurements of specific conductance, pH, water temperature, dissolved oxygen (DO), alkalinity, and bicarbonate were made onsite at the time of sample collection. All field measurements were completed according to NAWQA protocols (Shelton, 1994; Wilde and Radte, 1998). Instantaneous discharge was obtained from continuous-recording, streamflow-gaging stations at or near each site, maintained by USGS personnel in accordance with standard USGS procedures (Rantz and others, 1982).

NAWQA intensive fixed-site sampling protocols include more frequent sampling (weekly and bi-weekly) and the collection of samples for determining the occurrence and seasonal patterns of pesticides and VOCs. Water samples analyzed for pesticides were collected throughout the year (weekly for the Aberjona River from April 1999 through September 2000, and bi-weekly for the Charles River from May 1999 through March 2000). Samples analyzed for VOCs were collected throughout the year, although sample collection frequency ranged from monthly during April to November to weekly or bi-weekly during December to March. The more frequent sampling for VOCs was done during the winter when VOC detections is expected to be high because of cold temperatures (Lopes and Price, 1997).

Most surface-water samples were obtained by collecting depth-integrated subsamples at equal-width increments across the stream channel by wading, or from bridges or cableways, using a US DH-81 or US D-77 sampler (Shelton, 1994). During low flows and extreme high flows, a midpoint-depth integrated or grab sample was collected at the indicator sites. A weighted-bottle sampler was used separately to collect dissolved and suspended organic-carbon samples in a baked amber glass bottle at the midpoint in the stream. Water samples for VOC analysis were collected with a specially designed Wildco sampler at the midpoint in the river channel (Shelton, 1997).

Water samples were processed in the field according to NAWQA protocols (Shelton, 1994). A cone splitter was used to composite most of the samples into Teflon bottles. Samples analyzed for dissolved ions, nutrients, and field alkalinity were filtered through a 0.45-µm pore-size capsule filter, samples analyzed for dissolved and suspended organic carbon were filtered through a 0.45-µm pore-size silver filter, and samples analyzed for pesticides were filtered through a 0.7-µm pore-size glass-fiber filter. Suspended-sediment samples were collected and processed according to methods described by Edwards and Glysson (1988) and shipped to the USGS Sediment Laboratory in Louisville, Ky., for particle-size and concentration analysis. All other water-quality samples were shipped to the USGS National Water-Quality Laboratory (NWQL) in Denver, Colo., for analysis. Individual results for each water-quality constituent are published in selected USGS water-data reports (Socolow and others, 2000, 2001; Nielsen and others, 2000; Stewart and others, 2001).

Data Analysis

The StatView (SAS Institute, Inc., 1999) statistical software package was used for all statistical analysis. Nonparametric statistics were used on the assumption that the data were not normally distributed. Spearman rank-correlation analysis was used to compare water-quality data to urbanization in each drainage basin using the median concentration values

and the percentage of upstream urban land use. For this report, data were considered statistically correlated when *rho* values (the Spearman rank correlation coefficient) were equal to or greater than 0.40 and probability (*p*) was less than 0.05. The Kruskal-Wallis test was used to test for significant differences in median values among sites by performing a one-way analysis of variance on the ranks of the data. The Tukey-Kramer (or Tukey's HSD) multiple comparison test (Helsel and Hirsch, 1992) on rank-transformed data then was used to examine differences among sites if the Kruskal-Wallis results showed significant differences.

Data distributions of selected constituents for each site and among sites were displayed with boxplots (Helsel and Hirsch, 1992). The results of the multiple comparison tests are displayed as letters placed above the boxplots for each site to indicate significant groupings. The letter "A" is designated to the site(s) with the highest median concentration, and subsequent letters are assigned to sites with correspondingly lower median concentrations. More than one letter is designated to a site if the significant groupings overlap. For example, if three sites are assigned letters "A", "AB", and "B", respectively, sites A and B are significantly different, but site AB is not significantly different from either site A or site B.

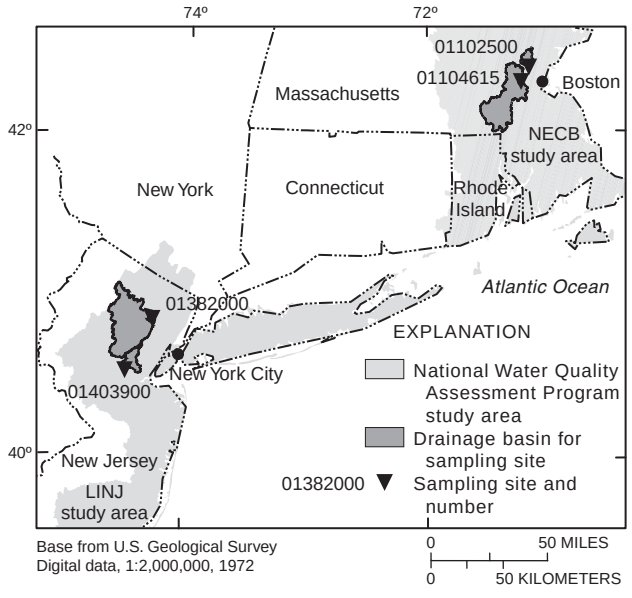


Figure 4. Location of the New England Coastal Basins (NECB) and Long Island-New Jersey (LINJ) study areas and the sampling sites used to compare water-quality data between the study areas. (Sampling sites in the LINJ study area are described in table 3)

In this report, total nitrogen is the sum of dissolved nitrite plus nitrate (NO_2+NO_3) and total ammonia (NH_3) plus organic nitrogen. Instantaneous discharge, concentration, and a conversion factor were used to calculate instantaneous loads for total nitrogen and total phosphorus, in kilograms per day. Instantaneous loads were calculated based on the general assumption that the instantaneous discharge and concentration were constant for that day, and, therefore, are reported in kilograms per day. Instantaneous loads for total nitrogen and total phosphorus for each site were divided by the respective basin drainage area to calculate instantaneous yields, in kilograms per day per square mile.

Qualitative comparisons of water-quality data from NECB monitoring sites in the Boston metropolitan area to data from monitoring sites in the New York City metropolitan area (fig. 4) and to national NAWQA results were done to determine the similarity of data from various urban areas throughout the Nation. Total nitrogen and total phosphorus data from the NECB monitoring sites were compared to data from two monitoring sites in the Long Island-New Jersey Coastal Drainages (LINJ) study unit and to other urban indicator and integrator sites monitored by the NAWQA Program to determine differences in median total nitrogen and total phosphorus concentrations on a regional and national scale. In addition, data for the most frequently detected pesticide and VOC compounds found in samples from the two NECB monitoring sites (Aberjona and Charles Rivers) were compared to the LINJ study results and to other urban sites in the NAWQA Program to determine differences in the occurrence and concentrations of the selected pesticides and VOCs on a regional and national scale.

The LINJ sites included in the regional comparison were Bound Brook at Middlesex, N.J. (urban indicator basin; station identification (ID) number 01403900) and Passaic River at Two Bridges, N.J. (integrator basin; station ID number 01382000) (Edward Pustay, U.S. Geological Survey, written commun., 2002) (fig. 4). Water-quality data from these two streams were collected from 1996 to 1998. The two LINJ monitoring sites have similar basin sizes and land uses compared to the two NECB monitoring sites (table 3).

For the national comparison, nutrient water-quality data were collected from more than 2,700 water samples in 48 urban indicator and 28 urban integrator sites monitored by the NAWQA Program during

1992-2000 (David Mueller, U.S. Geological Survey, written commun., 2003). Pesticide water-quality data were collected from more than 850 samples in 33 urban sites in the NAWQA Program during the same period (Jeffrey D. Martin, U.S. Geological Survey, written commun., 2003); data accessed on March 13, 2003, at http://ca.water.usgs.gov/pnsp/pestsw/Pest-SW_2001_Text.html. VOC water-quality data were collected from 711 samples in 26 urban sites in the NAWQA Program during 1996-2000; data accessed on May 16, 2003, at http://sd.water.usgs.gov/usgs/vocns/ifs-55-vocs-summary.xls.

WATER QUALITY OF SELECTED NEW ENGLAND COASTAL BASINS RIVERS

Summary statistics for selected water-quality field measurements and constituents analyzed for each site are presented in tables 4 and 5 (back of report), and discussed in the following sections. The relations of the results from the nine fixed sites to the percent of urban land use in the drainage basin and the relations among the groups of indicator and integrator sites are presented in table 6. Streamflow conditions at the fixed sites during the 1999 and 2000 water years[1] are described briefly and compared to historical mean streamflows.

Streamflow Conditions

Streamflow often affects the water-quality conditions of a stream. During high flow, concentrations of some water-quality constituents may decrease as a result of dilution, or increase as a result of inputs from stormwater runoff. A hydrograph showing the daily mean streamflow for the sampling period, an overlay of historical range of daily mean streamflow (based on 1940-2000 period of record), and the sampling dates for the Aberjona River at Winchester, Mass.—one of the nine fixed sites—is presented in figure 5. Generally, streamflow in the nine fixed sites during the study period was below normal during the spring and summer (April to August) in water year 1999 (Socolow and others, 2000; Nielsen and others, 2000) and normal to above normal throughout water year 2000 (Socolow and others, 2001; Stewart and others, 2001) when compared to historical means of long-term (1940-2000) discharge. For example, streamflow at the Aberjona River at Winchester, Mass., during the spring and summer in water year 1999 fell below the 25th percentile of historical daily mean streamflow (fig. 5).

[1]A water year begins on the first day of October and ends on the last day of September the following year. For example, the 1999 water year includes October 1, 1998, through September 30, 1999.

Table 3. Basin characteristics of the two Long Island-New Jersey Coastal Drainages NAWQA study unit monitoring sites in relation to New England Coastal Basins study unit monitoring sites

[USGS, U.S. Geological Survey; No., number; mi^2, square miles; Source: Reiser and O'Brien, 1998]

Site	USGS site No.	Drainage area (mi^2)	Land use (in percent)		
			Urban	Forest	Agri-culture
Passaic River at Two Bridges, N.J.	01382000	361	47	35	3
Bound Brook at Middlesex, N.J.	01403900	48.4	68	25	1

Field Measurements

Specific conductance is a measure of the ability of a substance to conduct an electrical currant, and is an indicator of the concentrations of dissolved ions or solids in solution. Median specific conductance values ranged from 105 (Stillwater River) to 521 µs/cm at 25° C (Aberjona River) in the six indicator rivers and from 67.5 (Kennebec River) to 326 µs/cm at 25° C (Charles River) in the three integrator rivers (tables 4 and 5, fig. 6). For both the indicator and integrator basins, specific-conductance values were correlated with urbanization (table 6), with higher specific conductance values measured at sites with higher percentages of urban land use than at sites with lower percentages of urban land use in the drainage basin (fig. 6).

Generally, samples collected during the summer, when streamflows were lowest, had higher specific-conductance values than samples collected during the winter. Specific conductance decreased as streamflow

Table 6. Relations between selected water-quality constituents and percent urban land use for the indicator and integrator sites in the New England Coastal Basins study area, 1998-2000

[Spearman's rank correlation coefficients (rho) and probability values (p-values) are significant (**in bold**) when rho is greater than 0.5, and p-values are less than 0.005; <, less than; negative values indicate an inverse relation]

Water-quality constituent	Percent urban land use			
	Indicator		Integrator	
	rho	p-value	rho	p-value
Specific conductance	**0.85**	**<0.0001**	**0.92**	**<0.0001**
Field pH	**.60**	**<.0001**	.093	.513
Dissolved oxygen	-.19	.0061	-.159	.1133
Calcium	**.89**	**<.0001**	**.87**	**<.0001**
Sulfate	**.83**	**<.0001**	**.73**	**<.0001**
Chloride	**.81**	**<.0001**	**.92**	**<.0001**
Ammonia	**.78**	**<.0001**	**.42**	**<.0001**
Ammonia + organic, dissolved	**.79**	**<.0001**	**.73**	**<.0001**
Ammonia + organic, total	**.82**	**<.0001**	**.75**	**<.0001**
Nitrite	**.75**	**<.0001**	**.43**	**<.0001**
Nitrite + nitrate	**.85**	**<.0001**	**.78**	**<.0001**
Nitrogen, total	**.92**	**<.0001**	**.83**	**<.0001**
Phosphorus, dissolved	-.04	.6173	-.00008	.9994
Phosphorus, ortho	.09	.1889	-.14	.1682
Phosphorus, total	**.40**	**<.0001**	.28	.0078
Total nitrogen, Yield	**.43**	**<.0001**	**.40**	**<.0001**
Total phosphorus, Yield	.13	.0793	.14	.186

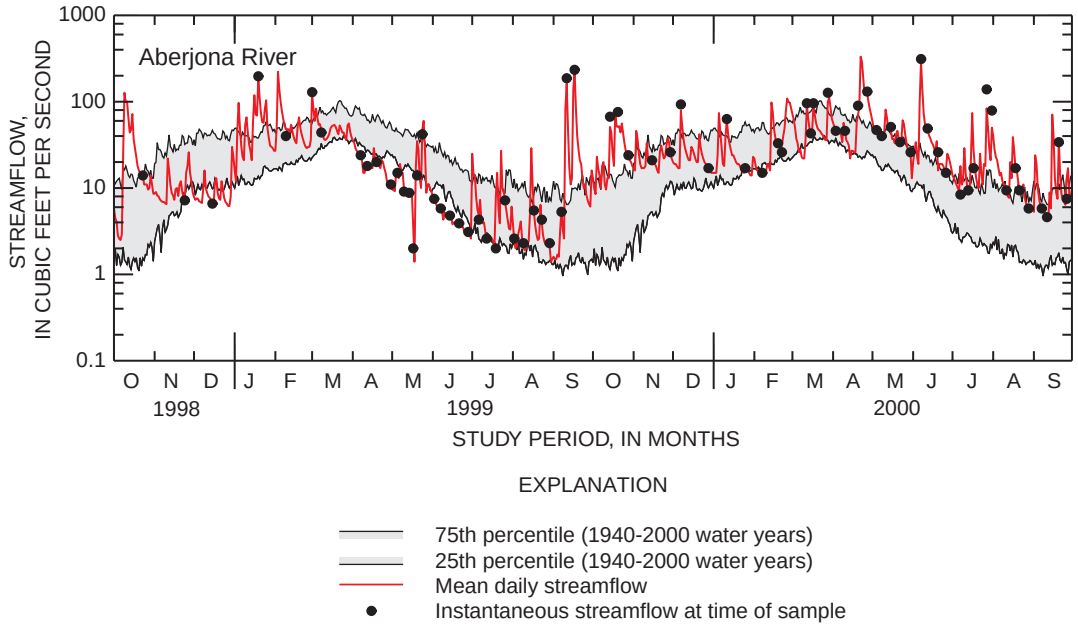


Figure 5. Historical daily mean streamflow for the period of record (1940-2000), and daily mean streamflow and sample-collection streamflows for the 1998-2000 study period at the Aberjona River at Winchester, Mass.

