Cover photo:
Charles River, looking east from the
Massachusetts Avenue Bridge, Boston, Massachusetts.

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

Streamflow, Water Quality, and Contaminant Loads in the Lower Charles River Watershed, Massachusetts, 1999–2000

By ROBERT F. BREAULT, JASON R. SORENSON, and PETER K. WEISKEL

Water-Resources Investigations Report 02-4137

In cooperation with the
U.S. ENVIRONMENTAL PROTECTION AGENCY, the
MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION, and the
MASSACHUSETTS WATER RESOURCES AUTHORITY

Northborough, Massachusetts
2002

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CONVERSION FACTORS

Multiply	By	To obtain
acre	0.00405	square kilometer
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609344	kilometer
square mile (mi^2)	2.58999	square kilometer
gallon (gal)	0.003785	cubic meter

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

$$°F = 1.8°C + 32$$

WATER-QUALITY UNITS

Concentrations of water-quality constituents are given in milligrams per liter (mg/L) and micrograms per liter (µg/L). Milligrams per liter (mg/L) are equivalent to parts per million (ppm). Micrograms per liter (µg/L) are equivalent to parts per billion (ppb). Turbidity is given in nephelometric turbidity units (NTUs), specific conductance in microseimens per centimeter at 25°C, (µS/cm), and bacteria concentrations in colony forming units (CFU) per 100 mL. Water volume is given in units of liters (L), cubic feet (ft^3), and gallons (gal). Rainfall intensity is in inches per hour (in/hr). Loads are in mass or trillion colony forming units (TCFUs) per unit time, per storm, or per year. Yields are given in mass or TCFUs per unit time, storm, or year per unit area.

ABBREVIATIONS AND ACRONYMS

ACS	American Chemical Society
BCF	Bias Correction Factor
BOD-5	Biochemical Oxygen Demand
BMPs	Best Management Practices
BWSC	Boston Water and Sewer Commission
CDPW	Cambridge Department of Public Works
CSO	Combined Sewer Overflow
CY	Calendar Year
DIW	Deionized Water
EDTA	ethylenediaminetetraacetic acid
EMC	Event Mean Concentration
EWI	Equal Width Increment
GIS	Geographic Information System
HCl	hydrochloric acid
hr	hour
LOWESS	Locally Weighted Scatterplot Smoother
MADEP	Massachusetts Department of Environmental Protection
MBTA	Massachusetts Bay Transit Authority
MDL	Method Detection Limit
MRL	Minimum Reporting Limit
MWRA	Massachusetts Water Resources Authority
NAQWA	National Water-Quality Assessment
nm	nanometer
NOAA	National Oceanic and Atmospheric Administration
NURP	National Urban Runoff Program
NWS	National Weather Service
PSI	Pound per square inch
RPD	Relative Percent Difference
SOD	Sediment Oxygen Demand
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Sediment
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WWTP	WasteWater Treatment Plant
WY	Water Year

Streamflow, Water Quality, and Contaminant Loads in the Lower Charles River Watershed, Massachusetts, 1999–2000

By Robert F. Breault, Jason R. Sorenson, *and* Peter K. Weiskel

Abstract

Streamflow data and dry-weather and stormwater water-quality samples were collected from the main stem of the Charles River upstream of the lower Charles River (or the Basin) and from four partially culverted urban streams that drain tributary subbasins in the lower Charles River Watershed. Samples were collected between June 1999 and September 2000 and analyzed for a number of potential contaminants including nitrate (plus nitrite), ammonia, total Kjeldahl nitrogen, phosphorus, cadmium, chromium, copper, lead, and zinc; and water-quality properties including specific conductance, turbidity, biochemical oxygen demand, fecal coliform bacteria, *Enterococcus* bacteria, total dissolved solids, and total suspended sediment. These data were used to identify the major pathways and to determine the magnitudes of contaminants loads that contribute to the poor water quality of the lower Charles River. Water-quality and streamflow data, for one small urban stream and two storm drains that drain subbasins with uniform (greater than 73 percent) land use (including single-family residential, multifamily residential, and commercial), also were collected. These data were used to elucidate relations among streamflow, water quality, and subbasin characteristics.

Streamflow in the lower Charles River Watershed can be characterized as being unsettled and flashy. These characteristics result from the impervious character of the land and the complex infrastructure of pipes, pumps, diversionary canals, and detention ponds throughout the watershed. The water quality of the lower Charles River can be considered good—meeting water-quality standards and guidelines—during dry weather. After rainstorms, however, the water quality of the river becomes impaired, as in other urban areas. The poor quality of stormwater and its large quantity, delivered over short periods (hours and days), together with illicit sanitary cross connections, and combined sewer overflows, results in large contaminant loads that appear to exceed the river's assimilative capacity.

Annual contaminant loads from stormwater discharges directly to the lower Charles River are large, but most dry-weather and stormwater contaminant loads measured in this study originate from upstream of the Watertown Dam and are delivered to the lower Charles River in mainstem flows. An exception is fecal coliform bacteria. Stony Brook, a large tributary influenced by combined sewer overflow, contributed almost half of the annual fecal coliform load to the lower Charles River for Water Year 2000. Much of this fecal coliform bacteria load is discharged from Stony Brook to the lower Charles River during rainstorms. Estimated stormwater loads for future conditions suggest that sewer separation in the Stony Brook Subbasin might reduce loads of constituents associated with sewage but increase loads of constituents associated with street runoff.

The unique environment offered by the lower Charles River must be considered when the environmental implications of large contaminant loads are interpreted. In particular, the lower Charles River has low hydraulic gradients, a lack of tidal flushing, a lack of natural uncontaminated sediment from erosion of upstream uncontaminated soils, and an anoxic, sulfide-rich bottom layer that forms a non-tidal salt wedge in the downstream part of the lower Charles River. Individually and in combination, these characteristics may increase the likelihood of adverse effects of some contaminants on the water, biota, and sediment of the lower Charles River.

INTRODUCTION

The Charles River (fig. 1), historically a tidal estuary, has been a major part of the economic, social, and recreational lives of the people of eastern Massachusetts over the past 6,000 years (Metropolitan District Commission, written commun., 2000). More recently, over the past 100 years, the river has served as a transportation corridor and industrial center, as the physical setting for some of the world's most prestigious colleges and universities, and as a focal point for many recreational activities including Boston's annual Fourth of July celebration. Unfortunately, the river has also served as a sanitary sewer carrying industrial and domestic wastes, including raw sewage. Adverse effects of the latter were initially dealt with by building an earthen dam between the river and Boston Harbor at the river's mouth. Damming of the river in the early 1900s flooded the "foul-smelling," "unsightly," and "distinctly unsanitary" tidal mud flats (Pritchett and others, 1903) and created a freshwater lake known locally as the lower Charles River, or the lower Charles River Basin, or simply the "Basin" (herein referred to as the lower Charles River to prevent confusion).

Today (2002) the lower Charles River is the focal point of the Charles River Reservation, a 19,500-acre urban park that serves as a major open-space resource for the population of the Boston metropolitan area. This park receives over 20,000 visitors daily and supports a variety of recreational activities, including boating, walking, jogging, and cycling (Metropolitan District Commission, 2000). Unfortunately, water-quality conditions of the lower Charles River still preclude swimming and a healthy aquatic environment able to support large and diverse populations of fish—surprisingly, for many of the same reasons present over 100 years ago. Consequently, the U.S. Environmental Protection Agency (USEPA) Region I has designated the lower Charles River as a priority water body and has set the goal of achieving "swimmable and fishable" water-quality conditions in the River by the year 2005.

Although the water quality of the lower Charles River has improved considerably in recent years—because of the combined efforts of government agencies and citizens' groups—achieving fishable and swimmable conditions will require further reductions in contaminant loads from different sources. These include: sources upstream of the Watertown Dam under both dry and stormwater conditions; illicit discharges to tributary streams during all weather conditions; stormwater from tributary streams and storm drains that enters the river during rainstorms and snowmelt events; Boston- and Cambridge-area combined sewer overflows (CSOs) that affect the river during large rainstorms; and internal loading from bottom sediments.

Contaminant loads to the lower Charles River from stormwater and other sources have been previously investigated, but more targeted information is needed to characterize and quantify loads from various sources to determine the best remediation actions. Previous studies suggested that the drainage basin upstream of Watertown Dam and stormwater discharges downstream of this dam are the primary sources of bacteria and other contaminants to the upper portion of the lower Charles River from Watertown to the Cottage Farm CSO Treatment Facility during moderate to large rainstorms (Massachusetts Water Resources Authority, 1994; 1997). Upstream and stormwater loads may also be quantitatively appreciable, relative to CSO loads, in the lower portion of the lower Charles River downstream of the Cottage Farm facility (Massachusetts Water Resources Authority, 1994; 1997). Accurate estimation of the dry-weather and stormwater loads from upstream flows and from tributary andstorm-drain discharges (non-CSO loads), however, has been hampered by the lack of simultaneous flow and chemical-concentration data. In addition, previous stormwater-sampling programs were not specifically designed to measure loads to the lower Charles River and, thus, do not allow for the characterization of spatial or temporal contaminant-loading patterns (Massachusetts Water Resources Authority, 1997).