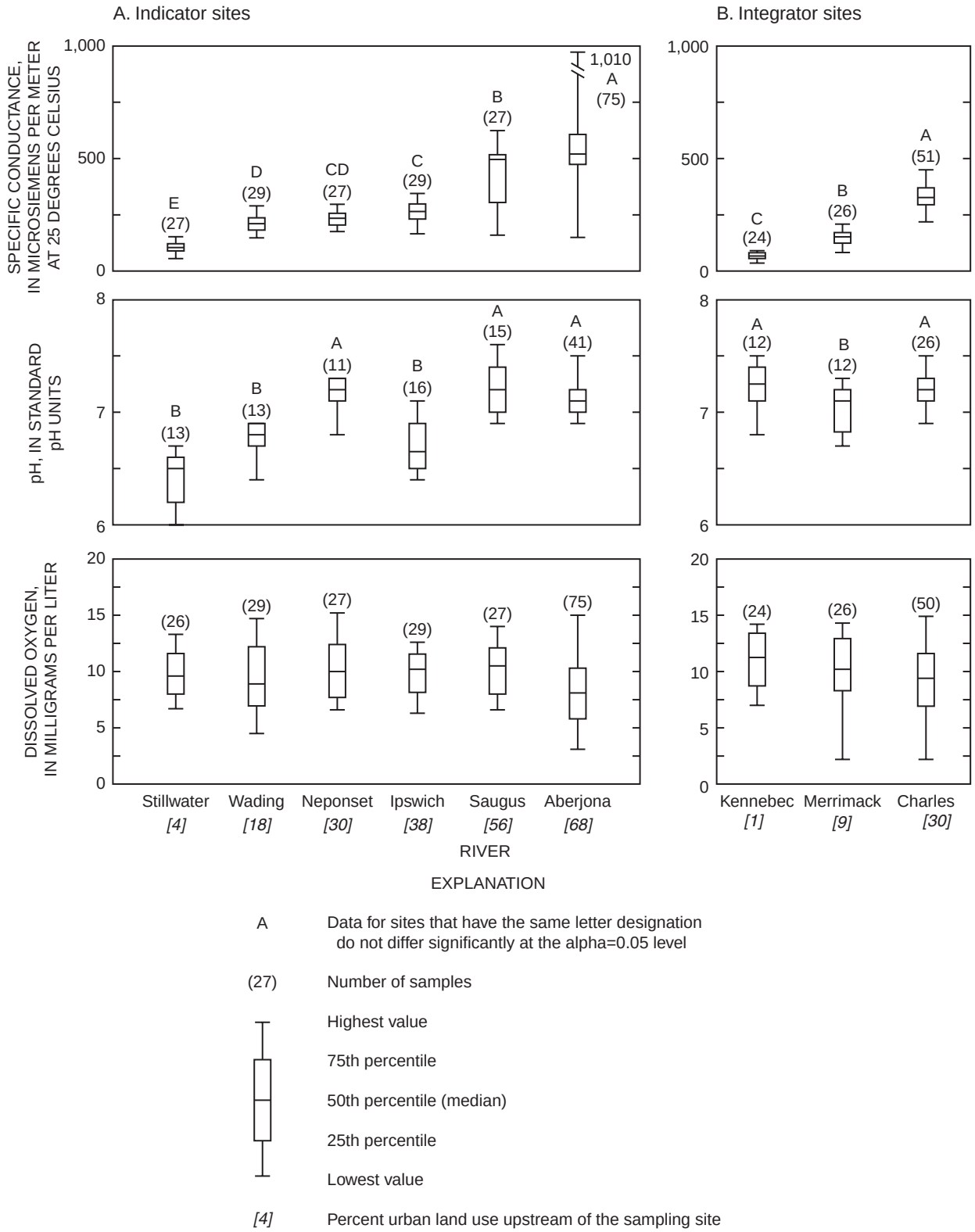


Figure 6. Distribution of specific conductance, pH, and dissolved oxygen, at the (A) six indicator and (B) three integrator sites in the New England Coastal Basins study area. (Location of sites shown in fig. 1.)

increased during storms because of dilution. At two of the more urban indicator sites (Aberjona and Ipswich Rivers), samples collected during the winter and early spring had greater specific conductance values than samples collected during summer and fall, possibly because of road de-icing applications. This result was most apparent in the Aberjona River, where specific conductance values exceeded 800 µs/cm at 25° C in water samples from winter and early spring.

The pH of water is a measure of the hydrogen ion concentration (acidity) in the water. The pH of water directly affects the physiological functions of plants and animals, and is an important indicator of the health of aquatic ecosystems. On the pH scale, 7 is neutral, less than 7 is acidic, and greater than 7 is alkaline. Median pH values in all nine basins consistently were around 7 (tables 4 and 5, fig. 6). The pH values from the indicator basins correlated with urbanization, with high pH values measured at sites with high percentages of urban land use. Measured pH values for the integrator basins did not correlate with the percentage of urban land use in the drainage basin (table 6). Multiple comparison tests on pH data from the indicator sites showed two significant groups: the Stillwater, Ipswich, and Wading Rivers had median pH values that were lower than the pH in the other rivers and slightly acidic; the other three sites had slightly alkaline median pH values (fig. 6). Seventy percent (9 of 13) of the pH values for the Stillwater River were less than or equal to the State of Massachusetts minimum criteria of 6.5 for Class A surface waters (Massachusetts Department of Environmental Protection, 1996); these low pH values are thought to be caused by natural factors such as soils, vegetation, and the geology of glacial sediments and near-surface bedrock.

Adequate dissolved oxygen (DO) concentrations in water are necessary for the survival and growth of most aquatic organisms. The State of Massachusetts requires that surface waters contain a minimum of 5.0 to 6.0 mg/L of DO to protect warm- and cold-water fisheries, respectively (Massachusetts Department of Environmental Protection, 1996). Median concentrations of DO measured at the six indicator sites ranged from 8.0 (Aberjona River) to 10.5 mg/L (Saugus River) (table 4, fig. 6). In the three integrator sites, median concentrations of DO ranged from 9.2 mg/L (Charles River) to 11.3 mg/L (Kennebec River) (table 5, fig. 6).

Another measure of DO in water is DO saturation. DO saturation is the percentage of the measured DO concentration in water compared to the saturated amount of DO in water at a given water temperature and barometric pressure. Median DO saturations ranged from 79 (Aberjona River) to 93 percent (Neponset River) (table 4) at the six indicator basins, and ranged from 87 (Charles River) to 98 percent (Kennebec River) at the three integrator sites (table 5).

DO concentrations at the indicator and integrator sites were not correlated with the percentage of urban land in the drainage basin (table 6). Various field DO measurements in the Aberjona, Merrimack, and Charles Rivers were below the Massachusetts minimum criteria of 5 mg/L for Class B surface waters. Concentrations of DO in 15 percent of water samples (11 of 75) collected in the Aberjona River were below the 5 mg/L criteria; 10 of these water samples were collected from May through August 1999 during a period of reduced streamflows (fig. 7). The lowest DO concentration and saturation value measured in the Aberjona River during that time were 3.2 mg/L and 35 percent, respectively. In the same time period, DO concentrations were measured below 5 mg/L in the Merrimack River once and in Charles Rivers at seven sampling events; the lowest DO saturation measured at both sites was 26 percent. At all nine sites, samples collected during the winter had higher DO concentrations and corresponding DO saturation values than samples collected during the summer. The low DO concentrations and saturations values correspond to periods of low streamflow and high water temperatures, as well as increased biological consumption of DO during the summer.

Dissolved Ions

The term “dissolved ions” represents a group of naturally occurring solutes in water; observed concentrations can be caused by a combination of natural and anthropogenic sources in a drainage basin. Selected dissolved ions for the fixed sites are discussed in the following sections. All dissolved ions analyzed in samples from the nine fixed sites are summarized in tables 4 and 5.

Calcium is the most abundant of the alkaline-earth elements and is a major component of the solutes in most natural water (Hem, 1992). Median calcium

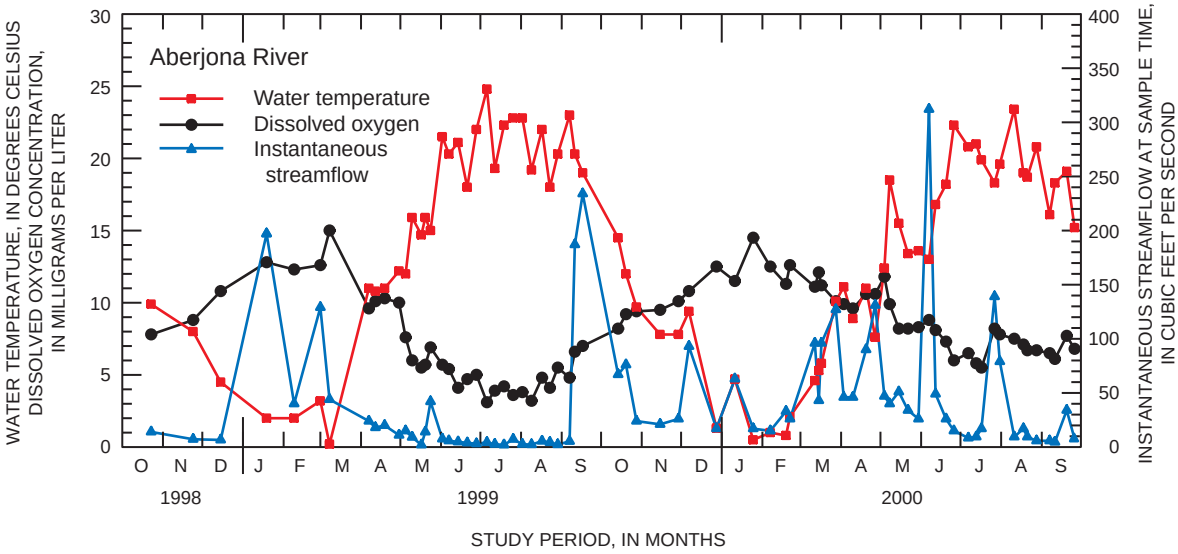


Figure 7. Water temperature, concentration of dissolved oxygen (same scales), and instantaneous streamflow at the Aberjona River, Mass., 1998-2000.

concentrations ranged from 5.2 (Stillwater River) to 29.4 mg/L (Aberjona River) in the indicator basins and from about 4.9 (Kennebec River) to 14.2 mg/L (Charles River) in the integrator basins (tables 4 and 5, fig. 8). Calcium concentrations correlated with the percentage of urban land in the drainage basin for both indicator and integrator basins (table 6). Calcium concentrations were highest at the sites representing moderately to intensely urban land use and smallest at sites representing minimal urban land use (fig. 8).

Dissolved sulfate occurs naturally in rivers from rock weathering and biological or biochemical processes (Hem, 1992). Atmospheric deposition of sulfate from the combustion of fuels and the smelting of ores is another major source to rivers (Hem, 1992). Median sulfate concentrations ranged from 6.9 (Stillwater River) to 25.8 mg/L (Aberjona River) in the indicator basins and from 7.1 (Kennebec River) to 12.25 mg/L (Charles River) in the integrator basins (tables 4 and 5, fig. 8). Like calcium, the percentage of urban land use in the drainage basin affects sulfate concentrations among the indicator and integrator basins (table 6). Among the indicator sites, sulfate concentrations were generally highest in the intensely urbanized Aberjona River and lowest in the minimally urbanized Stillwater River. Sulfate concentrations were statistically similar in the Saugus and Ipswich Rivers (56 and 38 percent urban land use, respectively); and in the Neponset and Wading Rivers (30 and 18 percent urban land use, respectively) (fig. 8).

Chloride in pristine, natural freshwater is at generally low concentrations (less than 4 mg/L). High chloride concentrations occur in streams experiencing inflows of high-chloride ground water, anthropogenic inputs such as stormwater runoff carrying road deicing salt, or marine tidal effects (Hem, 1992). Median chloride concentrations ranged from 18.3 (Stillwater River) to 108 mg/L (Aberjona River) in the indicator drainage basins and from 5.4 (Kennebec River) to 68.2 mg/L (Charles River) in the integrator drainage basins (tables 4 and 5, fig. 8). Chloride concentrations were correlated with urbanization for both indicator and integrator basins (table 6). The Saugus River sampling site is near a tidal estuary, and some high chloride concentrations may be attributed to marine effects. For both the indicator and integrator drainage basins, chloride concentrations were lowest in the drainage basins containing the smallest percentage of urban land use.

Concentrations of many of the dissolved ions show the same relations to seasons and streamflow as specific conductance. For example, concentrations of calcium are highest in the summer during low streamflows. Chloride concentrations are highest in the summer, but similarly high concentrations also are

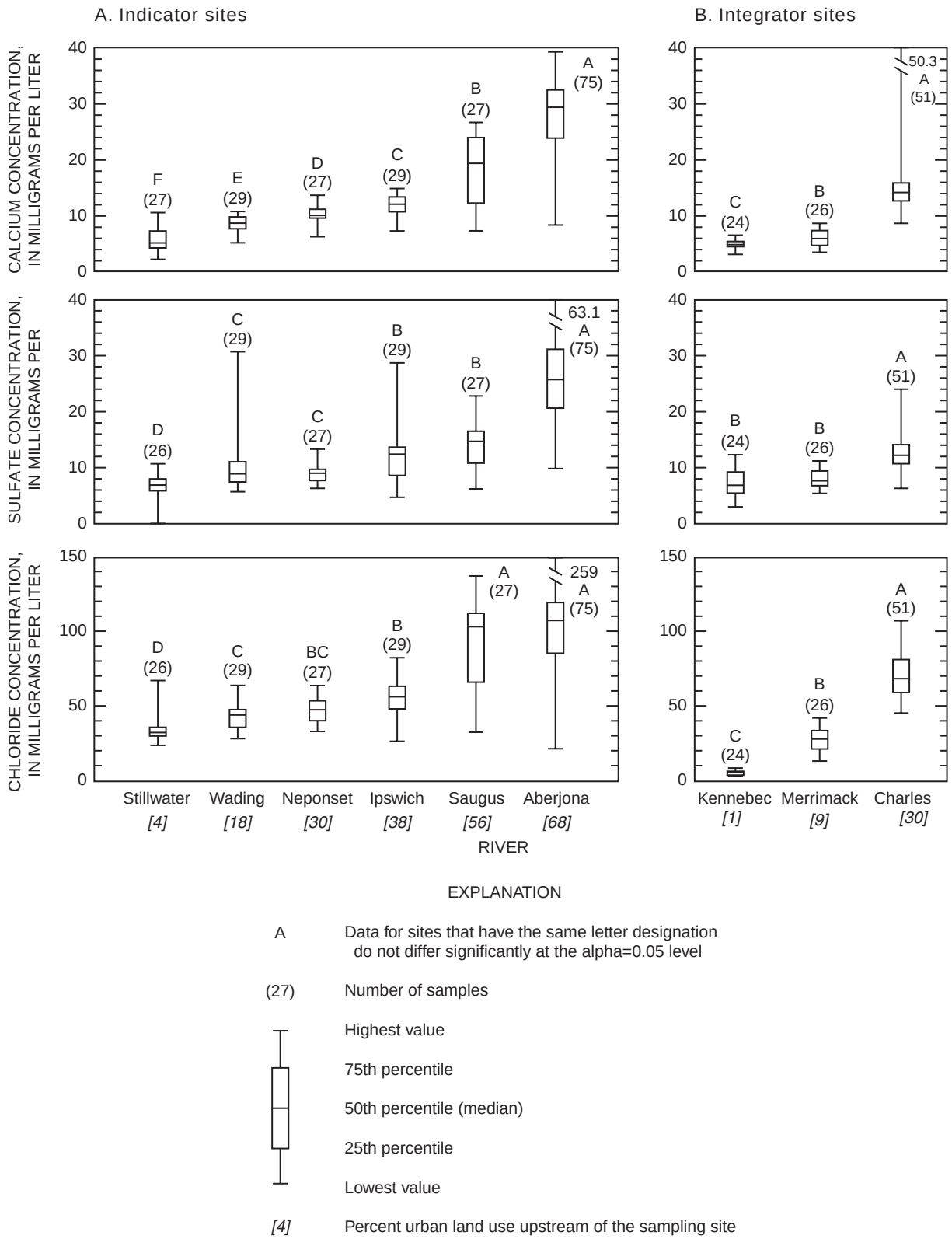


Figure 8. Distribution of calcium, sulfate, and chloride concentrations at the (A) six indicator and (B) three integrator sites in the New England Coastal Basins study area. (Location of sites shown in fig. 1.)

observed during winter months in the Aberjona and Ipswich Rivers and are likely attributed to road de-icing applications.