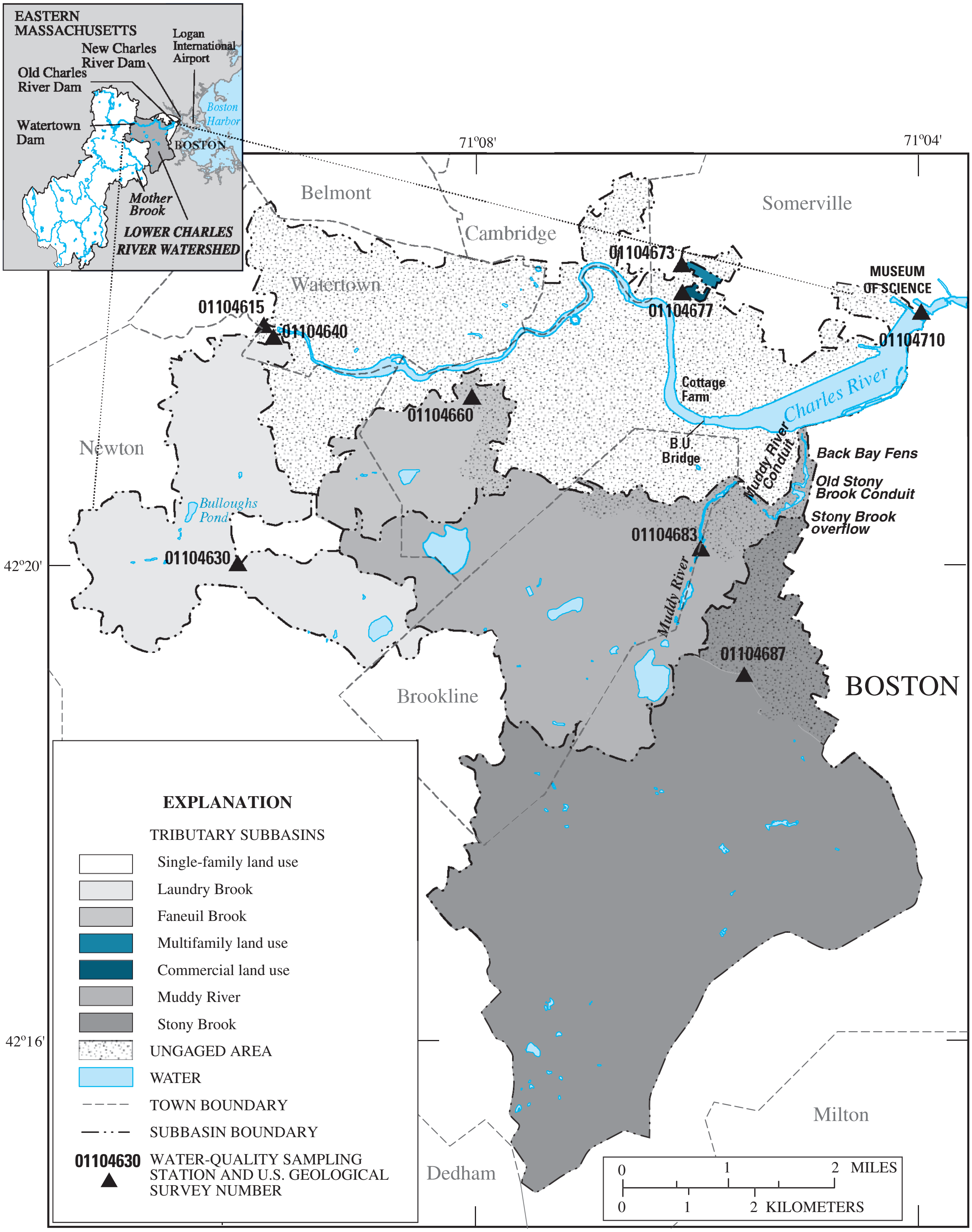


Figure 1. Location of tributary subbasins, major streams, and sampling stations in the lower Charles River Watershed, Massachusetts.

This type of information is needed for the implementation of targeted, cost-effective best management practices (BMPs). Finally, although recent programs to identify and eliminate illicit discharges and implement BMPs for stormwater control likely have resulted in improvements in stormwater quality, there is a lack of recent data to verify these changes. Selection of optimal remediation strategies for the lower Charles River, including appropriate levels of treatment for CSOs entering from Boston and Cambridge and appropriate stormwater-management options, depends critically upon accurate characterization of loads from all sources.

Purpose and Scope

The purpose of this investigation is to provide detailed information concerning water quality in the lower Charles River Watershed and patterns of contaminant loading to the lower Charles River from upstream and tributary subbasins. Contaminant loading from CSOs, however, is not discussed extensively in this report. The Massachusetts Water Resources Authority reports CSO loading patterns to the USEPA.

Water-quality samples were collected by the U.S. Geological Survey (USGS) between June 1999 and September 2000 and analyzed for several constituents, including nitrate (plus nitrite), ammonia, total Kjeldahl nitrogen (TKN), phosphorus (P), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn), and water-quality properties and indicators including specific conductance, turbidity, biochemical oxygen demand (BOD-5), fecal coliform bacteria, *Enterococcus* bacteria, total dissolved solids (TDS), and total suspended sediment (TSS). Loads were determined for most of these potential contaminants, including nitrate (plus nitrite), ammonia, TKN, phosphorus, cadmium, chromium, copper, lead, and zinc, biochemical oxygen demand, fecal coliform bacteria, *Enterococcus* bacteria, total dissolved solids, and total suspended sediment. Loading patterns were developed from analysis of water-quality samples collected during dry weather and relations among stormwater quality, rainfall characteristics, and antecedent conditions for Water Year 2000[1]. In addition, contaminant loads from two design storms with 3-month and 1-year return periods were calculated for existing conditions and for conditions expected after combined sanitary- and storm sewers (or combined sewers) in the Stony Brook Subbasin are physically separated, thus eliminating CSO loading to Stony Brook. Finally, water quality and streamflow in three relatively uniform land-use subbasins (located within the lower Charles River Watershed) also are described to elucidate relations among streamflow, water quality, and subbasin characteristics.

Acknowledgments

The authors express their gratitude to the following people and agencies for their cooperation and assistance with stormwater sampling and analysis during this study; Stacey Archfield (USGS), Mary Ashman (USGS), Claire Barker (Massachusetts Department of Environmental Protection, MADEP), Roger Frymire (USGS Volunteer for Science), Ronald Maribett (MADEP), Gail Moede (USGS), Nicole Napoleon (USGS), Owen O'Reardon (Cambridge Department of Public Works), Gene Parker (USGS), Isabella Ramirez (MADEP), Steven Rhode (Massachusetts Water Resources Authority, MWRA), Cheryl Stephenson-Marchioni (USGS), Nicole Parilla (MWRA), John Sullivan (Boston Water and Sewer Commission, BWSC), David Valley (National Weather Service, NWS), Mark Voorhees (USEPA), and Lisa Wong (MWRA); for technical and editorial assistance, Kevin Brander (MADEP), Lora Barlow (USGS), Mark Bonito (USGS), Timothy Cohn (USGS), John Colman (USGS), Leslie DeSimone (USGS), John Fulton (USGS), Gregory Granato (USGS), David Gray (USEPA), Richard Hooper (USGS), Lise Marx (MWRA), Christine Mendelsohn (USGS), Vicki-Rose Siegel (USGS), Kirk Smith (USGS), Marcus Waldron (USGS), Anne Weaver (USGS), William Walsh-Rogalski (USEPA), and Philip Zarriello (USGS).

[1]The term "Water Year" denotes the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 2000, is called "Water Year 2000."

FIELD METHODS

The gaging stations were designed to monitor streamflow, water-quality constituents, and certain water-quality properties. The instrumentation inside each station was customized for the physical and hydrological environment for that site and was programmed to collect stormwater samples.

Collection of Streamflow Data

Gaging stations (table 1 and fig. 1) were established on the main stem of the Charles River at the footbridge just upstream of the Watertown Dam [Charles River at Watertown (USGS station number 01104615)]; at or near the mouths of four major tributaries [Laundry Brook (01104640); Faneuil Brook (01104660); Muddy River (01104683); and Stony Brook (01104687)]; and on one small urban stream and two storm drains that drain subbasins with uniform land use, including single-family residential, multifamily residential, and commercial [single-family land use (01104630); multifamily land use (01104673); and commercial land use (01104677), respectively].

Table 1. Locations and USGS station numbers used in the study, lower Charles River Watershed, Massachusetts

[**Latitude and longitude**: In °, degrees; ′, minutes; and ″, seconds. USGS, U.S. Geological Survey]

Station name	USGS identifier	Latitude ° ′ ″	Longitude ° ′ ″
Charles River at Watertown	01104615	42 21 53	71 11 25
Single-family land use	01104630	42 20 08	71 11 47
Laundry Brook	01104640	42 21 53	71 11 20
Faneuil Brook	01104660	42 21 22	71 09 20
Multifamily land use	01104673	42 22 25	71 06 44
Commercial land use	01104677	42 22 13	71 06 52
Muddy River	01104683	42 20 14	71 06 42
Stony Brook	01104687	42 19 05	71 06 10
Charles River at Boston Science Museum	01104710	42 21 57	74 04 14

Various factors were considered in the selection of the locations for the gaging stations, including accessibility, security, and the absence of variable backwater (Rantz and others, 1982). The latter explains why the Faneuil Brook gaging station (01104660), Muddy River gaging station (01104683), and the Stony Brook gaging station (01104687) were installed upstream from their confluence with the lower Charles River (fig. 1).

At each gaging station, stage-discharge relations, or ratings, were established for a range of flows by direct measurements with fixed current meters in accordance with USGS protocols (Rantz and others, 1982) or theoretical ratings developed from steady-state hydraulic models (Zarriello and Barlow, 2002). These ratings were used to determine discharge from measurements of stage, which was continuously measured throughout the period of study (Rantz and others, 1982).

Stage-measurement instrumentation was chosen to suit the characteristics of each site: dual valve Safe Purge II nitrogen gas systems [Charles River at Watertown (01104615) and Muddy River (01104683)]; submersible KPSI pressure transducers [Stony Brook (01104687), single-family land use (01104630), and commercial land-use (01104677), and multifamily land-use (01104673) storm drains]; a Marsh-McBirney open-channel sensor [Faneuil Brook (01104660)]; and an ultrasonic transducer [Laundry Brook (01104640)]. Stage, however, often was below the minimum level needed for accurate measurement at the single-family land-use drain and Laundry Brook. Consequently, weirs were installed at these gaging stations, just downstream of the stage sensors, to create small impoundments. Weirs were constructed of a marine-grade polymer because of its flexibility, strength, and non-contaminating properties, and because it does not tend to become colonized by organisms (K.P. Smith, U.S. Geological Survey, oral commun., 2000.).

Stage instrumentation was housed in either a wooden shelter or a steel box (fig. 2). Each gaging-station shelter also housed a digital datalogger with a data-storage module (Campbell Scientific CR10X), which was used to record and store all generated data; equipment for the measurement of specific conductance and water temperature; and an ISCO 6700 sampler for the automatic collection of water samples.

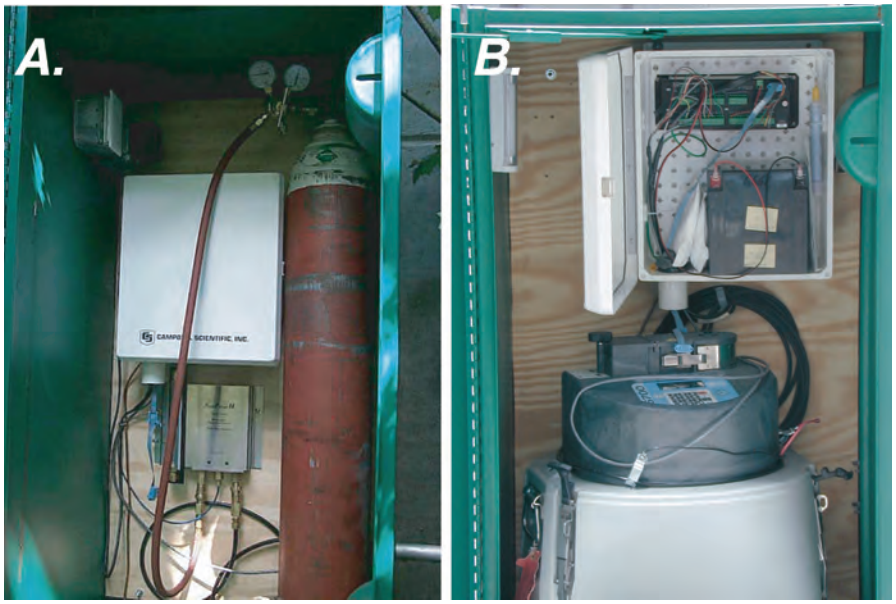


Figure 2. Inside of typical gaging station used in this study of the lower Charles River Watershed, Massachusetts, showing (*A*) a Dual valve Save Purge II nitrogen gas system and (*B*) an ISCO automated sampler, datalogger, and 26-ampere-hour sealed rechargeable battery.

Some gaging stations [Charles River at Watertown (01104615), Laundry Brook (01104640), Muddy River (01104683), Faneuil Brook (01104660), and Stony Brook (01104687)] also housed a telephone-modem system to allow near-real-time reporting of provisional stage, discharge, specific conductance, water temperature, and times of sample collection to the USGS Massachusetts–Rhode Island District Office at 15-minute intervals. This information was made available to the public on the local USGS Web site.

Instrumentation was powered by 26-ampere-hour sealed rechargeable batteries, with the exception of the ISCO samplers. At five of the eight gaging stations [Charles River at Watertown (01104615), Laundry Brook (01104640), Muddy River (01104683), Faneuil Brook (01104660), and Stony Brook (01104687)], battery charge was maintained by direct connection with a municipal power supply. At the remaining gaging stations [single-family land use (01104630), commercial land use (01104677), and multifamily land use (01104673)], batteries were routinely replaced with fully charged batteries. Each ISCO sampler was powered by 12-volt deep-cycle batteries that were recharged between storms.

Water-Quality Sampling

Water-quality monitoring stations were established at all of the gaging stations and at one ungaged site on the Charles River near the Museum of Science [(Charles River at Boston Science Museum (01104710)] (table 1). Dry-weather samples were collected monthly between June 1999 and July 2000 at these water-quality monitoring sites in accordance with USGS clean-sampling procedures (Wilde and Radtke, 1998). Dry-weather samples were collected on days for which there was less than about 0.1 in. of precipitation during the preceding 72 hr as measured by the USGS rain gage located at the Charles River at Watertown (01104615) station. Stormwater samples were collected over the course of nine individual storms between January and July 2000 by automated samplers at eight of the water-quality monitoring stations. Stormwater samples were collected during two of these storms at Charles River at Boston over this period.

Cleaning of Sampling Equipment

Polyethylene- and glass-sample bottles (including caps), weighted-bottle samplers, peristaltic-pumphead tubing, churns and all components of the automatic samplers that contacted the sample directly were decontaminated in the laboratory prior to each sampling by thoroughly rinsing, autoclaving, or baking. The metal springs standard in USGS-issued churn spigots were removed and replaced with small pieces of polyethylene tubing to eliminate the risk of metal contamination.

All sampling equipment was rinsed with non-phosphate laboratory-grade detergent and hot tap water. Prior to rinsing, a cotton ball was forced through the pumphead- and intake-tubing by water pressure from a laboratory sink to remove any of the large particles that, otherwise, would not have easily been removed. After the hot tap-water rinse, the polyethylene sample bottles, weighted-bottle samplers, and churns were rinsed with dilute (5 percent) American Chemical Society (ACS) trace-metal-grade hydrochloric acid (HCl), and sterile deionized water (DIW), in that order. The deionized-water system is equipped with an ultraviolet light to achieve sterility. (Horowitz and Sandstrom, 1998; Myers and Sylvester, 1998). The stainless-steel nipples, pumphead tubing, and glass sample bottles, spiked with a 15-percent solution of ethylenediaminetetraacetic acid (EDTA), were autoclaved in an instant sealing sterilization pouch at 132°C for 15 minutes at 15 pounds per square inch (PSI), to check if adequate temperature and pressure was attained during autoclaving (Myers and Sylvester, 1998). Each cap for the glass-sample bottles was placed under a 254-nm-wavelength ultraviolet lamp for up to an hour. The intake tubing, which did not fit in the autoclave, was baked in a laboratory oven at 170°C for about 2 hr (Myers and Sylvester, 1998) and rinsed with 5-percent ACS trace-metal-grade HCl and sterile DIW, in that order. The specific conductance of the final DIW rinsate was monitored; rinsing was considered complete when the specific conductance of the rinsate was equal to the original specific conductance of the DIW. Finally, the polyethylene-sample bottles, including caps, weighted-bottle samplers, churns, and intake tubing, were air-dried in a contaminant-free room, wrapped inside double plastic bags, and stored in plastic bins.

Intake tubes at two of the water-quality monitoring stations [Muddy River (01104683) and Stony Brook (01104687)] were so long that they could not easily be withdrawn and brought to the laboratory for cleaning between storms. Therefore, cleaning of intake tubes at these stations was done in the field. The tubes were rinsed by pumping 5-percent ACS trace-metal-grade HCl followed by a sterile DIW rinse (about 5 gal) from dedicated polyethylene carboys, by running the ISCO automatic sampler's peristaltic pump in reverse. Equipment-blank samples were collected to test the adequacy of this cleaning method.

Dry-Weather Sampling

Wadeable streams [Laundry Brook (01104640), single-family land use (01104630) and Muddy River (01104683)] were sampled by dipping sterile 250-mL polyethylene sample bottles into the centroid of flow in accordance with USGS guidelines for non-isokinetic sampling methods (Webb and others, 1998; Myers and Sylvester, 1998). It is important to note that some error can be introduced by this method of sampling if the constituents of interest are not uniformly distributed along the cross section (Horowitz, 1991); fortunately, however, the small cross-sectional area and high velocities of most these streams make the probability of a non-uniform distribution negligible. Storm drains [commercial land use (01104677) and the multifamily land use (01104673)] were sampled with a peristaltic pump and clean piece of tubing for each sample to collect point samples at the centroid of flow in accordance with USGS guidelines for pump-sampling methods (Webb and others, 1998). Pumping was necessary at these water-quality monitoring stations because water depths in the storm drains are insufficient for dip sampling during dry weather (in other words, the water is not deep enough to submerge the sample bottles wholly). Concerted efforts were made to ensure that no bottom sediment was entrained and subsequently collected during sampling. Deeper-river sites [Charles River at Watertown (01104615) and Charles River at Boston Science Museum (01104710)] were sampled by means of a weighted-bottle sampler in accordance with USGS equal-width increment (EWI) procedures for still-water sites (Webb and others, 1998).

Stony Brook (01104687) was also sampled by means of a weighted-bottle sampler because of difficult access; the base of the Stony Brook is located over 30 ft below land surface. Because of the special requirements for the collection of bacterial samples, bacteria at these water-quality monitoring stations were collected by dipping a sterilized bottle, secured in a weighted bottle sampler, into the centroid of flow in accordance with standard USGS procedures (Myers and Sylvester, 1998). Again, this method of collection may be the source of some error if bacterial densities are not uniformly distributed along the cross section.

Bacterial samples were put on ice within 5 minutes of collection and delivered by hand within 6 hr by USGS field personnel to the (MWRA) Laboratory, Deer Island, Massachusetts. Dry-weather samples collected by means of EWI procedures were composited in a pre-cleaned polyethylene churn splitter, and decanted into pre-cleaned polyethylene bottles in accordance with standard USGS churn-splitter procedures (Radtke and others, 1998). Immediately after collection or after compositing, dip or pump samples for trace-metal and nutrient analyses were preserved to a pH less than 2.0 by adding ACS trace-metal-grade concentrated nitric (HNO_3) and sulfuric acid (H_2SO_4), respectively. One milliliter of acid was added to each 250 mL of sample from dedicated Teflon dropping bottles. After preservation, all samples were put on ice and delivered to either the U.S. Environmental Protection Agency (USEPA) Region I Office of Environmental Measurement and Evaluation, Chelmsford, Massachusetts, or the Alpha Analytical Laboratory, Westborough, Massachusetts (table 2).

Stormwater Sampling

Stormwater samples were collected at eight water-quality sampling stations. Automatic samplers were used to collect stormwater samples in a flow proportional manner. Stormwater samples were collected and processed using standard USGS protocols.

Sample Collection, Instrumentation, and Programming

Stormwater samples were collected at each gaging station in a flow-proportional manner with an ISCO automated sampler controlled by a datalogger; the datalogger emits electrical pulses that trigger the ISCO to begin sample collection (fig. 3). When triggered by the datalogger, the ISCO's internal peristaltic pump draws samples into pre-cleaned sample containers.

The use of a peristaltic pump for sample collection is beneficial because it minimizes contact between sampling equipment and the sample. However, the maximum height a water sample can be lifted (the vertical head) through a tube by a peristaltic pump, which relies on suction, is limited to about 30 ft or less for longer tubes. Consequently, ISCOs at Muddy River (01104683) and Stony Brook (01104687), which required a long tube (150 ft) and had a vertical head greater than 30 ft, respectively, were each outfitted with a non-contaminating supplemental pump. The supplemental pump was placed at the submerged end of the intake tubing, in effect reducing the vertical head, so that suction from the peristaltic pump could lift the sample the rest of the distance.

The exact timing between activation of the supplemental pump and triggering of the ISCO was critical to prevent the collection of too much or too little sample; therefore, each supplemental pump was also controlled by the datalogger. The datalogger was programmed to turn the supplemental pump on and to allow enough elapsed time before triggering the ISCO, so that the vertical head was sufficiently reduced. The time interval between activation of the two pumps was determined by trial and error. The time interval was found to be a function of the length and inside diameter of the intake tube, the vertical head to be overcome, the specifications of the ISCO's peristaltic pump, and the volume of sample to be collected.