Nutrients

The occurrence and distribution of nitrogen and phosphorus in rivers are from rocks, soils, vegetation, treated wastewater effluents, stormwater runoff from urban, agricultural and forested lands, poorly functioning septic systems, pet waste, and atmospheric deposition (primarily for nitrogen). Nitrogen usually is a limiting nutrient for plant growth in estuarine and coastal waters, and phosphorus generally is the limiting nutrient for plant growth in freshwater bodies. In the following paragraphs, the occurrence of nitrogen and phosphorus in the sampled rivers are discussed.

Nitrogen

Median total nitrogen concentrations ranged from 0.42 (Stillwater River) to 2.74 mg/L (Aberjona River) for the indicator basins and from 0.4 (Kennebec River) to 1.16 mg/L (Charles River) for the integrator basins (tables 4 and 5, fig. 9). Concentrations of total nitrogen, as well as the nitrogen species (nitrite plus nitrate, ammonia and organic nitrogen), in the indicator and integrator drainage basins were correlated with the percentage of urban land in the drainage basin (table 6); the highest concentrations were measured at fixed sites draining moderately to intensely urbanized land areas (fig. 9). The intensely urbanized Aberjona River had a median total nitrogen concentration that was more than two to six times higher than the median total nitrogen concentration for other indicator sites.

The total nitrogen concentrations from both the indicator and integrator sites consisted of virtually all nitrate and organic nitrogen, with the exception of the Aberjona River, which had the highest percentage (30 percent) of dissolved ammonia (fig. 10). Median dissolved ammonia concentrations accounted for five percent or less of the median total nitrogen for the other five indicator sites (fig. 10). The source of the large dissolved ammonia concentrations at the Aberjona River is unknown, but possible sources may include fertilizers or undocumented point sources.

No water sample collected from any of the nine monitoring sites contained dissolved nitrate concentrations higher than the USEPA Maximum Contaminant Level (MCL) for drinking water of 10 mg/L (U.S. Environmental Protection Agency, 2000b). However, many of the total nitrogen concentrations were higher than the preliminary USEPA total nitrogen nutrient criterion of 0.71 mg/L for streams in the Eastern Coastal Plain ecoregion (U.S. Environmental Protection Agency, 2002b). The percentage of samples containing total nitrogen concentrations higher than 0.71 mg/L ranged from zero for the Stillwater and Kennebec Rivers to 100 for the Aberjona River.

Median instantaneous total nitrogen loads for the indicator basins ranged from 26 (Stillwater River) to 142 kg/d (Aberjona River), and median total nitrogen yields ranged from 0.8 (Stillwater River) to 5.9 kg/d/mi^2 (Aberjona River) (table 4, fig. 11). For the integrator basins, median total nitrogen loads ranged from 1,400 (Charles River) to 14,600 kg/d (Merrimack River), and median total nitrogen yields ranged from 1.2 (Kennebec River) to 5.1 kg/d/mi^2 (Charles River) (table 5). Calculated yields are designed to remove the effect of drainage-basin size on the loads; therefore, they provide a better comparison between rivers of the effect of land use on loads. Total nitrogen yields were correlated with the percentage of urban land use in the indicator and integrator basins (table 6).

Phosphorus

Streamwater samples were analyzed for total phosphorus, dissolved phosphorus, and dissolved orthophosphorus. Median total phosphorus concentrations ranged from 0.02 (Stillwater River) to 0.04 mg/L (Aberjona River) in the indicator basins and from 0.04 (Kennebec River) to 0.07 mg/L (Merrimack River) in the integrator basins (tables 4 and 5; fig. 12). Total phosphorus concentrations were correlated with the percentage of urban land use in the drainage basin for the indicator basins, but were not correlated for the integrator basins (table 6). Among integrator sites, the Merrimack River had the highest median total phosphorus concentration (0.07 mg/L) even though the Merrimack River drainage basin is not as intensively urbanized as the Charles River drainage basin. The high median total phosphorus concentration in the Merrimack River likely is the result of the presence of more than 48 municipal wastewater-treatment facilities upstream from the sampling site. The U.S. Environmental Protection Agency (2002a) has recommended a preliminary total phosphorus criterion

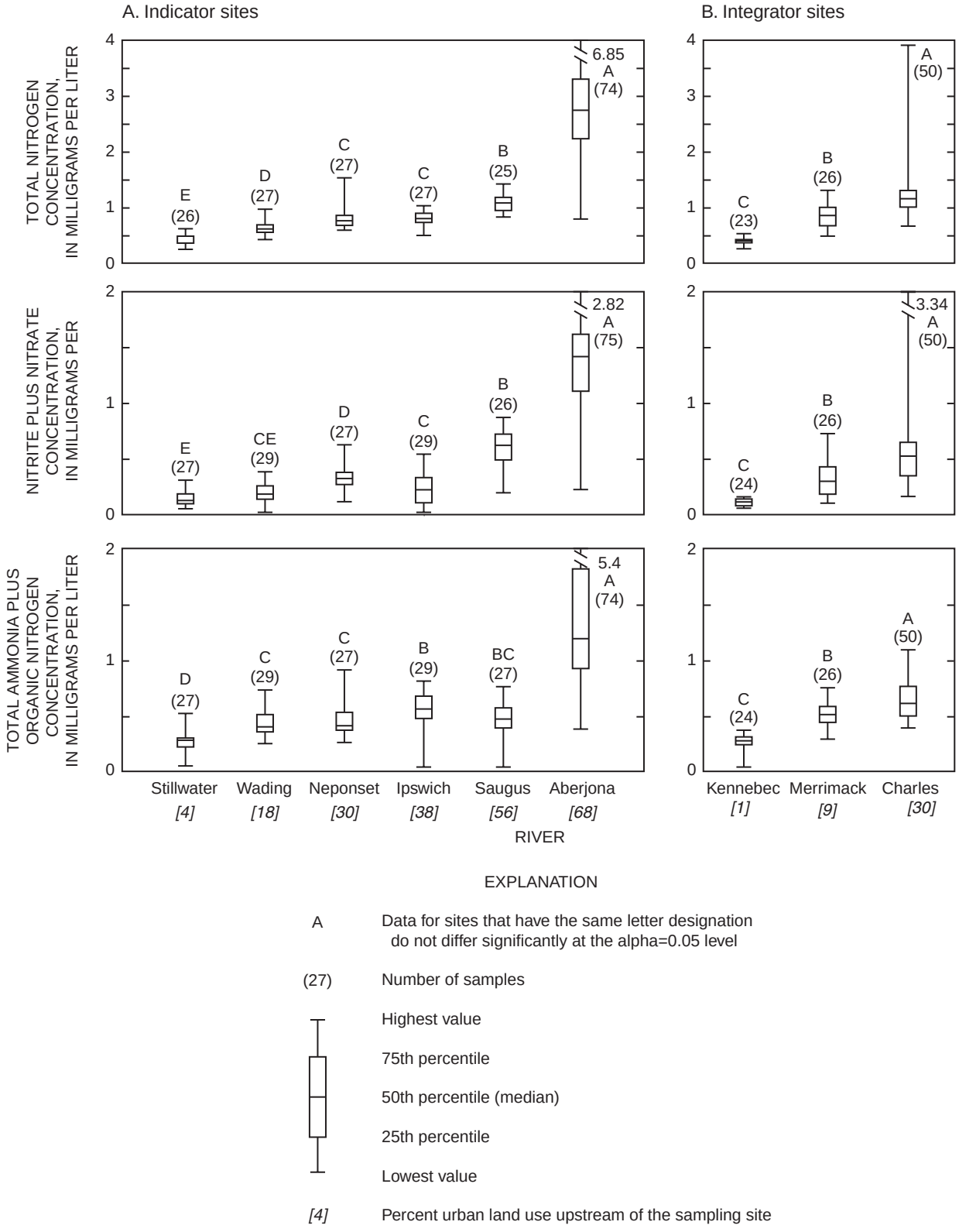


Figure 9. Distribution of total nitrogen, dissolved nitrate plus nitrite, and total ammonia plus organic nitrogen concentrations at the (A) six indicator and (B) three integrator sites in the New England Coastal Basins study area.

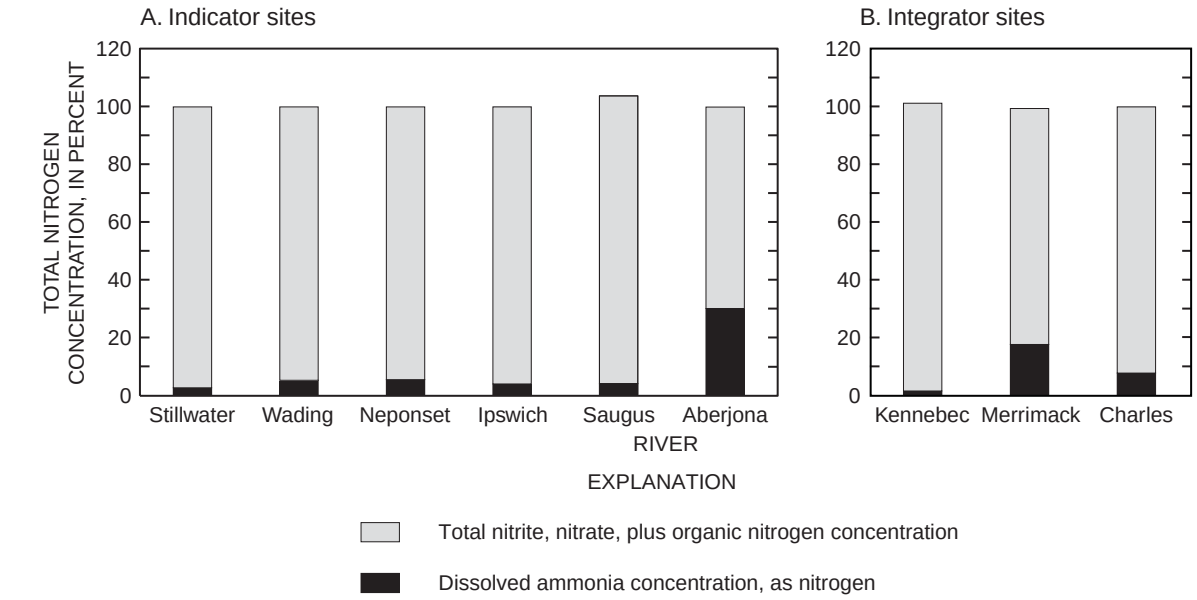


Figure 10. Composition of total nitrogen concentrations in the (A) six indicator and (B) three integrator basins in the New England Coastal Basins study area.

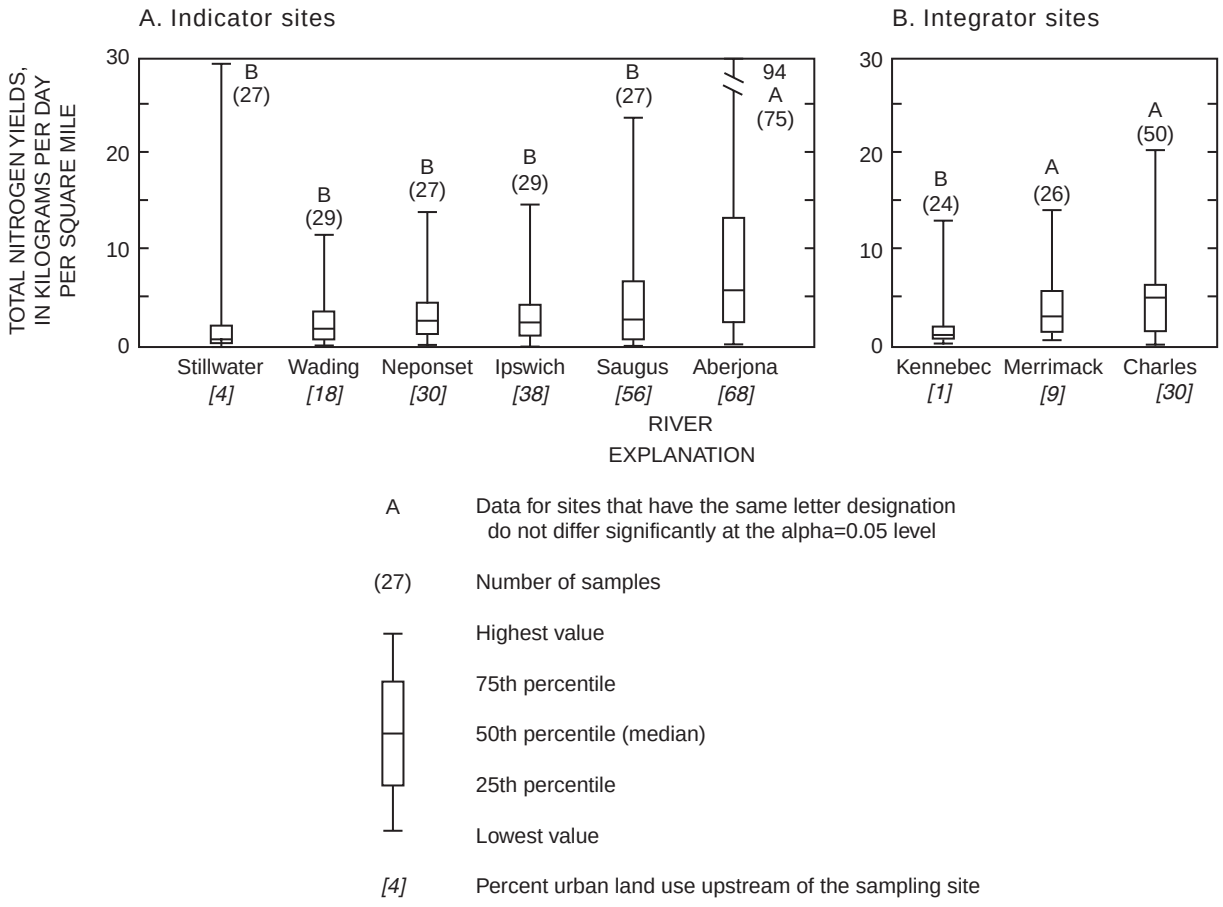


Figure 11. Distribution of instantaneous total nitrogen yields in the (A) six indicator and (B) three integrator sites in the New England Coastal Basins study area.