Two to 6 hr before each storm, alternating glass and plastic sample bottles were placed in each ISCO, and laboratory-cleaned tubing was re-strung, or tubes were cleaned *in situ* in the case of Muddy River (01104683) and Stony Brook (01104687). The dataloggers were programmed either manually or remotely from the USGS Massachusetts–Rhode Island Office in Northborough, Massachusetts. The dataloggers were programmed to:

Table 2. Analytes, laboratories, and analytical techniques used in this study, lower Charles River Watershed, Massachusetts

[**Analytical technique:** ICP-MS, Inductively Coupled Plasma-Mass Spectrometry; UV-VIS, Ultraviolet-visible. **USEPA Method:** Used by analyzing agency or USEPA method to which analyzing agency method was similar. MRL, minimum reporting level; MWRA, Massachusetts Water Resources Authority; USEPA, U.S. Environmental Protection Agency; USGS, U.S. Geological Survey; CFU/100mL, colony-forming units per 100 milliliters; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; °, degree; --, Not applicable or unknown]

Analyte and unit of measure	Laboratory	Analytical technique	MRL	USEPA Method	Reference
Specific conductance, laboratory (µS/cm)	USGS	Wheatstone type-bridge or equivalent at 25°C	1	120.1	Radtke and others, 1998
Turbidity, laboratory (NTU)	USGS	Nephelometer	0.05	180.1	Wilde and Gibs,1998
Biochemical oxygen demand, 5-day (mg/L)	Alpha Analytical	Modified Winkler with full bottle technique or probe method	2	405.1	U.S. Environmental Protection Agency, 1983
Coliform, fecal, membrane filter (CFU/100mL)	MWRA	Membrane filtration/ incubation	10	--	Massachusetts Water Resources Authority, 1996
Enterococcus, membrane filter (CFU/100mL)	MWRA	Membrane filtration/ incubation	10	--	Massachusetts Water Resources Authority, 1999
Dissolved solids (mg/L)	USEPA	Glass fiber filter/ Gravimetry	5–10	160.1	U.S. Environmental Protection Agency, 1983
Suspended solids (mg/L)	USEPA	Glass fiber filter/ Gravimetry	5–10	160.2	U.S. Environmental Protection Agency, 1983
Nitrate plus nitrite (mg/L as N)	USEPA	Ion Chromatography	0.023	300.0A	U.S. Environmental Protection Agency, 1993a
Nitrogen, ammonia, total (mg/L as N)	Alpha Analytical	Technicon Auto Analyzer/Colormetric, automated phenate	0.075	350.1	U.S. Environmental Protection Agency, 1993a
Nitrogen, total Kjeldahl (mg/L as N)	Alpha Analytical	Spectrophotometer, colormetric, titrimetric, or potentiometric	0.15	351.3/.1	U.S. Environmental Protection Agency, 1983
Phosphorus, total (mg/L)	USEPA	Technicon Auto Analyzer/Colormetric, automated, ascorbic acid	0.01–0.1	365.2	Hach Company, 1998
Cadmium, total (µg/L)	USEPA	ICP-MS	0.05– 0.5	200.8	U.S. Environmental Protection Agency, 1994
Chromium, total (µg/L)	USEPA	ICP-MS	0.2– 5	200.8	U.S. Environmental Protection Agency, 1994
Copper, total (µg/L)	USEPA	ICP-MS	0.2	200.8	U.S. Environmental Protection Agency, 1994
Lead, total (µg/L)	USEPA	ICP-MS	0.05	200.8	U.S. Environmental Protection Agency, 1994
Zinc, total (µg/L)	USEPA	ICP-MS	2–10	200.8	U.S. Environmental Protection Agency, 1994

- initiate sample collection once a pre-established stage threshold was realized, usually 0.1 to 0.2 ft above the pre-storm stage;
- use stage-discharge relations to compute and record the volume of water that passed the gaging station once sample collection had begun;
- trigger successive “sampling episodes” during the storm whenever a predetermined volume of water or trigger threshold volume flowed past the gage;
- ensure enough suction to collect an adequate sample volume;
- collect the correct number of samples within each sampling episode; and
- record the time of each sampling episode.

Because of the different sample container requirements for bacterial samples (sterility and the EDTA spike) and trace-metal samples (acid-rinsing), two samples were collected per sampling episode;

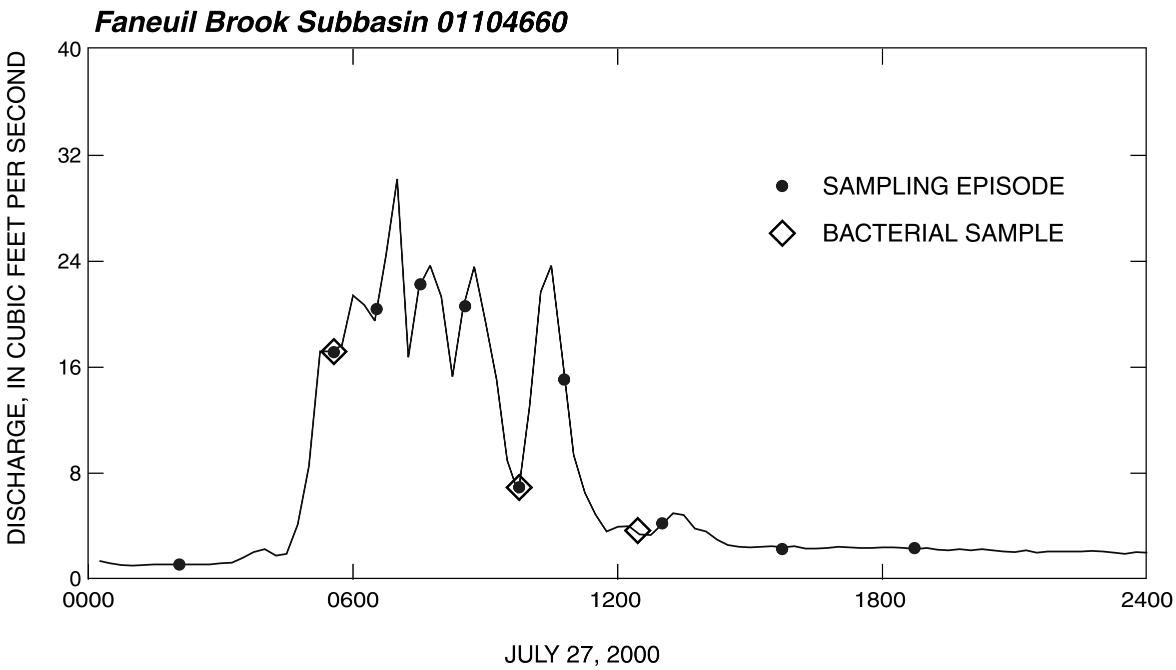


Figure 3. Typical hydrograph with distribution of flow-proportional stormwater samples, lower Charles River Watershed, Massachusetts.

the bacterial sample was pumped into a sterile 1-L glass sample bottle, and the trace-metal and nutrient sample was pumped into the adjacent 1-L acid-rinsed polyethylene sample bottle. Samples collected during the same episode, usually within 5 minutes of one another, were considered to represent similar conditions.

The ISCO sampler holds 12 1-L sample bottles, sufficient for a maximum of 6 sampling episodes based on sample volume requirements. The dataloggers were programmed to stop triggering the ISCOs after six sampling episodes. The dataloggers, however, continued to record the total volume of water passing the gaging station after sample collection had stopped. Consequently, in cases when more than six sampling episodes were required to characterize a storm on the basis of the trigger thresholds, field personnel gathered samples and replaced bottles frequently enough to ensure that trigger thresholds were not exceeded between sampling episodes; thus, the flow-proportional character of the samples was maintained.

The ISCOs also were programmed to purge the intake tube between sampling episodes to minimize the amount of cross contamination. Water in the pumphead, stainless-steel nipple, and intake tube was evacuated automatically by running the ISCO in reverse. This evacuation procedure may not have entirely eliminated cross-contamination bias, especially when high-concentration samples were followed by low-concentration samples. The compositing of adjacent samples, however, minimized cross-contamination bias.

Trigger-threshold volumes were uniquely determined for each storm; they were based on site-specific hydrologic conditions and responses, predictions of total rainfall amounts, storm duration and intensity, and the number of available sample bottles (about 36 per station). Predicting storm characteristics, however, was extremely difficult, even though near-real-time weather Web sites and frequent weather updates from National Oceanic and Atmospheric Administration (NOAA) meteorologists were available. Consequently, trigger thresholds were determined by trial and error, on the basis of detailed knowledge of each site and weather patterns of the study area.

The trigger-threshold volumes determined the temporal distribution, number, and streamflow represented by individual samples collected during each storm. Ideally, appropriate trigger-threshold volumes should facilitate (1) collection of samples throughout the storm, (2) adequate sample volume collection, (3) good characterization of intense rainfall-runoff periods through collection of multiple samples, and (4) sufficient time for field personnel to retrieve and replace sample bottles. Inappropriate trigger-threshold volumes can undermine the quality of a storm-sampling episode. For example, trigger-threshold volumes based on underpredicted rainfall amounts may cause samples to be collected too quickly, prematurely filling all of the available sample bottles before they can be gathered and replaced by field personnel. The sampling episode would be truncated and the flow-proportional character of the sampling compromised. Conversely, if trigger thresholds are based on overpredicted rainfall amounts, it is likely that too few samples, and thus, an insufficient volume for analysis, will be collected. Similarly, storm duration and intensity governs the relative proportion of stormwater and base flow that passes a gaging station during and after a storm. A long, subdued storm results in a larger proportion of base flow, whereas a short, intense storm creates a smaller proportion of base flow. As with total rainfall, accurate prediction of storm duration and intensity is especially important for estimating trigger threshold volumes.

Estimation of stage thresholds, which were used to initiate sample collection for a storm, were also based on site-specific hydrologic conditions, responses, and predictions of total rainfall amounts, storm duration, and storm intensity. Although it might seem that determination of stage thresholds would be straightforward, compared to volume thresholds, it proved difficult to make accurate estimates of stage thresholds for individual storms because of the complex hydrologic conditions at each monitoring station. For example, the stage at Charles River at Watertown (01104615) often decreased just before or during many of the storms. This decrease was the result of diverting flow through Mother Brook to the Neponset River, in order to reduce the risk of flooding in Boston and Cambridge. A similar decrease occurs at Muddy River (01104683), as water from the lower Charles River is pumped out at the New Charles River Dam in advance of a storm. This pumping can cause the stage of the Muddy River to fall during the initial portion of larger storms.

Sample Retrieval and Processing

Sample bottles for each sampling episode were removed from the ISCO, immediately capped, placed in pre-labeled 2-gal sealable plastic bags, stored on ice, and replaced with clean sample bottles if it was still raining or the stage was still higher than the pre-storm stage. The time of each sampling episode was downloaded from the datalogger, recorded in a bound field notebook, and cross-referenced with the sampling-episode number on each bag.

In addition to gathering samples and replacing sample bottles, field personnel collected bacterial samples and delivered them to the MWRA analytical laboratory within the 6-hr holding-time limit for bacterial analysis (Massachusetts Water Resources Authority, 1996; 1999); meanwhile, sampling of the stormflow continued at the stations. The average duration of a rain storm in Boston is about 11 hr (Zarriello and Barlow, 2002). Approximately 3 of the 12 1-L bottles were reserved for bacterial analysis for each storm. Sampling episodes were selected by interpreting near-real-time flow data on the USGS Web site or commercially available weather web sites to predict time intervals for the rising limb, peak, and falling limb of the hydrograph. Bacterial samples were vigorously shaken and then poured out of the 1-L glass bottle into a separate 250-mL sterile polyethylene bottles, put on ice, and delivered to the MWRA laboratory on Deer Island by either USGS field personnel or volunteers. Some bacterial samples were composited in the field.