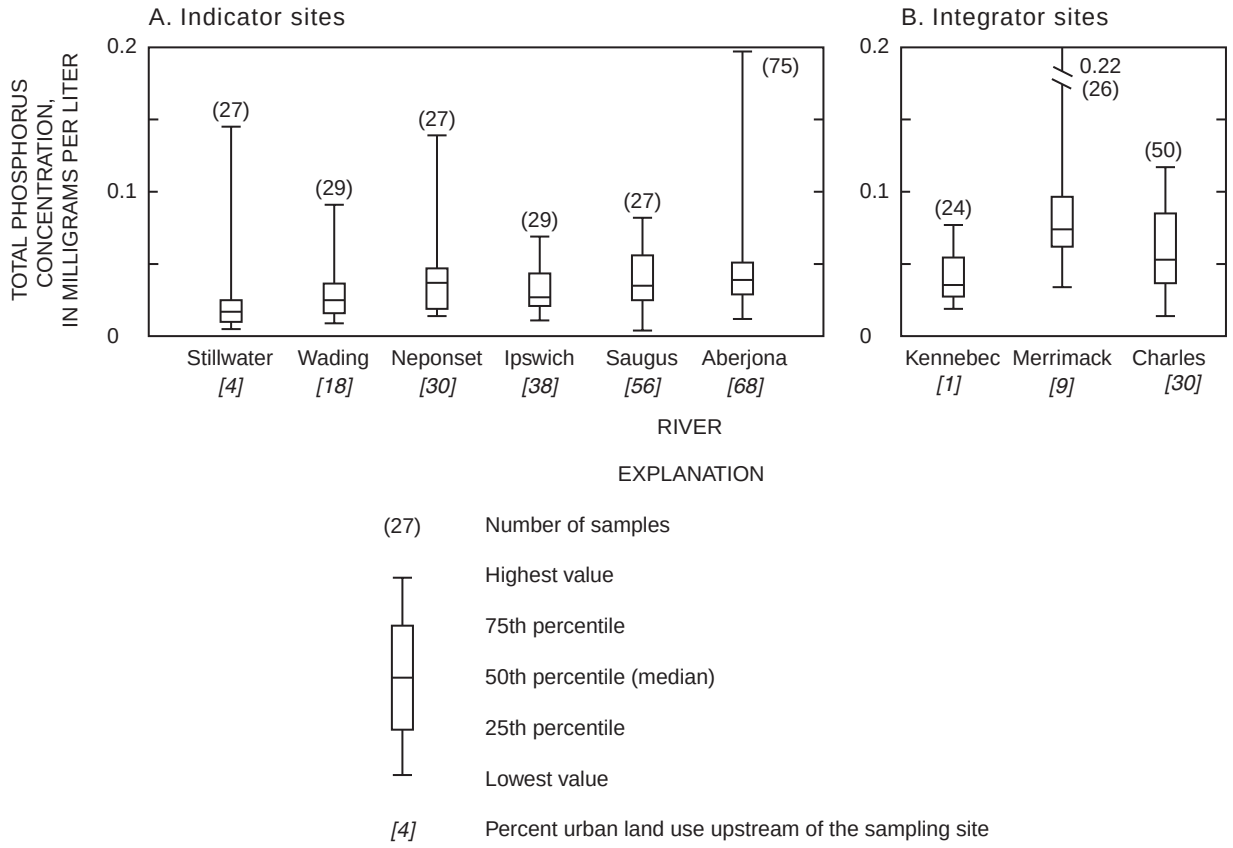


Figure 12. Distribution of total phosphorus concentrations at the (A) six indicator and (B) three integrator sites in the New England Coastal Basins study area.

of 0.031 mg/L for streams in the Eastern Coastal Plain ecoregion. This criterion was exceeded in samples from all nine sites. The percentage of samples that exceeded the recommended total phosphorus criterion by site ranged from 15 (Stillwater River) to 100 percent (Merrimack River).

Median dissolved orthophosphorus concentrations were at or less than the laboratory reporting level (LRL) of 0.01 mg/L for the six indicator basins, indicating that inorganic suspended phosphorus is the primary form of total phosphorus in the water at these sites. The composition of total phosphorus at the three integrator sites varied; total phosphorus concentrations from the Charles and Merrimack Rivers primarily were composed of suspended phosphorus, whereas total phosphorus concentrations at the Kennebec River were mostly from dissolved phosphorus.

Phosphorus normally is strongly sorbed to sediment (Hem, 1992). The relation of total phosphorus concentrations to suspended sediment concentrations for the indicator and integrator sites is shown in figure 13. A LOWESS smoothing line was applied to provide a picture of the relation between the two variables in the scatter plot. Total phosphorus concentrations at the indicator and integrator sites often increased when suspended-sediment concentrations increased during high streamflows.

Instantaneous total phosphorus yields were not correlated to the percentage of urban land use in the drainage basin among either the indicator or integrator sites (table 6). The Merrimack River had the highest median total phosphorus yield (0.3 kg/d/mi^2) among all nine sampling sites (tables 4 and 5), likely because of the upstream discharge of municipal-wastewater effluent.

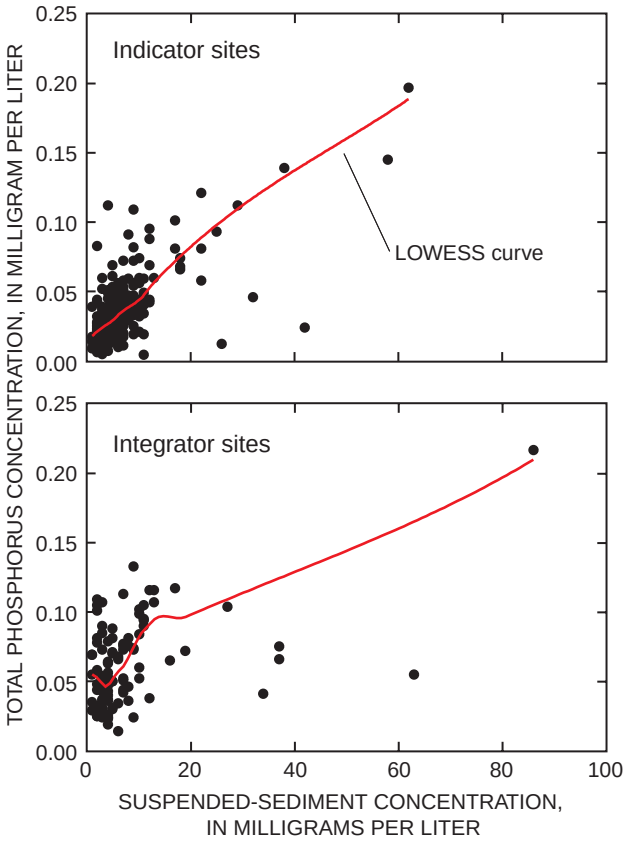


Figure 13. Relation between concentrations of total phosphorus and suspended sediment for the six indicator sites and three integrator sites in the New England Coastal Basins study area.

Pesticides

Pesticides were analyzed in 50 and 20 water samples collected from the Aberjona and Charles Rivers, respectively, during 1999 and 2000. Samples were analyzed for 44 pesticides and 4 degradation products (degradates) that include herbicides, insecticides, and fungicides (the compounds analyzed are listed in appendix 2). Pesticides were detected at both the Aberjona and Charles River sites, but with higher detection frequencies from samples collected during the spring and summer than during the winter. At both sites, herbicides were detected more frequently than insecticides, but the concentrations of insecticides were higher than the herbicide concentrations.

Sixteen pesticides (11 herbicides, 3 insecticides, and 2 degradates) were detected in one or more samples in the Aberjona River from April 1999 through September 2000 at concentrations less than 0.5 µg/L (table 7). Four pesticides were detected in more than 50 percent of the samples; these pesticides included the herbicides prometon (78 percent) and atrazine (58 percent), and the insecticides diazinon (84 percent) and carbaryl (72 percent). Because the Aberjona River Basin is intensely urbanized (68 percent), with little agriculture (2 percent), the pesticides detected likely are from applications to homes, businesses, utility right-of-ways, and highways. No water samples from the Aberjona River contained a pesticide concentration exceeding present USEPA drinking-water standards or USEPA criteria for protection of freshwater aquatic life (table 7). In three water samples from the Aberjona River, however, two pesticides were observed at concentrations exceeding the Canadian criteria for the protection of freshwater aquatic life (Canadian Council of Resources and Environmental Ministers, 2001) (table 7). The Canadian criteria of 0.2 µg/L for carbaryl was exceeded twice in May 1999, with estimated concentrations of 0.49 and 0.45 µg/L, and once in March 2000, with an estimated concentration of 0.21 µg/L (an estimated concentration indicates that the compound was detected in the water sample, but not accurately quantified). The Canadian criteria for the protection of freshwater aquatic life of 0.0035 µg/L for chlorpyrifos was exceeded twice in May 1999, with concentrations of 0.008 and 0.006 µg/L, and once in September 1999, with an estimated concentration of 0.01 µg/L. Carbaryl and chlorpyrifos are insecticides commonly used outdoors in urban areas of the Nation (Larson and others, 1997).

Fourteen pesticides (11 herbicides, 2 insecticides, and 1 degradate) were detected in one or more samples collected in the Charles River from May 1999 through March 2000 (table 7). Three pesticides were detected in more than 50 percent of all the samples—diazinon (80 percent), prometon (70 percent), and atrazine (50 percent). Pesticide concentrations generally were lower in the Charles River than concentrations in the Aberjona River. None of the water samples analyzed for pesticides in the Charles River exceeded any USEPA drinking water or United States or Canadian criteria for the protection of freshwater aquatic life.

Seasonal variations in pesticide concentrations and occurrence were observed in samples from the Aberjona River. Detection frequencies were greatest in spring and summer. The highest concentrations of atrazine were detected in samples from the middle and

Table 7. Statistical summary of pesticide compounds detected in water samples from the Aberjona and Charles Rivers in the New England Coastal Basins study area, 1998-2000

[All concentrations are in micrograms per liter (µg/L); All pesticide water samples filtered through a 0.7 micrometer (µm) size glass fiber filter; Min, minimum; Max, maximum; e, estimated concentration; H, Herbicide; I, Insecticide; M, Metabolite or break-down product; DCPA, Dimethyl tetrachloroterephthalate; EPTC, Ethyl dipropylthiocarbamate; DDE, Dichlorodiphenyl-dichloroethylene; <, less than; --, not applicable]

Pesticide compound name (type)	Laboratory reporting level, in µg/L	Aberjona River				Charles River				USEPA drinking water MCL[1]	USEPA chronic criteria for freshwater aquatic life[2]	CCREM guideline for freshwater aquatic life[3]
		Sample size	Percent detection	Concentration		Sample size	Percent detection	Concentration				
				Min	Max			Min	Max			
Atrazine (H)	0.001	50	58	<0.001	0.009	20	50	<0.001	0.010	3	12	2
Benfluralin (H)	.002	50	8	e .001	e .003	20	5	<.002	e .002	--	--	--
Carbaryl (I)	.003	50	72	<.003	e .49	20	40	<.003	e .098	--	--	0.2
Chlorpyrifos (I)	.004	50	6	<.004	e .010	20	0	<.004	<.004	--	--	.0035
Cyanazine (H)	.004	50	0	<.004	<.007	20	5	<.004	.008	--	--	2.0
											--	
DCPA (Dacthal) (H)	.002	50	2	<.002	e .001	20	25	e .001	.010	--	--	--
Deethyl Atrazine (M)	.002	50	30	<.002	e .006	20	20	<.002	e .004	--	--	--
Diazinon (I)	.002	50	84	<.002	.27	20	80	<.002	.036	--	--	--
EPTC (H)	.002	50	4	e .001	e .003	20	5	<.002	e .001	--	--	--
Metolachlor (H)	.002	50	46	e .0019	.008	20	10	<.002	.006	--	--	8
Napropamide (H)	.003	50	2	<.003	.029	20	0	<.003	<.003	--	--	--
p,p'- DDE (M)	.006	49	4	<.006	e .002	20	0	<.006	<.006		--	--
Pendimethalin (H)	.004	49	16	<.004	.024	20	5	<.004	.017		--	--
Prometon (H)	.018	50	78	e .004	.021	20	70	<.018	e .010	--	--	--
Simazine (H)	.005	50	40	e .003	.007	20	35	<.005	.008	4	--	10
Tebuthiuron (H)	.010	50	26	e .001	e .010	20	5	<.010	e .002	--	--	1.6
Trifluralin (H)	.002	50	30	e .0014	.005	20	10	<.002	e .003	--	--	.20

[1]Maximum Contaminant Level (MCL) established by the U.S. Environmental Protection Agency (2000a,b,c).

[2]Chronic criteria recommendations developed by the U.S. Environmental Protection Agency for the protection of freshwater aquatic life. Chronic is defined by the U.S. Environmental Protection Agency as the 4-day average concentration of targeted compound not to exceed criteria more than once every 3 years, on average (accessed on May 30, 2002, at http://www.epa.gov/waterscience/criteria/atrazine/atrazinefacts.html).

[3]Canadian water-quality guidelines for the protection of freshwater aquatic life (Canadian Council of Resources and Environmental Ministers, 2001).

late summer in 1999 and 2000. The two highest concentrations of prometon, a herbicide typically applied to control vegetation in utility right-of-ways, were in samples from October and November 1999. Metolachlor, an herbicide used primarily to control vegetation on agricultural lands, was detected in 46 percent of the samples from the Aberjona River and had the greatest number of detections in samples from late winter through mid summer. Few detectable concentrations of metolachlor were from samples collected in the fall and early winter. Higher concentrations of carbaryl and diazinon were observed in samples from May through October 1999, and from June through August 2000, than in other parts of the year. The highest insecticide concentrations were detected during the spring through fall months because these months are times of increased insect activity in New England. Seasonal variations in pesticide detection frequencies were less apparent in the Charles River than in the Aberjona River; although concentrations of atrazine and diazinon generally were higher in the summer than in other times of the year.

Volatile Organic Compounds

A variety of fuel, solvent, fumigants, refrigerants, and disinfection by-product compounds were found in the Aberjona and Charles Rivers at levels that are mostly less than freshwater aquatic life protection and drinking-water criteria. Eighty-four VOCs were analyzed in 23 and 29 water samples from the Aberjona and Charles Rivers, respectively, from October 1998 through March 2000 (appendix 3). Thirty different VOCs were detected in the Aberjona River; but only six of these compounds were detected at concentrations higher than the LRL (fig. 14). The remaining 24 compounds were at estimated concentrations less than the LRL. Water samples from the Charles River contained 29 VOCs, 10 of which had concentrations greater than the LRL. The solvents trichloroethylene (TCE), tetrachloroethylene (PCE), and *cis*-1,2- dichloroethylene (*cis*-DCE) were detected in all water samples from both rivers. The gasoline oxygenate methyl-*tert*-butyl ether (MTBE) and chloroform, a by-product of water chlorination and a widely used solvent, were found in all water samples from the Aberjona River and in 96 percent of the Charles River samples.

No VOC concentrations exceeded either USEPA freshwater acute and chronic toxicity criteria or Canadian water-quality guidelines as defined by Rowe and others (1997). One sample from the Charles River had a TCE concentration of 17.3 µg/L, which approached the Canadian TCE guideline of 21 µg/L, and one sample from the Aberjona River had a chloroform concentration of 1.87 µg/L, near the Canadian guideline of 2.0 µg/L. Two water samples from the Charles River had TCE concentrations that exceeded the USEPA MCL of 5 µg/L for drinking water (U.S. Environmental Protection Agency, 2000b); however, the Charles River at Watertown is not used as a drinking-water supply. Although concentrations of most individual compounds did not exceed current (2003) guidelines, the long-term and synergistic effects on aquatic life of a large number of VOCs detected at low levels in the two rivers is unknown and may be cause for concern.

Seasonal occurrence patterns of the commonly detected VOCs provide clues to the possible sources of these compounds. In both the Aberjona and Charles Rivers, chloroform concentrations, a by-product of water chlorination, are highest in the summer when reduced streamflows lessen the effects of dilution and the irrigation of lawns and gardens with chlorinated municipal water is common (figs. 15 and 16). This seasonal pattern also is evident in the Aberjona River for concentrations of bromodichloromethane. Bromodichloromethane is another by-product of chlorinated municipal drinking water, and was detected in 11 of the 23 samples collected at the Aberjona River, with the highest concentrations measured from June through September 1999.

Concentrations of MTBE show different seasonal patterns in the Charles and Aberjona Rivers. In the Aberjona River, concentrations were highest in the cool months; this seasonal pattern may be attributed to low volatilization of these compounds at comparatively low temperatures (Lopes and Price, 1997; and National Science and Technology Council, 1997) (fig. 15). Conversely, the Charles River had the highest MTBE concentrations in the summer when volatilization is expected to be highest (fig. 16). This occurrence pattern suggests a potential ground-water source of MTBE in the Charles River. In addition, the use of recreational motorized boats is extensive upstream of the monitoring site during the summer and the use of reformulated gasoline and oils by these boats also may be a source of MTBE.

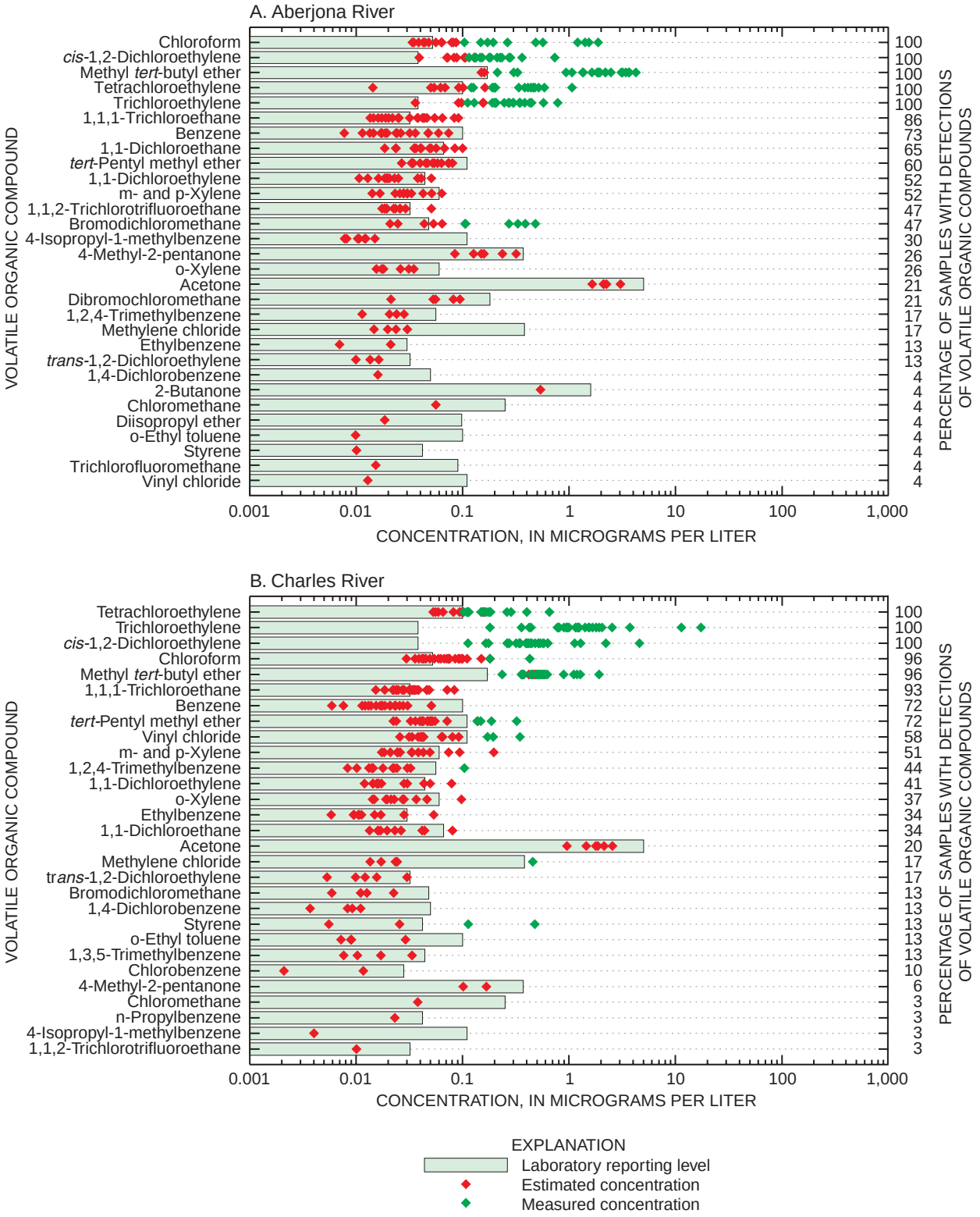


Figure 14. Concentrations of volatile organic compounds detected in water samples in the (A) Aberjona and (B) Charles Rivers, Mass.

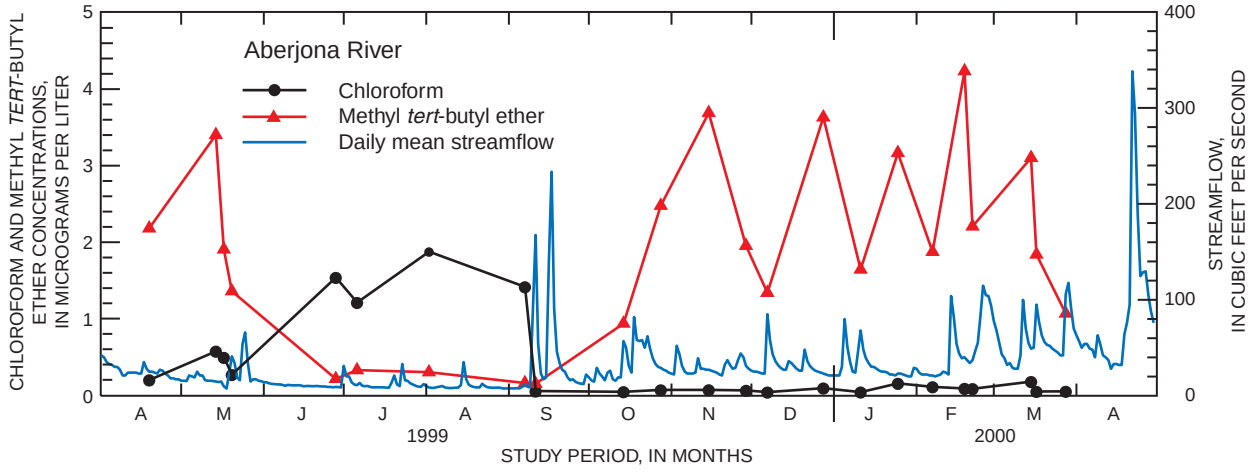


Figure 15. Chloroform and methyl *tert*-butyl ether concentrations, and daily mean streamflow in the Aberjona River, Mass., from April 1999 to April 2000.

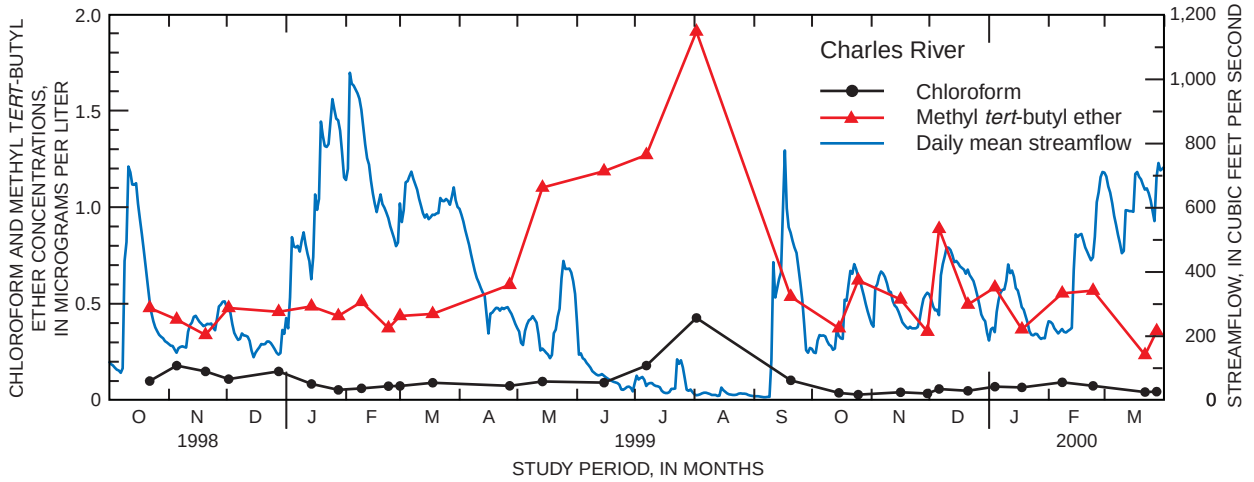


Figure 16. Chloroform and methyl *tert*-butyl ether concentrations in the Charles River at Watertown, Mass., and daily mean streamflow at the Charles River at Waltham, Mass., from October 1998 to April 2000.

Concentrations of the solvents *cis*-DCE, PCE and TCE in both rivers also were highest in the summer, when streamflows were lowest. Concentrations of *cis*-DCE, PCE and TCE in the Aberjona River also were high in the winter when streamflow was less than 20 ft^3/s, but may be attributed to low volatilization of these compounds at cool temperatures. This year-round inverse relation to streamflow indicates that *cis*-DCE, PCE and TCE concentrations may be from a continuous source(s), such as a point source or ground-water discharge.

WATER-QUALITY CONDITIONS OF MONITORING SITES IN THE NEW ENGLAND COASTAL BASINS, LONG ISLAND-NEW JERSEY COASTAL DRAINAGES, AND OTHER NATIONAL WATER-QUALITY ASSESSMENT PROGRAM URBAN SITES

The presence and concentrations of selective nutrients, pesticides, and VOCs in the Aberjona and Charles River monitoring sites were similar and different to what was found as part of NAWQA studies in the LINJ study unit in the New York City metropolitan region and across the Nation. Ayers and others (2000) presents a summary of findings from the LINJ study, and a summary of NAWQA Program findings nationally for nutrients and pesticides are reported in U.S. Geological Survey (1999).

Nutrients

The median total nitrogen concentration in the Aberjona River (2.7 mg/L) was more than twice the median total nitrogen concentration found in Bound Brook, New Jersey (1.27 mg/L), and the median concentration of 48 urbanized NAWQA indicator sites (1.27 mg/L) across the Nation (fig. 17a). The median total nitrogen concentration in the other five NECB indicator sites all were less than the national NAWQA median concentration. In a comparison of median total nitrogen concentrations for integrator sites, all three of the NECB integrator sites had lower median total nitrogen concentrations than was found in the Passaic River in New Jersey and in 28 other NAWQA integrator sites throughout the Nation (fig. 17a).

Median total phosphorus concentrations for all NECB indicator and integrator sites were lower than what was found at the two LINJ and 76 NAWQA-sampled sites (fig. 17b). Median total phosphorus concentrations were nearly six times higher in the Passaic River than in the similar-sized and urbanized Charles River, more than four times higher than the Merrimack River, and nearly two times higher than the national median concentration for 28 integrator sites. The high concentrations of total nitrogen and total phosphorus in the Passaic River are likely from the presence of 22 municipal wastewater-treatment facility discharges in the drainage basin upstream of the sampling site (Reiser and O'Brien, 1998). The Charles River has five municipal wastewater-treatment facility discharges upstream of the sampling site (Laura Hayes, U.S. Geological Survey, written commun., 2002). As previously noted, the Merrimack River also has numerous municipal wastewater-treatment facility discharges upstream from the sampling site.

The generally lower concentrations of median total nitrogen and median total phosphorus in NECB rivers than what were found in the LINJ rivers and other NAWQA-sampled rivers nationally may be due to a variety of factors. These factors include nutrient-poor glacial sediments and soils in comparison to soils in other areas of the Nation, riparian stream banks that are more vegetated and less developed than found elsewhere in other urban areas of the Nation, and an appreciable percentage of treated, municipal wastewater being directly discharged to offshore coastal waters near Boston (Medalie, 1996).

Pesticides

Median concentrations and detection frequencies of the four pesticides atrazine, prometon, carbaryl, and diazinon were higher in the two LINJ rivers than in either the NECB streams or in 33 other NAWQA urban streams sampled throughout the Nation (figs. 18a and b). The insecticides carbaryl and diazinon were detected more frequently and at higher median concentrations in the Aberjona River than the median of 33 other urban streams sampled throughout the Nation (figs. 18a and b). Overall, pesticide detections were more frequent and at higher concentrations in the spring and summer growing seasons in both the LINJ (Reiser, 1999) and NECB sites than in winter, indicating that the pesticides likely are being transported to the streams by storm runoff soon after applications.