After the storm, non-bacterial samples collected from each water-quality monitoring station, brought to the USGS laboratory were composited, to produce a single sample for each station that represented flow from the entire storm. Stormwater samples were composited by pouring one of the 1-L samples from each selected sampling episode into a pre-cleaned polyethylene churn splitter. In some cases, flow-proportional composites were prepared manually on the basis of datalogger records. Samples were mixed in the churn splitter according to standard USGS procedures (Wilde and others, 1998), decanted into pre-cleaned polyethylene bottles, preserved, and delivered to either the USEPA or Alpha Analytical Laboratory (table 2). The analysis of composited, flow-proportional samples yields contaminant concentrations that represent an mean concentration over the course of the entire storm, defined as an event mean concentration (EMC).

Continuously Monitored Water-Quality Properties

Water temperature and specific-conductance measurements were monitored continuously (every 2 to 15 minutes) by a Campbell Scientific 247 conductivity/ temperature probe at each of the gaged water-quality monitoring stations. These probes were calibrated to standards that ranged from 50 to 50,000 μS/cm at 25°C in the office prior to deployment, and calibrated and cleaned in the field each month throughout the study. Near-real-time (every 15 minutes) water-temperature and conductance data were reported from stations outfitted with a telephone-modem system to the Northborough office of the USGS and posted on the local USGS Web site.

DATA-ANALYSIS METHODS

A variety of statistical methods was used to summarize water-quality data and estimate constituent loads. Particular attention was given to censored data, that is, concentrations less than the detection limit. Summary statistics for constituents with censored data were calculated by means of the USGS's Method Detection Limit (MDL) computer program, unless otherwise noted. The MDL program uses a log-probability method for determining summary statistics. The details of these statistical methods are described by Helsel and Cohn (1998).

Dry-Weather Mean Concentrations and Stormwater Event Mean Concentrations

The overall dry-weather mean concentration of each constituent was calculated as the arithmetic mean of the concentrations for that constituent measured in dry-weather samples collected at each site (table 22 at back of report). In addition, an overall dry-weather "flow-weighted" mean concentration for each constituent was also calculated as the arithmetic mean of the monthly dry-weather concentrations multiplied by the discharge (ft^3/s) at the time of sampling divided by the sum of the discharges (table 3). The overall dry-weather mean concentration assigned to the ungaged portion of the study area, not including the ungaged drainage area in the gaged subbasins, was set equal to the mean of the overall arithmetic and flow-weighted dry-weather concentrations at Muddy River (01104683) and Laundry Brook (01104040).

The mean was favored over the use of other measures of central tendency (median, mode, or geometric mean) because the arithmetic mean is more suitable for estimating total loads (T.A. Cohn, U.S. Geological Survey, oral commun., 2001). The arithmetic mean is sensitive to outliers. Outliers, which may represent unusually high-flow events, can contribute a large proportion of the total contaminant load, albeit infrequently. An alternative method that involved the use of relations between water quality and drainage-basin characteristics was considered, but was rejected because of the complexity of these relations at the uniform land-use sites.

Stormwater EMCs for the non-bacterial samples were obtained from flow-proportional, composited samples (table 23 at back of report). Bacterial EMCs, for each storm, were estimated by linear interpolation between discrete bacterial (table 24 at back of report) sample concentrations using a 15-minute time step. These linearly interpolated concentrations were multiplied by the corresponding 15-minute water volumes, summed, and divided by the total volume for the storm (table 3). The overall stormwater EMC was calculated as the arithmetic mean of the stormwater EMCs estimated for each site. The overall stormwater "flow-weighted" EMC was calculated for each site as the arithmetic mean of the stormwater EMCs multiplied by the total discharge volume for each storm divided by the total volume of all the storms sampled (table 4). Summary statistics of dry-weather and stormwater-constituent concentrations and water-quality properties are shown in table 25 (at back of report).

Table 3. Discharge at the time of sampling (dry weather) or total stormwater volume (stormwater), lower Charles River Watershed, Massachusetts, Water Year 2000

[**Date:** Is in month, day, and year. **Time:** All times are eastern standard time and are in hours and minutes. ft^3, cubic feet; ft^3/s, cubic feet per second; --, not measured]

Dry weather			Stormwater				
Date	Time	ft^3/s	Start date and time		End date and time		ft^3
Charles River at Watertown (01104615)							
6-29-99	0930	--	1-10-00	1430	1-11-00	1845	63,500,000
7-19-99	1300	--	4-09-00	0015	4-10-00	0000	60,900,000
7-30-99	1225	--	5-18-00	1600	5-20-00	0000	71,800,000
8-26-99	1100	--	6-02-00	1630	6-03-00	0730	22,100,000
9-27-99	1245	--	6-06-00	0800	6-07-00	1900	108,000,000
10-26-99	1245	511	7-09-00	1915	7-10-00	2330	25,700,000
11-19-99	0950	348	7-16-00	0000	7-16-00	1800	12,000,000
12-29-99	1245	380	7-27-00	0545	7-28-00	0000	34,900,000
1-24-00	1350	360	9-15-00	0730	9-16-00	0000	23,200,000
2-24-00	0900	593	--	--	--	--	--
3-23-00	1050	820	--	--	--	--	--
5-01-00	0930	1,065	--	--	--	--	--
6-27-00	1350	351	--	--	--	--	--
7-25-00	0530	190	--	--	--	--	--
Single-family land use (01104630)							
6-29-99	--	--	1-10-00	1515	1-10-00	2200	145,000
7-19-99	1130	--	4-09-00	0015	4-09-00	0930	105,000
7-30-99	1045	--	5-18-00	1845	5-18-00	1645	61,400
8-26-99	0930	--	6-02-00	1745	6-02-00	2100	65,300
9-27-99	1041	--	6-06-00	0800	6-07-00	1030	702,000
10-26-99	0950	0.11	7-09-00	1915	7-09-00	2345	73,300
11-19-99	1145	.10	7-16-00	0000	7-16-00	0615	37,200
12-29-99	1200	.10	7-27-00	0400	7-27-00	1515	229,000
1-24-00	1245	.10	9-15-00	0630	9-15-00	1445	306,000
2-24-00	1030	.10	--	--	--	--	--
3-24-00	1100	.13	--	--	--	--	--
5-01-00	1145	.19	--	--	--	--	--
6-27-00	1030	.15	--	--	--	--	--
7-25-00	0645	.10	--	--	--	--	--
Laundry Brook (01104640)							
6-29-99	--	--	1-10-00	1445	1-11-00	1215	1,100,000
7-19-99	1207	--	4-09-00	0015	4-09-00	2115	949,000
7-30-99	1025	--	5-18-00	1600	5-19-00	2330	671,000
8-26-99	1000	--	6-02-00	1730	6-03-00	1145	542,000
9-27-99	1126	--	6-06-00	0815	6-08-00	0000	5,920,000
10-26-09	1042	1.01	7-09-00	1915	7-10-00	2000	444,000
11-19-99	1215	.92	7-16-00	0000	7-16-00	2045	230,000
12-29-99	1045	.93	7-27-00	0445	7-27-00	2115	1,280,000
1-24-00	1320	.97	9-15-00	0615	9-15-00	1700	1,190,000
2-24-00	1000	1.04	--	--	--	--	--

Table 3. Discharge at the time of sampling (dry weather) or total stormwater volume (stormwater), lower Charles River Watershed, Massachusetts, Water Year 2000—*Continued*

Dry weather			Stormwater				
Date	Time	ft^3/s	Start date and time		End date and time		ft^3
Laundry Brook (01104640)—*Continued*							
3-24-00	1000	1.27	--	--	--	--	--
5-01-00	0645	1.95	--	--	--	--	--
6-27-00	1126	1.45	--	--	--	--	--
7-25-00	1042	.95	--	--	--	--	--
Faneuil Brook (01104660)							
6-29-99	--	--	1-10-00	1500	1-10-00	0245	324,000
7-19-99	1340	--	4-09-00	0015	4-09-00	0915	129,000
7-30-99	0745	--	5-18-00	1900	5-19-00	0818	125,000
8-26-99	1115	--	6-02-00	1730	6-02-00	2115	88,200
9-27-99	1120	--	6-06-00	0815	6-07-00	1115	1,340,000
10-26-99	1100	0.66	7-09-00	1930	7-10-00	0230	89,000
11-19-99	1300	.58	7-16-00	0000	7-16-00	0445	87,000
12-29-99	1230	.58	7-27-00	0345	7-27-00	1500	492,000
1-24-00	1415	.59	9-15-00	0615	9-15-00	1500	493,000
2-24-00		.60	--	--	--	--	--
3-24-00	0930	.75	--	--	--	--	--
5-01-00	1045	1.44	--	--	--	--	--
6-27-00	1230	.86	--	--	--	--	--
7-25-00	0800	.57	--	--	--	--	--
Multifamily land use (01104673)							
6-29-99	--	--	1-10-00	1445	1-10-00	2200	56,100
7-19-99	--	--	4-09-00	0145	4-09-00	0815	61,900
7-30-99	0900	--	5-18-00	1845	5-18-00	2030	22,200
8-26-99	0930	--	6-02-00	1730	6-03-00	0245	35,900
9-27-99	1040	--	6-06-00	0800	6-07-00	1430	388,000
10-26-99	1100	0.01	7-09-00	1845	7-10-00	0200	29,800
11-19-99	1225	.01	7-16-00	0000	7-16-00	0745	45,300
12-29-99	1135	.01	7-27-00	0215	7-27-00	1830	112,000
1-24-00	1200	.01	9-15-00	0615	9-15-00	1800	110,000
2-24-00	1220	.01	--	--	--	--	--
3-24-00	1030	.01	--	--	--	--	--
5-01-00	1145	.016	--	--	--	--	--
6-27-00	1045	.015	--	--	--	--	--
7-26-00	0742	.014	--	--	--	--	--
Commercial land use (01104677)							
6-29-99	--	--	1-10-00	1445	1-10-00	2200	38,200
7-19-99	--	--	4-09-00	0145	4-09-00	0815	44,400
7-30-99	1045	--	5-18-00	1845	5-19-00	2145	68,200
8-26-99	1015	--	6-02-00	1730	6-03-00	0245	473,000
9-27-99	1015	--	6-06-00	0730	6-07-00	1430	193,000

Table 3. Discharge at the time of sampling (dry weather) or total stormwater volume (stormwater), lower Charles River Watershed, Massachusetts, Water Year 2000—*Continued*

Dry weather			Stormwater				
Date	Time	ft^3/s	Start date and time		End date and time		ft^3
Commercial land use (01104677)—*Continued*							
10-26-09	0945	0.20	7-09-00	1915	7-10-00	0100	44,700
11-19-99	1145	.20	7-16-00	0000	7-16-00	0945	40,700
12-29-99	1055	.20	7-27-00	0215	7-27-00	1800	113,000
1-24-00	1100	.20	9-15-00	0630	9-15-00	1430	884,200
2-24-00	1055	.20	--	--	--	--	
3-24-00	1120	.20	--	--	--	--	--
5-01-00	1215	.20	--	--	--	--	--
6-27-00	1000	.20	--	--	--	--	--
7-25-00	0825	.20	--	--	--	--	--
Muddy River (01104683)							
6-29-99	--	--	1-10-00	1445	1-11-00	1500	3,110,000
7-19-99	1450	--	4-09-00	0015	4-09-00	2330	2,840,000
7-30-99	--	--	5-18-00	1745	5-19-00	2330	1,760,000
8-26-99	0840	--	6-02-00	1530	6-03-00	0830	2,080,000
9-27-99	0957	--	6-06-00	0945	6-07-00	1445	23,100,000
10-26-09	0930	1.49	7-09-00	1915	7-10-00	0900	1,690,000
11-19-99	1025	1.2	7-16-00	0000	7-16-00	1645	1,120,000
12-29-99	1230	1.14	7-27-00	0245	7-28-00	0000	7,190,000
1-24-00	1210	1.14	9-15-00	0815	9-15-00	2115	6,910,000
2-24-00	1100	1.23	--	--	--	--	--
3-24-00	1325	1.32	--	--	--	--	--
5-01-00	1230	1.95	--	--	--	--	--
6-27-00	1100	1.21	--	--	--	--	--
7-25-00	1000	1.32	--	--	--	--	--
Stony Brook (01104687)							
6-29-99	--	--	1-10-00	1445	1-10-00	1145	3,950,000
7-19-99	--	--	4-09-00	0015	4-09-00	2045	3,690,000
7-30-99	0900	--	5-18-00	1600	5-19-00	2330	1,810,000
8-26-99	0815	--	6-02-00	1530	6-03-00	0730	2,410,000
9-27-99	0855	--	6-06-00	0800	6-07-00	1715	41,600,000
10-26-99	0835	10.7	7-09-00	2000	7-10-00	0930	1,770,000
11-19-99	1000	10.7	7-16-00	0000	7-16-00	1200	1,610,000
12-29-99	0945	10.7	7-27-00	0345	7-27-00	2330	4,730,000
1-24-00	1310	10.7	9-15-00	0815	9-16-00	0000	5,230,000
2-24-00	0930	10.7	--	--	--	--	--
3-24-00	1330	10.7	--	--	--	--	--
5-01-00	1325	10.7	--	--	--	--	--
6-27-00	1145	10.8	--	--	--	--	--
7-25-00	0910	10.7	--	--	--	--	--

Table 4. Annual dry-weather and stormwater-discharge volumes and yields from tributary subbasins to the lower Charles River Watershed, Massachusetts, Water Year 2000

[ft^3, cubic feet; ft^3/mi^2, cubic feet per square mile]

Station name	Total (million ft^3)	Dry weather		Stormwater	
		Volume (million ft^3)	Yield (million ft^3/mi^2)	Volume (million ft^3)	Yield (million ft^3/mi^2)
Charles River at Watertown (01104615)	15,300	10,600	39.7	4,640	17.3
Single-family land use (01104630)	9.51	3.18	8.88	6.31	17.5
Laundry Brook (01104640)	82.3	26.0	5.46	56.3	11.8
Faneuil Brook (01104660).........	38.0	16.5	11.6	21.5	15.1
Faneuil Brook Subbasin[1]	49.1	16.6	9.34	32.5	18.3
Multifamily land use (01104673)	3.04	.20	4.99	2.84	71.0
Commercial land use (01104677)	8.11	5.98	299	2.13	106
Muddy River (01104683)...........	209	35.0	6.44	174	31.9
Muddy River conduit	197	60.6	--	137	--
Muddy River Subbasin[1, 2, 3].......	340	92.6	14.8	248	39.6
Stony Brook (01104687)............	479	292	24.8	187	15.8
Stony Brook overflow	11.3	0	--	11.3	--
Stony Brook Subbasin[1, 4]...........	489	255	19.5	234	18.7
Ungaged areas[5]	284	72.6	7.50	211	21.8

[1]Includes ungaged portions of gaged subbasin, respectively.
[2]Includes Muddy River conduit.
[3]Excludes Stony Brook overflow.
[4]Includes Stony Brook overflow.
[5]Does not include ungaged portions of gaged subbasins.

Regression equations (table 26, at back of the report) that relate measured stormwater EMCs to antecedent conditions and rainfall characteristics (table 5) were also developed. Regression analyses were done with Statview 5.0 (SAS Institute Inc.) software and included an evaluation of the regression diagnostics in accordance with Helsel and Hirsch (1992).

In general, these equations were developed without the need for logarithmic transformation. However, because the fecal coliform and *Enterococcus* bacteria data were lognormally distributed, it was necessary to transform fecal coliform and *Enterococcus* bacteria EMCs into logarithmic units in order to achieve acceptable model fits. Because retransformation back into the original linear units (CFUs/100 mL) can cause an underestimation of predicted bacterial EMCs, a bias-correction factor was multiplied by the predicted bacterial EMCs (U.S. Geological Survey, 1992). The bias-correction factor follows Duan's smearing method (Duan, 1983) and given as

$$BCF = \frac{\left(\sum Residuals\right)}{n}, \quad (1)$$

where

BCF is the bias-correction factor, and
n is the number of samples.
Residuals refers to the sum of the residuals of the regression equation (observed values minus predicted values), which have been transformed back into original arithmetic units.

Annual Loads for Water Year 2000

Dry-weather loads for WY 2000 were estimated as the product of the overall dry-weather mean concentrations or the overall dry-weather flow-weighted mean concentrations and dry-weather flows. Stormwater loads for WY 2000 were estimated on the basis of a combination of mean stormwater EMCs (arithmetic and flow-weighted) and regression-based estimates of EMCs multiplied by stormwater flows. Finally, annual WY 2000 loads to the lower Charles River were determined by adding dry-weather loads and stormwater loads. All flows used in load calculations were obtained from calibrated rainfall-runoff models (Zarriello and Barlow, 2002), with the exception of upstream loads.

Table 5. Characteristics of storms sampled during this study of the lower Charles River Watershed, Massachusetts, storms recorded at Logan Airport National Weather Service station between 1970 and 1995, and Massachusetts Water Resources Authority design storms

[**Date:** Is in month, day, and year. in., inches; in/hr, inches per hour; >, greater than value shown; --, unknown or not applicable]

Date	Antecedent rainfall (in.)				Average intensity (in/hr)	Duration (hours)	Maximum intensity (in/hr)	Antecedent dry period for different ranges of total rainfall (hours)					Average storm volume (in.)	Total volume (in.)
	24 hours	48 hours	72 hours	168 hours				>0.0—0.09 in.	>0.1 —0.19 in.	>0.2—0.49 in.	>0.5—0.99 in.	>1 in.		
Sampled Storms														
1-10-00 to 1-11-00	0	0	0	1.077	0.13	8.67	0.25	118	118	118	118	233.00	--	0.80
4-09-00 to 4-10-00	0	.027	.027	.317	.05	15.33	.16	51	90	91	160	160.33	--	.79
5-18-00 to 5-20-00	0	0	0	.283	.02	31.17	.12	104	104	104	177	589.50	--	.53
6-02-00 to 6-03-00	0	0	0	.000	.11	5.67	.41	201	208	208	208	830.17	--	.59
6-06-00 to 6-07-00	.008	.008	.008	.595	.16	26.33	.44	60	80	80	115	916.17	--	4.07
7-09-00 to 7-10-00	0	.008	.008	.022	.11	4.33	.25	153	251	390	596	695.50	--	.47
7-16-00	0	0	0	.470	.10	6.00	.24	145	145	145	634	844.50	--	.46
7-27-00 to 7-28-00	0	0	0	.550	.06	35.33	.35	95	95	109	162	910.83	--	1.84
9-15-00 to 9-16-00	0	.057	.125	.125	.15	9.83	.60	47	47	381	702	1188.67	--	1.43
Average	.001	.011	.019	.382	.10	15.85	.31	108	126	181	319	707.63	--	1.22
25th percentile	0	0	0	.125	.06	6.00	.24	60	90	104	160	589.50	--	.53
Median	0	0	0	.317	.11	9.83	.25	104	104	118	177	830.17	--	.79
75th percentile	0	.008	.008	.550	.13	26.33	.41	145	145	208	596	910.83	--	1.43
Water Year 2000														
October	0	0.045	0.296	1.002	0.06	10.14	0.19	68	83	83	118	415.86	0.59	4.12
November	0	.071	.088	.193	.04	13.11	.11	114	131	182	319	593.11	.38	2.84
December	.011	.016	.019	.475	.03	11.67	.09	78	147	150	184	534.39	.30	2.31
January	.010	.014	.030	.439	.04	7.98	.10	125	246	272	361	511.49	.32	2.66
Febuary	.072	.152	.337	.511	.03	13.41	.07	80	131	144	315	460.45	.34	2.68
March	.173	.286	.341	.862	.05	8.87	.12	84	136	142	174	291.22	.53	3.88
April	.006	.050	.314	1.086	.03	18.02	.11	51	73	86	99	221.74	.69	5.45
May	.034	.081	.159	.471	.03	10.04	.12	64	86	138	200	465.93	.31	2.90
June	.027	.137	.173	.982	.07	7.43	.20	71	99	133	196	431.24	.63	6.05
July	.021	.043	.121	.669	.09	10.63	.26	101	115	157	371	724.31	.69	4.43
August	.056	.108	.210	.773	.05	5.02	.09	58	115	128	255	343.51	.18	1.78
September	0	.011	.052	.495	.06	9.98	.24	132	141	219	465	724.04	.55	2.98
Annual average	.038	.092	.190	.697	.05	10.27	.14	81	121	148	241	458.49	.45	3.51
Annual 25th percentile	0	0	0	.110	.02	2.21	.04	34	54	64	87	188.75	.05	2.67
Annual median	0	0	.013	.483	.04	6.00	.09	66	95	115	180	393.00	.23	2.94

Table 5. Characteristics of storms sampled during this study of the lower Charles River Watershed, Massachusetts, storms recorded at Logan Airport National Weather Service station between 1970 and 1995, and Massachusetts Water Resources Authority design storms—*Continued*