Volatile Organic Compounds

Median VOC concentrations and detection frequencies of TCE, PCE, *cis*-DCE, MTBE, were higher in the Aberjona and Charles Rivers than in the two LINJ rivers and in 26 other urban rivers monitored by the NAWQA Program throughout the Nation

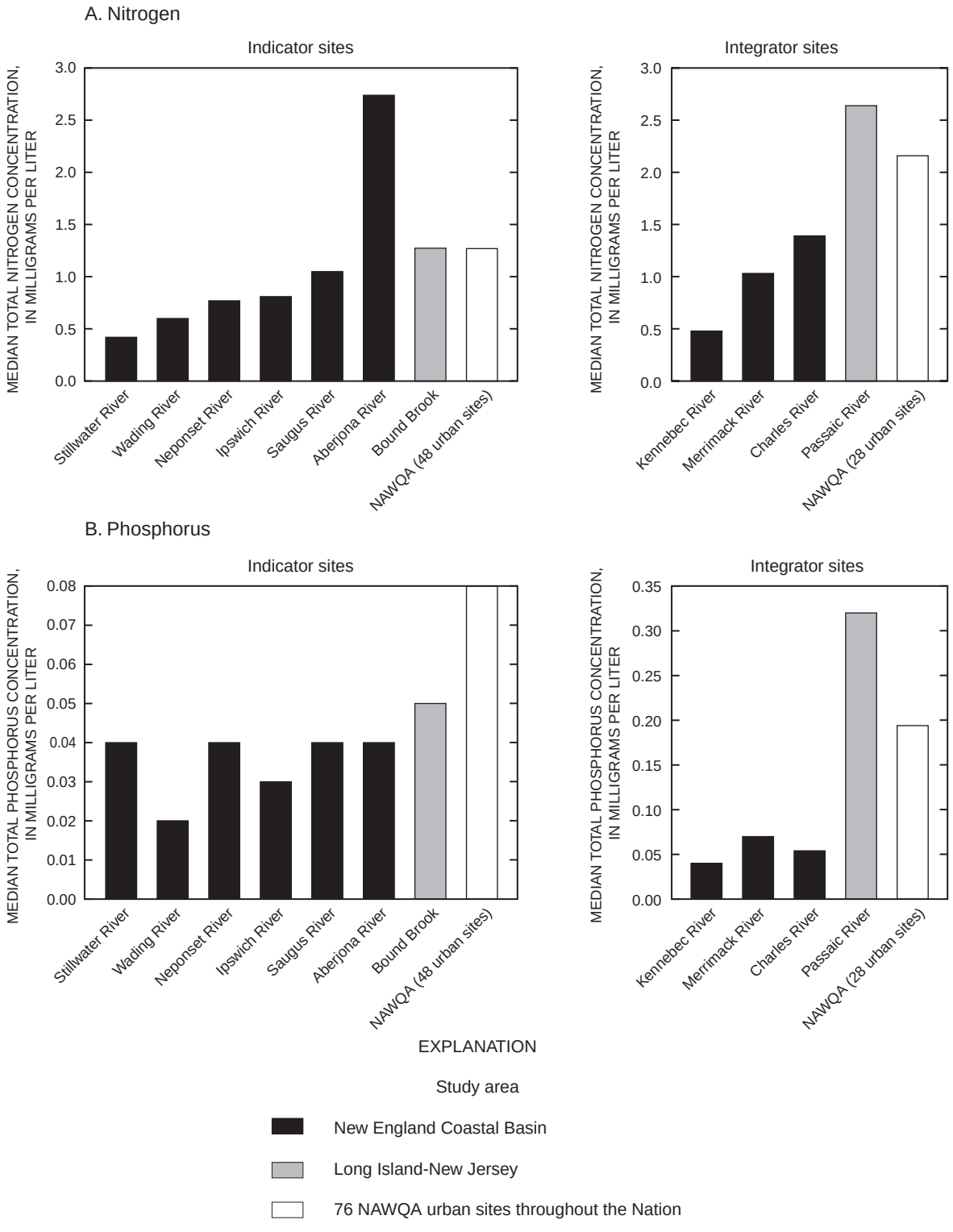


Figure 17. Median total nitrogen (A) and median total phosphorus concentrations (B) of the New England Coastal Basins (NECB) fixed-site network in relation to the Long Island-New Jersey (LINJ) study area basins at Bound Brook at Middlesex and Passaic River at Two Bridges, N.J., and 76 urban rivers monitored by the National Water-Quality Assessment (NAWQA) Program throughout the Nation by indicator and integrator sites.

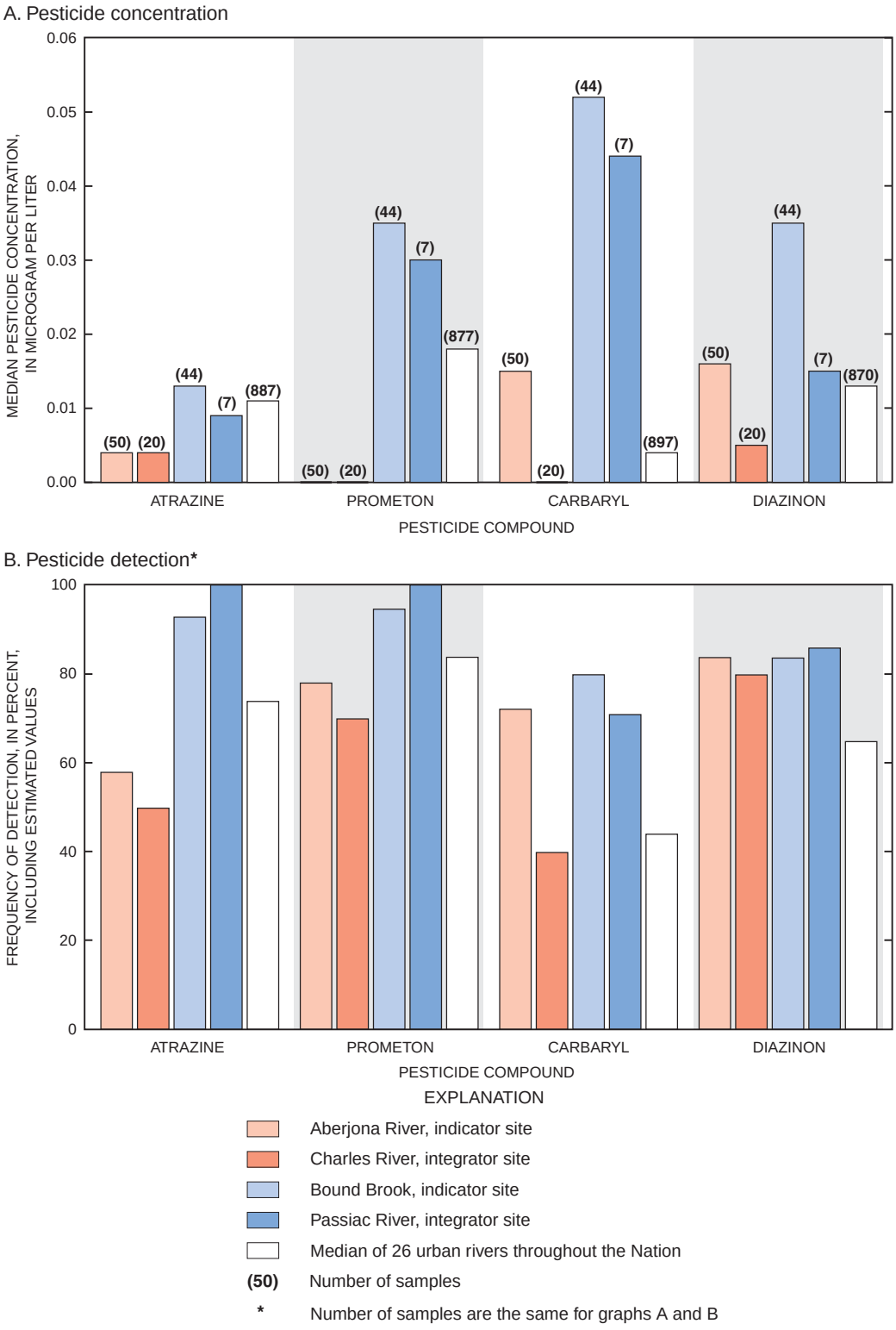


Figure 18. Median concentrations (A) and frequency of detection (B) of the pesticide compounds atrazine, prometon, carbaryl, and diazinon in the Aberjona River at Winchester, Mass., Bound Brook at Middlesex, N.J., Charles River at Watertown, Mass., and Passaic River at Two Bridges, N.J., in relation to 33 urban rivers monitored by the National Water Quality Assessment Program (NAWQA) throughout the Nation. A median of 0.0 indicates that the median concentration was less than the NAWQA long-term method detection level for that compound.

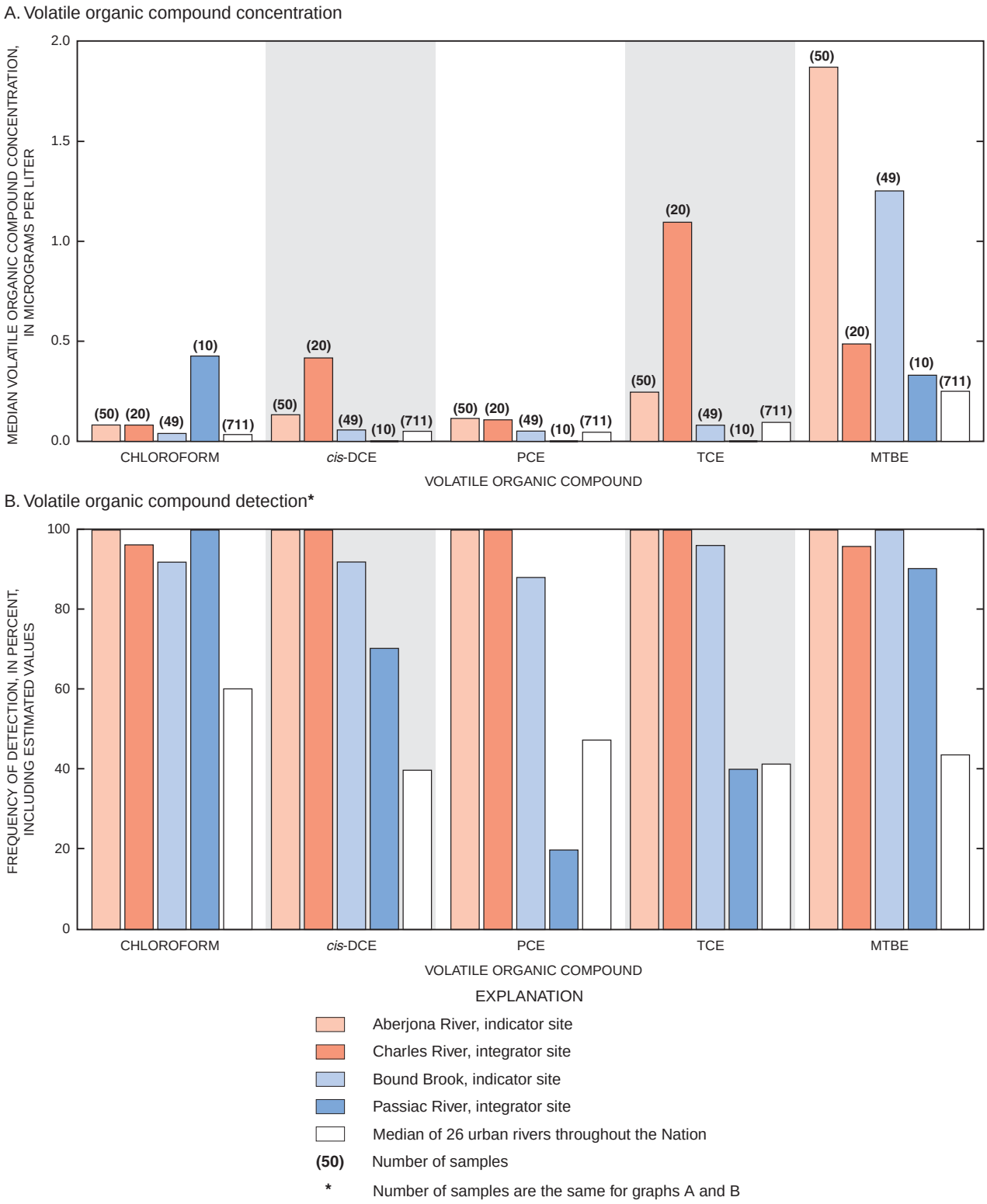


Figure 19. Median concentrations (A) and frequency of detection (B) of the volatile organic compounds chloroform, *cis*-1,2, dichloroethene (*cis*-DCE), tetrachloroethylene (PCE), trichloroethylene (TCE), and methyl *tert*-butyl ether (MTBE) in the Aberjona River at Winchester, Mass., Bound Brook at Middlesex, N.J., Charles River at Watertown, Mass., and Passaic River at Two Bridges, N.J., in relation to 26 urban rivers monitored by the National Water Quality Assessment Program (NAWQA) throughout the Nation. A median concentration of 0.0 indicates that the median concentration was less than the NAWQA long-term method-detection level for that compound.

(figs. 19a and b). Regionally, median concentrations of the gasoline additive MTBE were higher in the NECB and LINJ rivers, especially in the Aberjona River and Bound Brook indicator sites, than the median concentration of 26 other urbanized rivers throughout the Nation. MTBE was detected in nearly all of the water samples in the NECB and LINJ streams compared to 44 percent nationally. The median TCE concentration (1.17 µg/L) and detection frequency (100 percent) in the Charles River integrator drainage basin was higher than in either the Passaic River (less than 0.1 µg/L and 40 percent) or the national NAWQA median (0.09 µg/L and 41 percent).

Chloroform was the only VOC compound detected more frequently and at a higher median concentration in a LINJ sampling stream (the Passaic River) than in either of the NECB sampling streams. Chloroform concentrations were highest in both the NECB and LINJ streams in summer and during low flows. In the Passaic River, the chloroform concentrations may be related to the presence of numerous chlorinated wastewater discharges (Reiser and O'Brien, 1998, table 9, p. 6). In contrast, chlorinated wastewater discharges in the Aberjona and Charles Rivers are minimal, indicating that chloroform in the NECB sites may be derived from nonpoint sources, especially runoff from the irrigation of lawns and gardens.

The two LINJ rivers had higher concentrations of MTBE, TCE, and PCE in water samples collected during the winter than in water samples collected in the summer (Reiser and O'Brien, 1998, table 9, p. 6). In contrast, the two NECB rivers had higher concentrations of TCE and PCE in water samples collected during the summer than in samples collected in the winter. The Charles River also had the highest MTBE concentrations during the summer (fig. 16). These differences in seasonal patterns of VOC concentrations between the LINJ and NECB rivers indicate that sources and movement of VOCs differ between these rivers.

SUMMARY AND CONCLUSIONS

Concentrations of selected major ions and nutrients, and values of field parameters in streams of the New England Coastal Basins (NECB) study area are affected by the amount of urbanization in the watershed. This conclusion is based on 2 years of routine monitoring, from October 1998 to September 2000, of nine rivers in the study area by the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program. Eight of these nine rivers (Aberjona, Saugus, Ipswich, Stillwater, Neponset, Wading, Charles, and Merrimack Rivers) are in the Boston metropolitan area of Massachusetts; the ninth river (Kennebec River) is in central Maine. The nine rivers represent a range of urbanization from 1 percent (Kennebec River) to 68 percent (Aberjona River). Six of the sites represent small drainage basins (less than 50 mi^2) called indicator sites, and three (Kennebec, Merrimack, and Charles Rivers) of the sites are called integrator sites that drain large (greater than 250 mi^2) basins.

Specific-conductance data from all rivers were correlated with the percentage of urban land use in the drainage basin; specific-conductance values increased during periods of reduced streamflows and during winter months possibly because of road de-icing applications. Median pH values in all nine sampling sites were around the neutral value of 7; although pH values increased as the percentage of urban land use increased. Concentrations of dissolved oxygen (DO) in water samples from the Aberjona, Charles, and Merrimack Rivers were below the Massachusetts minimum criteria of 5 mg/L during periods of low streamflows and high water temperatures. Concentrations of the major ions calcium, sodium, sulfate, and chloride were correlated with the percentage of urban land use in a drainage basin. In the intensely urbanized drainage basins, concentrations of sodium and chloride increase in the summer and winter indicating that low flows and road de-icing applications affect concentrations of these ions.