Date	Antecedent rainfall (in.)				Average intensity (in/hr)	Duration (hours)	Maximum intensity (in/hr)	Antecedent dry period for different ranges of total rainfall (hours)					Average storm volume (in.)	Total volume (in.)
	24 hours	48 hours	72 hours	168 hours				>0.0—0.09 in.	>0.1 —0.19 in.	>0.2—0.49 in.	>0.5—0.99 in.	>1 in.		
Annual 75th percentile	0	.036	.216	.963	.06	13.67	.21	104	167	216	321	644.00	.67	4.20
Logan Airport 1970 to 1995 (for all storms)														
October	0.027	0.105	0.206	0.594	0.05	11.87	0.16	106	144	167	286	654.57	0.55	3.57
November	.024	.123	.248	.791	.04	13.29	.13	89	123	146	255	492.69	.57	4.14
December	.008	.099	.185	.740	.03	12.35	.09	74	110	144	258	556.04	.46	3.98
January	.034	.118	.210	.704	.03	11.40	.09	78	118	145	340	625.55	.45	3.63
Febuary	.016	.107	.213	.710	.03	13.25	.09	84	116	150	328	604.41	.50	3.34
March	.041	.123	.228	.729	.03	13.34	.10	82	115	138	236	615.25	.48	3.99
April	.042	.135	.258	.695	.04	10.16	.10	73	120	167	263	678.14	.43	3.57
May	.026	.105	.192	.553	.04	11.00	.11	76	122	165	318	738.31	.39	3.35
June	.037	.117	.226	.676	.05	8.54	.14	80	133	166	337	945.01	.36	2.93
July	.032	.127	.220	.530	.06	7.57	.18	85	130	178	432	1274.87	.39	3.06
August	.044	.148	.218	.646	.07	9.42	.19	95	130	160	306	792.04	.48	3.45
September	.049	.118	.203	.680	.05	9.51	.16	93	145	188	316	680.81	.47	3.21
Annual average................	.031	.118	.217	.671	.04	10.96	.13	84	125	159	306	723.61	.46	3.52
Annual 25th percentile	0	0	0	.100	.01	2.00	.03	35	51	62	99	212.00	.05	3.31
Annual median	0	0	.010	.390	.03	7.00	.07	66	96	121	210	502.00	.21	3.51
Annual 75th percentile	0	.060	.230	.978	.06	15.00	.17	111	168	217	417	995.00	.62	3.72
Logan Airport 1970 to 1995 (for storms >0.5 in.)														
Annual average................	0.013	0.082	0.174	0.675	0.08	21.06	0.28	88	128	161	298	694.22	1.19	--
Annual 25th percentile	0	0	0	.100	.04	11.00	.15	41	58	70	105	208.00	.68	--
Annual median	0	0	0	.400	.06	17.00	.23	72	101	122	198	462.00	.94	--
Annual 75th percentile	0	.020	.170	1.000	.09	27.00	.35	113	169	211	420	962.00	1.43	--
Design Storms														
7-20-82 (3 month)	--	--	--	--	0.09	21.00	0.40	--	--	--	--	--	1.84	--
9-20-61 (1 year)	--	--	--	--	.13	22.00	.65	--	--	--	--	--	2.79	--

Dry Weather

Dry-weather annual loads (table 27 at back of report) were calculated for upstream and tributary subbasins draining to the lower Charles River. Dry-weather loads were estimated by multiplying annual dry-weather flow volumes (table 4) by each overall dry-weather mean concentration (arithmetic and flow weighted; table 25). Dry-weather flow was distinguished from stormwater flow for each station by identification of the flow threshold, the point on the hydrograph where streamflow increases as a result of storm runoff. A single flow threshold was used for many of the smaller storm drains and urban streams; however, because of seasonal changes in base flow, larger tributaries required the use of different flow thresholds to separate dry-weather flows from stormwater flows. In particular, Charles River at Watertown (01104615) required a different flow threshold for every storm because of continuously changing base-flow conditions (fig. 4) as a result of (1) alteration of flow by wetlands in the headwaters of the Charles River, (2) regulation of flow at the Mother Brook diversion, and (3) water withdrawals from upstream communities.

Stormwater

Stormwater loads for sampled storms (table 6) were estimated by multiplying stormwater-flow volumes (table 3) by the corresponding stormwater EMCs for each station (table 23). Annual stormwater loads were estimated by multiplying annual stormwater-flow volumes (table 4) by the corresponding overall stormwater EMCs (arithmetic and flow-weighted) for each station (table 25). Station-specific regression equations were also used to estimate EMCs for individual WY 2000 storms on the basis of the antecedent conditions and rainfall characteristics of each storm. The load for a given storm was calculated by multiplying individual storm EMCs by the discharge volume for the corresponding storm. The annual (WY 2000) stormwater load was then calculated as the sum of the individual storm loads. For some storms, the regression equations resulted in negative EMCs, and in these cases zero was used. For some constituents, the regression-equations approach did not produce a statistically significant equation; in these cases the overall mean stormwater EMC was used.

Design-Storm Loads

To compare stormwater-contaminant loading patterns among upstream, tributary-subbasin, and CSO sources and between present and future planned conditions, it is necessary for loads to be estimated under identical conditions (for example, rainfall characteristics and antecedent conditions). Two historic storms on September 21, 1961, and July 19–20, 1982, were selected by the MWRA for estimation of loads (table 7). The recurrence interval of the 1982 storm was estimated to be 3 months (known as the "3-month storm") and the recurrence interval of the 1961 storm was estimated to be 1 year (the "1-year storm;" Leo and others, 1994). In other words, storms of similar magnitude can be expected to occur once every 3 months and once every year, respectively. The rationale behind selection of these two storms is presented in Metcalf & Eddy, Inc. (1994).

Design-storm loads (table 27) were determined by means of the regression equations and the actual rainfall characteristics of the two historic storms, in combination with median antecedent conditions (table 5). Actual antecedent conditions were unavailable for these storms; therefore, median antecedent conditions measured between 1970 and 1995 at Logan International Airport, 10 mi east of the study area, were used to calculate the design storm EMCs by means of the regression equations. These median antecedent conditions were similar to those for storms with a total rainfall of at least 0.5 in. As with estimated stormwater loads, the overall arithmetic mean stormwater EMC was used in instances where regression equations were not adequate. It is important to note that although the design storms are actual storms, estimated loads presented herein do not reflect historical loads but rather loads that could be expected under present environmental conditions for the given rainfall characteristics and long-term median antecedent conditions.

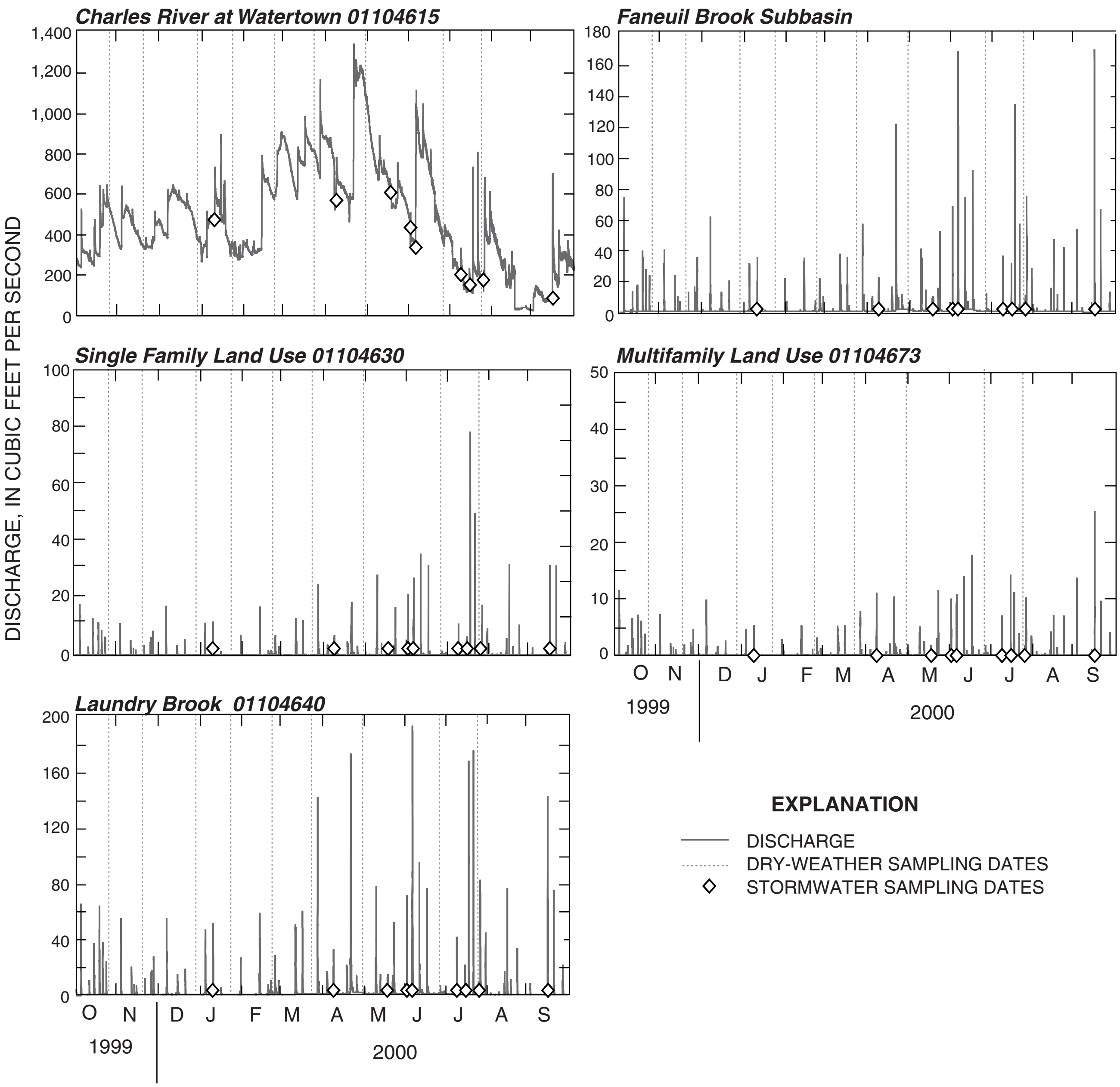


Figure 4. Modeled and observed (upstream) discharge and dates of dry-weather and stormwater sampling at selected gaging stations and subbasins, lower Charles River Watershed, Massachusetts, Water Year 2000.