Concentrations of total nitrogen, as well as the various organic and inorganic species of nitrogen, were correlated with the percentage of urban land use in a drainage basin. Median concentrations for total nitrogen and all nitrogen species were highest at the sites with the highest percentage of urban land use, indicating that the amount of urbanization in a drainage basin affects total nitrogen concentrations in the NECB study area. Specific sources of the total nitrogen are not known, but likely include nonpoint sources such as fertilizer application, atmospheric deposition, unknown point sources, leaking sewer lines, and contaminated ground water. Total nitrogen concentrations from eight of the nine sites were composed of primarily nitrate

and organic nitrogen; the exception is the Aberjona River, which had a high percentage of ammonia. The USEPA preliminary total nitrogen criterion of 0.71 mg/L for the region frequently was exceeded at many of the rivers. Similar to nitrogen concentrations, total nitrogen yields were correlated with the percentage of urban land use, and the highly urbanized Aberjona and Charles Rivers had the highest median total nitrogen yields.

Total phosphorus concentrations also were correlated with the percentage of urban land use in a drainage basin for the indicator basins, but were not for the integrator basins. Total phosphorus concentrations in the study area typically are composed of inorganic suspended phosphorus. Total phosphorus concentrations increased with increasing suspended-sediment concentrations at many of the sites. The USEPA-recommended total phosphorus criterion of 0.031 mg/L was exceeded in various samples collected from all sites. Instantaneous total phosphorus yields were not correlated to the percentage of urban land use in a drainage basin among either the indicator or integrator sites. Samples from the Merrimack River had the highest median total phosphorus yield, likely a result of numerous municipal wastewater-effluent discharges upstream of the monitoring site.

Pesticides and volatile organic compounds (VOCs) were analyzed in 70 samples from the highly urbanized Aberjona and Charles Rivers in the Boston metropolitan area. Pesticides frequently were detected in samples collected during the spring and summer months when pesticide usage is greatest. A total of 16 different pesticide compounds were detected in the two rivers, but at concentrations less than 0.5 µg/L. At both sites, herbicides were more commonly detected than insecticides. The herbicides prometon and atrazine and the insecticide diazinon were detected in more than 50 percent of all samples collected from both rivers. No water sample contained pesticide concentrations exceeding any USEPA drinking-water standard or criteria for protecting freshwater aquatic life. However, three water samples from the Aberjona River contained two pesticides (carbaryl and chlorpyrifos) at concentrations exceeding the Canadian criteria for the protection of freshwater aquatic life.

Volatile organic compounds were frequently detected in the Aberjona and Charles Rivers, but at concentrations that were generally below USEPA drinking-water and freshwater aquatic-life protection criteria. The solvents TCE, PCE, and *cis*-DCE were detected in all water samples from both rivers. The gasoline oxygenate MTBE and chloroform were detected in all 23 water samples from the Aberjona River, and in all but 1 of 29 water samples (97 percent) from the Charles River. Two water samples from the Charles River had TCE concentrations that exceeded the USEPA Maximum Contaminant Level (MCL) of 5 µg/L for drinking water (although the Charles River is not used as a drinking-water supply at the sampling site).

The VOCs chloroform, *cis*-DCE, PCE, and TCE had high concentrations in the summer when streamflows are lowest indicating that these compounds may be originating from a continuous source such as an unknown point source or ground-water recharge. MTBE concentrations in the Aberjona River were highest in the winter. Conversely, the Charles River had high concentrations of MTBE in samples from the summer when volatilization is expected to be greatest; recharge from gasoline-contaminated discharge from ground water and(or) recreational motorized boats upstream (that use reformulated gasoline and oils) of the monitoring site may be sources of MTBE to the river.

Water-quality conditions were compared to conditions in two NAWQA-sampled rivers in the New York City metropolitan area, and to NAWQA-sampled rivers in other urban areas across the Nation. Median total nitrogen and total phosphorus concentrations in the NECB rivers sampled generally were lower than median concentrations found in other NAWQA urban rivers sampled in the Long Island-New Jersey (LINJ) area and across the Nation. The one exception was the Aberjona River. The median total nitrogen concentration in this river was almost twice the median concentration found in other NAWQA urban rivers nationally. Possible explanation for the low nutrient concentrations in the NECB study area include the presence of nutrient-poor glaciated sediments and soils, riparian stream banks that are more vegetated and less developed than elsewhere in other urban areas of the Nation, and an appreciable percentage of treated, municipal wastewater being directly discharged to offshore coastal waters.

The most frequently detected pesticides in two NECB rivers (atrazine, carbaryl, diazinon and prometon) generally had median concentrations lower than concentrations in urbanized rivers in the LINJ area and nationally. Median concentrations of carbaryl and

diazinon in the Aberjona River near Boston, however, were higher than the median of all other NAWQA urban rivers.

The VOC compound MTBE was detected in nearly 100 percent in the NECB and LINJ rivers compared to the national median of 44 percent—a reflection of the high use of MTBE in gasoline in the Boston and New York City metropolitans areas. The median PCE concentration in the Charles River was more than six times higher than the median concentrations in the LINJ rivers or other urbanized NAWQA sampling sites. Median concentration and detection frequencies of TCE, PCE, and *cis*-DCE were higher in the two NECB rivers than in the two LINJ rivers. Chloroform was the only VOC found more frequently and at a higher median concentration in a LINJ river than in the two NECB rivers. Differences in seasonal patterns of VOC concentrations between the NECB and LINJ rivers indicate that sources and movement of VOCs differ among the four rivers in the two study areas.

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Table 4. Summary statistics for selected water-quality constituents in the six indicator sites in the New England Coastal Basins study area, 1998-2000

[Min, minimum; Med, median; Max, maximum; µs/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; <, less than; kg/d, kilograms per day; kg/d/mi^2, kilograms per day per square mile; µg/L, micrograms per liter]

Water-quality constituent	Indicator sites											
	Aberjona River				Ipswich River				Neponset River			
	Sample size	Min	Med	Max	Sample size	Min	Med	Max	Sample size	Min	Med	Max
Field measurements												
Specific conductance, in µs/cm at 25°C	76	150	521	1,010	29	166	265	345	27	176	235	297
pH, standard units	41	6.9	7.1	7.5	16	6.4	6.7	7.1	11	6.8	7.2	7.3
Water temperature, in °C	76	0.2	14.9	24.8	29	0.1	8	23.1	27	1.3	11.8	24.1
Dissolved oxygen, in mg/L as O_2	76	3.1	8	15	29	6.3	10.2	12.6	27	6.6	10	15.2
Dissolved oxygen, percent saturation	75	35	79.5	110	29	73	85	94	27	78	93	109
Alkalinity, dissolved, incremental (mg/L as $CaCO_3$)	70	20	53	75	28	10	21	44	25	12	23	34
Major ions												
Calcium, dissolved (mg/L as Ca)	75	8.39	29.4	39.3	29	7.33	12.1	14.9	27	6.3	10.1	13.7
Magnesium, dissolved (mg/L as Mg)	75	1.38	5.09	6.56	29	1.61	2.77	3.36	27	1.82	2.86	4.04
Sodium, dissolved (mg/L as Na)	75	14.6	58.1	148	29	16.9	31	47.5	27	20.2	26	39
Potassium, dissolved (mg/L as K)	75	1.82	3.37	4.28	29	1.67	2.34	4.76	27	1.14	1.77	2.5
Sulfate, dissolved (mg/L as SO_4)	75	9.9	25.8	63.1	29	4.8	12.5	28.8	27	6.4	9.1	13.4
Chloride, dissolved (mg/L as CL)	75	22.1	108	259	29	26.3	56.1	82.2	27	32.9	47.4	63.6
Fluoride, dissolved (mg/L as F)	75	<0.1	0.1	0.3	29	<0.1	<0.1	0.2	27	<0.1	<0.1	0.1
Silica, dissolved (mg/L as SiO_2)	75	2.7	7.7	10.3	29	1.6	7.6	14.2	27	3.1	5.9	10.2
Nutrients												
Ammonia, dissolved (mg/L as N)	75	0.02	0.82	4.93	29	<0.02	0.03	0.16	27	<0.02	0.04	0.18
Ammonia + organic, dissolved (mg/L as N)	74	.1	1.1	4.5	29	.27	.47	.75	27	.2	.37	.59
Ammonia + organic, Total (mg/L as N)	74	.39	1.2	5.4	29	.1	.57	.82	27	.27	.42	.92

Table 4. Summary statistics for selected water-quality constituents in the six indicator sites in the New England Coastal Basins study area, 1998-2000--Continued

[Min, minimum; Med, median; Max, maximum; µs/cm, microsiemens per centimeter at 25ºC; ºC, degrees Celsius; mg/L, milligrams per liter; <, less than; kg/d, kilograms per day; kg/d/mi^2, kilograms per day per square mile; µg/L, micrograms per liter]

Water-quality constituent	Indicator sites											
	Aberjona River				Ipswich River				Neponset River			
	Sample size	Min	Med	Max	Sample size	Min	Med	Max	Sample size	Min	Med	Max
Nutrients--Continued												
Nitrite + nitrate, dissolved (mg/L as N)	75	0.23	1.42	2.82	29	0.05	0.23	0.55	27	0.12	0.33	0.63
Nitrite, dissolved (mg/L as N)	75	<.01	0.039	0.25	29	<.01	<.01	.014	27	<.01	<.01	.02
Nitrogen, Total (mg/L as N)	75	.8	2.74	6.85	29	.46	.81	1.04	27	.6	.77	1.54
Nitrogen, Total, load (kg/d)	75	5.9	142	2,260	29	.25	115	660	27	7.87	92	490
Nitrogen, Total, yield (kg/d/mi^2)	75	.24	5.9	94	29	.01	2.6	15	27	.23	2.7	14
Phosphorus, dissolved (mg/L as P)	75	<.004	.008	.03	29	<.004	.013	.1	27	<.05	.013	.03
Phosphorus, ortho, dissolved (mg/L as P)	75	<.01	<.01	.02	29	<.01	<.01	.03	27	<.01	<.01	.02
Phosphorus, Total (mg/L as P)	75	.012	.039	.2	29	.011	.03	.07	27	.014	.04	.14
Phosphorus, Total, load (kg/d)	72	.14	1.7	67	26	.009	4.2	21	24	.4	2.8	44
Phosphorus, Total, yield (kg/d/mi^2)	72	.006	.07	2.8	26	2.1e-04	.09	.5	24	.01	.08	1.3
Iron, dissolved (µg/L as Fe)	75	20	140	520	29	140	320	1,270	27	120	260	700
Manganese, dissolved (µg/L as Mn)	75	67.3	201	549	29	18.8	114	1,010	27	38.8	101	241
Sediment												
Suspended sediment, in mg/L	75	2	7	62	29	1	4	32	27	1	6	38

Table 4. Summary statistics for selected water-quality constituents in the six indicator sites in the New England Coastal Basins study area, 1998-2000--Continued

[Min, minimum; Med, median; Max, maximum; µs/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; <, less than; kg/d, kilograms per day; kg/d/mi^2, kilograms per day per square mile; µg/L, micrograms per liter]

Water-quality constituent	Indicator sites											
	Saugus River				Stillwater River				Wading River			
	Sample size	Min	Med	Max	Sample size	Min	Med	Max	Sample size	Min	Med	Max
Field measurements												
Specific conductance, in µs/cm at 25°C	27	160	496	624	27	56	105	153	29	148	211	290
pH, standard units	15	6.9	7.2	7.6	13	6	6.5	6.7	13	6.4	6.8	6.9
Water temperature, in °C	27	.1	8.5	21	27	.1	10.3	21.3	29	.1	11	24.5
Dissolved oxygen, in mg/L as O_2	27	6.6	10.5	14	26	6.7	9.6	13.3	29	4.5	8.9	14.7
Dissolved oxygen, percent saturation	27	75	89	100	26	69	87	97	29	55	86	112
Alkalinity, dissolved, incremental (mg/L as $CaCO_3$)	26	18	47.5	76	26	2	8.5	27	27	6	16	31
Major ions												
Calcium, dissolved (mg/L as Ca)	27	7.35	19.4	26.7	27	2.26	5.2	10.6	29	5.21	8.72	10.8
Magnesium, dissolved (mg/L as Mg)	27	2.28	6.61	10.8	27	0.47	1	2.02	29	0.99	2.06	2.67
Sodium, dissolved (mg/L as Na)	27	19.5	54.4	69.7	27	6.2	10.7	32.6	29	15.7	26.2	35.9
Potassium, dissolved (mg/L as K)	27	1.4	2.57	3.9	27	.7	1.25	2	29	.9	1.57	2.41
Sulfate, dissolved (mg/L as SO_4)	27	6.3	14.8	22.9	27	.1	6.9	10.7	29	5.8	9	30.8
Chloride, dissolved (mg/L as CL)	27	32.4	103	137	26	9.7	18.3	53.1	29	28.1	43.9	63.7
Fluoride, dissolved (mg/L as F)	27	<0.1	<0.1	0.3	26	<.1	<0.1	0.1	29	<.1	<0.1	0.2
Silica, dissolved (mg/L as SiO_2)	27	3.3	9.1	13.9	27	3.8	6.4	8.5	29	1.3	5.5	9.5
Nutrients												
Ammonia, dissolved (mg/L as N)	27	<0.02	0.04	0.16	27	<0.02	<0.02	0.05	29	<0.02	0.03	0.15
Ammonia + organic, dissolved (mg/L as N)	27	.1	.41	.81	27	.06	.21	.38	29	.19	.34	.69
Ammonia + organic, Total (mg/L as N)	27	.1	.48	.77	27	.06	.29	.53	29	.26	.41	.74

Table 4. Summary statistics for selected water-quality constituents in the six indicator sites in the New England Coastal Basins study area, 1998-2000--Continued

[Min, minimum; Med, median; Max, maximum; µs/cm, microsiemens per centimeter at 25ºC; ºC, degrees Celsius; mg/L, milligrams per liter; <, less than; kg/d, kilograms per day; kg/d/mi^2, kilograms per day per square mile; µg/L, micrograms per liter]

Water-quality constituent	Indicator sites											
	Saugus River				Stillwater River				Wading River			
	Sample size	Min	Med	Max	Sample size	Min	Med	Max	Sample size	Min	Med	Max
Nutrients--Continued												
Nitrite + nitrate, dissolved (mg/L as N)	26	0.2	0.63	0.88	27	0.06	0.13	0.31	29	<0.05	0.19	0.39
Nitrite, dissolved (mg/L as N)	27	<.01	<.01	.02	27	<.01	<.01	.02	29	<.01	<.01	.02
Nitrogen, Total (mg/L as N)	27	.7	1.05	1.4	27	.23	.42	.63	29	.43	.6	.98
Nitrogen, Total, load (kg/d)	27	2.3	67	560	27	.54	26	930	29	2.5	84	510
Nitrogen, Total, yield (kg/d/mi^2)	27	.1	2.9	24	27	.02	0.8	29	29	.06	2.0	12
Phosphorus, dissolved (mg/L as P)	27	<.05	.011	.06	27	<.004	.005	.013	29	<.05	.01	.04
Phosphorus, ortho, dissolved (mg/L as P)	27	<.01	.010	.03	27	<.01	<.01	.02	29	<.01	<.01	.02
Phosphorus, Total (mg/L as P)	27	<.004	.035	.08	27	<.008	.02	.15	29	<.05	.02	.09
Phosphorus, Total, load (kg/d)	24	.1	2.1	34	24	.02	1.1	215	26	.07	3.0	75
Phosphorus, Total, yield (kg/d/mi^2)	24	.004	.09	1.5	24	.001	.03	7	26	.002	.07	1.7
Iron, dissolved (µg/L as Fe)	27	60	200	530	27	50	140	290	29	90	240	690
Manganese, dissolved (µg/L as Mn)	27	41.5	97.4	306	27	19.1	43.3	177	29	26.9	63.3	191
Sediment												
Suspended sediment, in mg/L	27	2	4	42	27	2	4	58	29	1	4	13

Table 5. Summary statistics for selected water-quality constituents in the three integrator sites in the New England Coastal Basins study area, 1998-2000

[Min, minimum; Med, median; Max, maximum; µs/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; <, less than; kg/d, kilograms per day; kg/d/mi^2, kilograms per day per square mile; µg/L, micrograms per liter]

Water-quality constituent	Integrator sites											
	Charles River				Kennebec River				Merrimack River			
	Sample size	Min	Med	Max	Sample size	Min	Med	Max	Sample size	Min	Med	Max
Field measurements												
Specific conductance, in µs/cm at 25°C	52	219	326	450	24	36	67.5	91	27	83	153	209
pH, standard units	26	6.9	7.2	7.5	12	6.8	7.25	7.5	12	6.7	7.1	7.3
Water temperature, in °C	52	0.1	12	27	24	0.1	7.9	23.5	27	0.1	12	26.7
Dissolved oxygen, in mg/L as O_2	51	2.2	9.2	14.9	24	7	11.3	14.2	27	.5	10	14.3
Dissolved oxygen, percent saturation	50	26	87	104	23	82	98	110	26	26	95	131
Alkalinity, dissolved, incremental (mg/L as $CaCO_3$)	49	14	27	51	21	8	17	31	23	4	12	23
Major ions												
Calcium, dissolved (mg/L as Ca)	51	8.69	14.2	50.3	24	3.14	4.88	6.57	26	3.52	5.97	8.69
Magnesium, dissolved (mg/L as Mg)	51	2.09	3.18	11.4	24	.69	1.03	1.33	26	.72	1.2	1.72
Sodium, dissolved (mg/L as Na)	51	25.5	38.4	98.2	24	2	5.85	9.1	26	8.4	16.8	25.9
Potassium, dissolved (mg/L as K)	51	.68	2.62	4.36	24	.53	.74	1.53	26	.85	1.49	2.81
Sulfate, dissolved (mg/L as SO_4)	52	6.4	12.25	24.1	25	3.1	7.1	12.4	27	5.5	7.8	12.3
Chloride, dissolved (mg/L as CL)	51	45.2	68.2	107	24	3.1	5.4	8.4	26	13.1	27.9	41.9
Fluoride, dissolved (mg/L as F)	51	<.1	<0.1	0.2	24	<.1	<.1	<0.1	26	<.1	.1	.2
Silica, dissolved (mg/L as SiO_2)	51	1.3	5.2	28.1	24	2.5	3.7	5	26	3	4.75	6.9
Nutrients												
Ammonia, dissolved (mg/L as N)	50	0.026	0.09	0.57	24	<0.02	<0.02	0.14	26	0.04	0.15	0.42
Ammonia + organic, dissolved (mg/L as N)	50	.29	.5	.9	23	.1	.24	.34	26	.21	.4	1.7
Ammonia + organic, Total (mg/L as N)	50	.4	.62	1.1	24	.1	.29	.38	26	.3	.52	.76

Table 5. Summary statistics for selected water-quality constituents in the three integrator sites in the New England Coastal Basins study area, 1998-2000--Continued

[Min, minimum; Med, median; Max, maximum; µs/cm, microsiemens per centimeter at 25ºC; ºC, degrees Celsius; mg/L, milligrams per liter; <, less than; kg/d, kilograms per day; kg/d/mi^2, kilograms per day per square mile; µg/L, micrograms per liter]

Water-quality constituent	Integrator sites											
	Charles River				Kennebec River				Merrimack River			
	Sample size	Min	Med	Max	Sample size	Min	Med	Max	Sample size	Min	Med	Max
Nutrients--Continued												
Nitrite + nitrate, dissolved (mg/L as N)	50	0.167	0.53	3.34	24	0.062	0.19	0.16	26	0.11	0.30	0.73
Nitrite, dissolved (mg/L as N)	50	<.01	.012	.06	24	<.01	<.01	.02	26	<.01	.013	.03
Nitrogen, Total (mg/L as N)	50	.67	1.16	3.91	24	.19	.4	.53	26	.49	.86	1.31
Nitrogen, Total, load (kg/d)	50	56	1,400	5,500	24	1,600	6,560	70,700	26	3,120	14,600	65,700
Nitrogen, Total, yield (kg/d/mi^2)	50	.21	5.1	20	24	.3	1.2	13	26	.67	3.1	14
Phosphorus, dissolved (mg/L as P)	50	<.05	.02	.06	24	.006	.03	.06	26	.01	.04	.08
Phosphorus, ortho, dissolved (mg/L as P)	50	<.01	.02	.05	24	<.01	.02	.05	26	<.01	.03	.07
Phosphorus, Total (mg/L as P)	50	.014	.05	.18	24	.02	.04	.08	26	.03	.07	.22
Phosphorus, Total, load (kg/d)	45	5.7	48	260	22	234	677	9,150	23	297	1,250	15,000
Phosphorus, Total, yield (kg/d/mi^2)	45	.02	.2	1	22	.04	.13	1.7	23	.06	.3	3.3
Iron, dissolved (µg/L as Fe)	51	90	230	850	24	40	60	90	26	20	120	270
Manganese, dissolved (µg/L as Mn)	51	38	81.2	211	24	3.9	12.8	18.4	26	2.2	37.1	84.3
Sediment												
Suspended sediment, in mg/L	51	1	6	27	24	1	3	63	25	2	5	86

Appendix 1. Constituents analyzed in surface-water samples from fixed sites in the New England Coastal Basins study area, 1998-2000

[Dissolved oxygen, in milligrams per liter; pH standard units for laboratory and field; $CaCO_3$, in milligrams per liter; alkalinity and bicarbonate, in milligrams per liter as HCO_3; SP, specific conductance in microsiemens per centimeter at 25° C, temperature in degrees Celsius, °C]

	Laboratory analyses		
Field measurements	**Major constituents**	**Nutrients**	**Suspended sediment**
Specific conductance	Dissolved solids	Nitrogen	Concentration
pH	Major ions and metals	Dissolved	Sieve diameter (percent finer than 0.0625 millimeter)
Temperature	Calcium	Dissolved ammonia (as N)	
Dissolved oxygen	Chloride	Dissolved nitrite (as N)	
Alkalinity	Fluoride	Dissolved nitrate (as N)	
Bicarbonate	Iron	Dissolved ammonia and organic nitrogen (as N)	
	Magnesium	Total ammonia and organic nitrogen (as N)	
	Manganese	Phosphorus	
	Potassium	Total	
	Silica	Dissolved	
	Sodium	Orthophosphorus (as P)	
	Sulfate	Organic carbon	
		Suspended	
		Dissolved	

Appendix 2. Pesticides and degradation products analyzed in surface-water samples from the Aberjona and Charles Rivers in the New England Coastal Basins study area, 1998-2000

[CAS, Chemical Abstract Services; No., number]

Compound	Description	CAS No.	Compound	Description	CAS No.
2,6-Diethylalanine	Degradation product	579-66-8	Malathion	Insecticide	121-75-5
Acetochlor	Herbicide	34256-82-1	Metolachlor	Herbicide	51218-45-2
Alachlor	Herbicide	15972-60-8	Metribuzin	Herbicide	21087-64-9
alpha-HCH	Degradation product	319-84-6	Molinate	Herbicide	2212-67-1
Atrazine	Herbicide	1912-24-9	Napropamide	Herbicide	15299-99-7
Azinphos-methyl	Insecticide	86-50-0	p,p'-DDE	Degradation product	72-55-9
Benfluralin	Herbicide	1861-40-1	Parathion	Insecticide	56-38-2
Butylate	Herbicide	2008-41-5	Parathion-methyl	Insecticide	2998-00-0
Carbaryl	Insecticide	63-25-2	Pebulate	Herbicide	1114-71-2
Carbofuran	Insecticide	1563-66-2	Pendimethalin	Herbicide	40487-42-1
Chlorpyrifos	Insecticide	2921-88-2	Phorate	Insecticide	298-02-2
cis-Permethrin	Insecticide	54774-45-7	Prometon	Herbicide	1610-18-0
Cyanazine	Herbicide	21725-46-2	Propachlor	Herbicide	1918-16-7
Dacthal	Herbicide	1861-32-1	Propanil	Herbicide	709-98-8
Deethylatrazine	Degradation product	6190-65-4	Propargite	Insecticide	2312-35-8
Diazinon	Insecticide	333-41-5	Propyzamide	Herbicide	23950-58-5
Dieldrin	Insecticide	60-57-1	Simazine	Herbicide	122-34-9
Disulfoton	Insecticide	298-04-4	Tebuthiuron	Herbicide	34014-18-1
EPTC	Herbicide	759-94-4	Terbacil	Herbicide	5902-51-2
Ethalfluralin	Herbicide	55283-68-6	Terbufos	Insecticide	13071-79-9
Ethoprophos	Insecticide	13194-48-4	Terbuthylazine	Herbicide	5915-41-3
Fonofos	Insecticide	944-22-9	Thiobencarb	Herbicide	28249-77-6
Lindane	Insecticide	58-89-9	Tri-allate	Herbicide	2303-17-5
Linuron	Herbicide	330-55-2	Trifluralin	Herbicide	1582-09-8

Appendix 3. Volatile organic compounds analyzed in surface-water samples from the Aberjona and Charles Rivers in the New England Coastal Basins study area, 1998-2000

[CAS, Chemical Abstract Services; No., number]

Compound	Primary use or source	CAS No.	Compound	Primary use or source	CAS No.
1,1,1,2-Tetrachloroethane	Solvent	630-20-6	Carbon tetrachloride (tetrachloromethane)	Solvent	56-23-5
1,1,1-Trichloroethane (TCA)	Solvent	71-55-6	Chlorobenzene	Solvent	108-90-7
1,1,2,2-Tetrachloroethane	Solvent	79-34-5	Chloroethane	Solvent	75-00-3
1,1,2-Trichloroethane	Solvent	79-00-5	Chloroform (trichloromethane)	Disinfection by-product	67-66-3
1,1,2-Trichlorotrifluoroethane (CFC-113 or 1,1,3-Freon)	Refrigerant	76-13-1	Chloromethane (Methyl chloride)	Refrigerant	74-87-3
1,1-Dichloroethane	Solvent	75-34-3	Dibromochloromethane	Disinfection by-product	124-48-1
1,1-Dichloroethylene	Organic synthesis	75-35-4	Dibromomethane	Solvent	74-95-3
1,1-Dichloropropene	Organic synthesis	563-58-6	*cis*-1,2-Dichloroethylene	Solvent	156-59-2
1,2,3,4-Tetramethylbenzene	Hydrocarbon	488-23-3	*cis*-1,3-Dichloropropene	Fumigant	10061-01-5
1,2,3,5-Tetramethylbenzene (isodurene)	Hydrocarbon	527-53-7	*trans*-1,2-Dichloroethylene	Solvent	156-60-5
1,2,3-Trichlorobenzene	Organic synthesis	87-61-6	*trans*-1,3-Dichloropropene	Fumigant	10061-02-6
1,2,3-Trichloropropane	Solvent	96-18-4	*trans*-1,4-Dichloro-2-butene	Organic synthesis	110-57-6
1,2,3-Trimethylbenzene	Gasoline	526-73-8	Dichlorodifluoromethane (CFC-12)	Refrigerant	75-71-8
1,2,4-Trichlorobenzene	Solvent	120-82-1	Diethyl ether	Solvent	60-29-7
1,2,4-Trimethylbenzene	Organic synthesis	95-63-6	Diisopropyl ether	Gasoline	108-20-3
1,2-Dibromo-3-chloropropane	Fumigant	96-12-8	Ethyl methacrylate	Organic synthesis	97-63-2
1,2-Dibromoethane	Solvent	106-93-4	Ethyl *tert*-butyl ether (ETBE)	Gasoline	637-92-3
1,2-Dichlorobenzene	Solvent	95-50-1	Ethylbenzene	Gasoline	100-41-4
1,2-Dichloroethane	Solvent	107-06-2	Hexachlorobutadiene	Organic synthesis	87-68-3
1,2-Dichloropropane	Solvent	78-87-5	Hexachloroethane	Solvent	67-72-1
1,3,5-Trimethylbenzene	Gasoline	108-67-8	Isopropyl-benzene	Organic synthesis	98-82-8
1,3-Dichlorobenzene	Solvent	541-73-1	m- and p-Xylene	Gasoline	108-38-3 106-42-3
1,3-Dichloropropane	Organic synthesis	142-28-9	Methyl acrylate	Organic synthesis	96-33-3
1,4-Dichlorobenzene	Fumigant	106-46-7	Methyl acrylonitrile	Organic synthesis	126-98-7
2,2-Dichloropropane	Organic synthesis	594-20-7	Methyl *tert*-butyl ether (MTBE)	Gasoline	1634-04-4
			Methyl ethyl ketone (2-Butanone)	Solvent	78-93-3
			Methyl iodide	Organic synthesis	74-88-4
2-Chlorotoluene	Solvent	95-49-8	Methyl methacrylate	Organic synthesis	80-62-6
2-Hexanone	Solvent	591-78-6	Methylene chloride (dichloromethane)	Solvent	75-09-2
3-Chloropropene	Organic synthesis	107-05-1	Naphthalene	Organic synthesis	91-20-3
4-Chlorotoluene	Solvent	106-43-4	n-Propyl-benzene	Solvent	103-65-1

Appendix 3. Volatile organic compounds analyzed in surface-water samples from the Aberjona and Charles Rivers in the New England Coastal Basins study area, 1998-2000--Continued

[CAS, Chemical Abstract Services; No., number]

Compound	Primary use or source	CAS No.	Compound	Primary use or source	CAS No.
4-Isopropyl-1-methylbenzene (p-iso propyltoluene)	Organic synthesis	99-87-6	o-Ethyl toluene	Hydrocarbon	611-14-3
4-Methyl-2-pentanone (methyl isobutyl ketone)	Solvent	108-10-1	o-Xylene	Gasoline	95-47-6
Acetone	Solvent	67-64-1	sec-Butylbenzene	Organic synthesis	135-98-8
Acrylonitrile	Organic synthesis	107-13-1	Styrene	Organic synthesis	100-42-5
Benzene	Gasoline	71-43-2	*tert*-Butylbenzene	Organic synthesis	98-06-6
			tert-Pentyl methyl ether (TAME)	Organic synthesis	994-05-8
Bromobenzene	Solvent	108-86-1	Tetrachloroethylene (PCE)	Solvent	127-18-4
Bromochloromethane	Organic synthesis	74-97-5	Tetrahydrofuran	Solvent	109-99-9
Bromodichloromethane	Disinfection by-product	75-27-4			
Bromoethene	Organic synthesis	593-60-2	Trichloroethylene (TCE)	Solvent	79-01-6
Bromoform (tribromomethane)	Disinfection by-product	75-25-2	Trichlorofluoromethane (CFC-11)	Refrigerant	75-69-4
Bromomethane (methyl bromide)	Fumigant	74-83-9	Vinyl chloride	Organic synthesis	75-01-4
Butylbenzene	Organic synthesis	104-51-8			
Carbon disulfide	Organic synthesis	75-15-0			