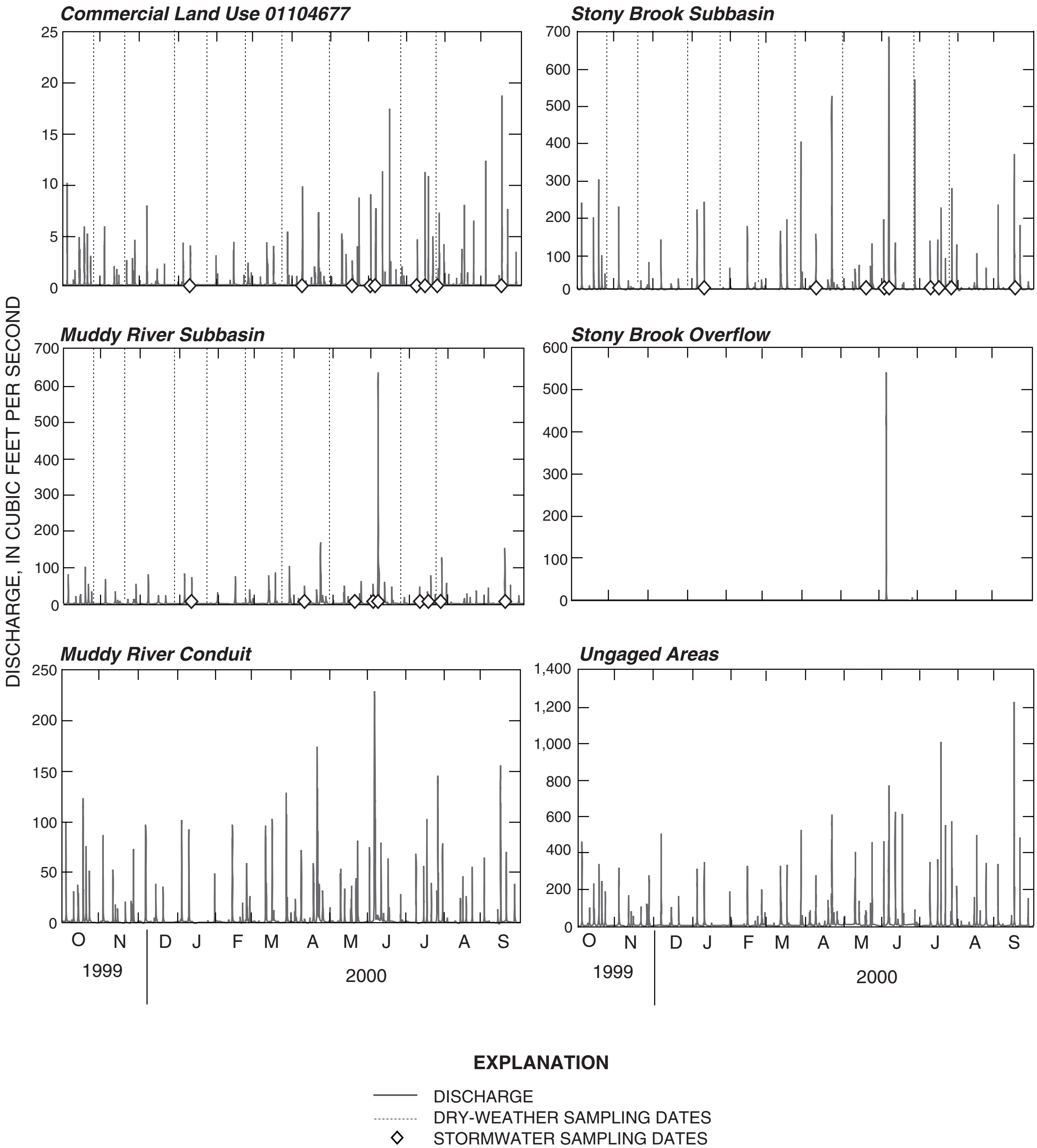


Figure 4. Modeled and observed (upstream) discharge and dates of dry-weather and stormwater sampling at selected gaging stations and subbasins, lower Charles River Watershed, Massachusetts, Water Year 2000—*Continued.*

Table 6. Constituent loads for sampled storms, lower Charles River Watershed, Massachusetts

[**Date:** Is in month, day, and year. **Time:** All times are eastern standard time and are in hours and minutes. g, gram; kg, kilogram; TCFU, trillion colony-

Start date and time	End date and time	Biochemical oxygen demand, 5-day (kg)	Coliform, fecal, membrane filter (TCFU)	Enterococcus, membrane filter (TCFU)	Dissolved solids (kg)	Suspended solids (kg)	Nitrate, total (kg as N)	Nitrogen, ammonia, total (kg as N)
Charles River at Watertown (01104615)								
1-10-00 1430	1-11-00 1845	3,800	12	31	385,000	12,600	1,200	260
4-09-00 0015	4-10-00 0000	--	3.7	3.1	269,000	16,700	790	130
5-18-00 1600	5-20-00 0000	4,100	10	16	356,000	20,900	1,100	230
6-02-00 1630	6-03-00 0730	2,100	24	16	113,000	7,200	380	110
6-06-00 0800	6-07-00 1900	--	59	49	419,000	43,800	1,400	280
7-09-00 1915	7-10-00 2330	--	32	20	160,000	7,280	390	120
7-16-00 0000	7-16-00 1800	680	18	13	64,300	2,030	130	58
7-27-00 0545	7-28-00 0000	2,000	46	82	158,000	15,800	170	250
9-15-00 0730	9-16-00 0000	--	110	--	85,300	13,100	220	110
Single-family land use (01104630)								
1-10-00 1515	1-10-00 2200	16	0.70	0.20	486	375	2.4	1.4
4-09-00 0015	4-09-00 0930	--	.10	.30	127	307	.90	.20
5-18-00 1845	5-18-00 1645	23	.50	1.5	113	95.5	1.0	.40
6-02-00 1745	6-02-00 2100	44	.30	.70	240	497	2.4	2.3
6-06-00 0800	6-07-00 1030	--	6.8	6.0	397	1,210	4.8	2.4
7-09-00 1915	7-09-00 2345	41	1.9	.80	249	170	4.1	2.7
7-16-00 0000	7-16-00 0615	16	.20	.10	33.7	28.4	1.3	.80
7-27-00 0400	7-27-00 1515	20	2.1	3.5	246	311	1.8	1.0
9-15-00 0630	9-15-00 1445	--	--	--	--	--	--	--
Laundry Brook (01104640)								
1-10-00 1445	1-11-00 1215	160	1.1	0.50	5,340	496	29	3.1
4-09-00 0015	4-09-00 2115	--	.30	1.0	3,330	1,380	17	2.0
5-18-00 1600	5-19-00 2330	140	1.7	2.5	2,920	384	14	2.0
6-02-00 1730	6-03-00 1145	310	5.5	1.6	2,610	2,180	17	12
6-06-00 0815	6-08-00 0000	--	34	39	12,000	3,170	46	15
7-09-00 1915	7-10-00 2000	150	1.2	.60	2,510	779	13	6.9
7-16-00 0000	7-16-00 2045	84	4.0	2.6	997	299	5.3	4.9
7-27-00 0445	7-27-00 2115	120	12	17	3,010	653	9.4	4.9
9-15-00 0615	9-15-00 1700	--	11	--	4,030	1,210	14	7.9
Faneuil Brook (01104660)								
1-10-00 1500	1-10-00 0245	77	2.5	1.2	1,400	448	10	1.3
4-09-00 0015	4-09-00 0915	--	.90	.20	564	124	2.5	.30
5-18-00 1900	5-19-00 0818	30	1.5	2.2	750	158	3.9	.30
6-02-00 1730	6-02-00 2115	50	1.0	.90	--	794	2.0	1.9
6-06-00 0815	6-07-00 1115	--	8.0	7.3	3,880	1,620	13	2.9
7-09-00 1930	7-10-00 0230	40	.70	.80	857	237	5.5	1.6
7-16-00 0000	7-16-00 0445	32	2.1	1.2	394	246	4.4	1.0
7-27-00 0345	7-27-00 1500	39	5.7	7.9	2,930	404	10	2.5
9-15-00 0615	9-15-00 1500	--	42	--	2,380	2,240	14	3.7

forming units; --, not determined]

Start date and time	End date and time	Nitrogen, total Kjeldahl (kg as N)	Phosphorus, total (kg)	Cadmium, total (g)	Chromium, total (g)	Copper, total (g)	Lead, total (g)	Zinc, total (g)
Charles River at Watertown (011046215)								
1-10-00 1430	1-11-00 1845	1,400	110	360	3,600	7,400	8,600	28,000
4-09-00 0015	4-10-00 0000	1,400	86	860	3,400	8,600	9,000	29,000
5-18-00 1600	5-20-00 0000	1,600	350	410	4,100	10,000	11,000	31,000
6-02-00 1630	6-03-00 0730	630	88	140	1,300	5,600	5,300	19,000
6-06-00 0800	6-07-00 1900	2,200	280	610	6,700	17,000	25,000	76,000
7-09-00 1915	7-10-00 2330	800	80	150	1,500	7,300	4,700	15,000
7-16-00 0000	7-16-00 1800	320	24	68	680	1,600	1,500	4,800
7-27-00 0545	7-28-00 0000	770	66	200	2,500	7,800	9,900	18,000
9-15-00 0730	9-16-00 0000	1,100	110	130	2,000	5,300	8,500	60,000
Single-family land use (01104630)								
1-10-00 1515	1-10-00 2200	5.8	0.8	0.9	37	130	240	330
4-09-00 0015	4-09-00 0930	3.9	.50	1.5	29	93	160	250
5-18-00 1845	5-18-00 1645	4.5	.80	.30	12	62	56	160
6-02-00 1745	6-02-00 2100	9.6	1.7	1.0	32	130	250	430
6-06-00 0800	6-07-00 1030	17	6.0	4.0	85	270	450	890
7-09-00 1915	7-09-00 2345	7.9	1.1	.70	17	130	110	330
7-16-00 0000	7-16-00 0615	2.5	.40	.50	5.3	37	24	97
7-27-00 0400	7-27-00 1515	6.0	.80	1.4	35	130	230	410
9-15-00 0630	9-15-00 1445	--	--	--	--	--	--	--
Laundry Brook (01104640)								
1-10-00 1445	1-11-00 1215	26	1.9	6.2	93	500	490	1,200
4-09-00 0015	4-09-00 2115	32	4.0	13	130	540	1,000	3,100
5-18-00 1600	5-19-00 2330	27	4.2	3.8	57	490	340	1,200
6-02-00 1730	6-03-00 1145	52	8.9	14	230	1,300	1,600	4,100
6-06-00 0815	6-08-00 0000	110	15	27	390	1,700	2,400	5,100
7-09-00 1915	7-10-00 2000	33	3.9	3.6	63	450	490	1,500
7-16-00 0000	7-16-00 2045	16	2.1	4.5	27	180	220	920
7-27-00 0445	7-27-00 2115	51	1.9	7.3	110	380	430	880
9-15-00 0615	9-15-00 1700	110	9.1	6.7	100	510	610	1,500
Faneuil Brook (01104660)								
1-10-00 1500	1-10-00 0245	10	1.0	1.8	37	140	310	780
4-09-00 0015	4-09-00 0915	3.1	.50	1.8	15	54	84	250
5-18-00 1900	5-19-00 0818	6.0	1.1	.70	14	98	74	250
6-02-00 1730	6-02-00 2115	8.5	.40	2.0	39	180	360	580
6-06-00 0815	6-07-00 1115	29	3.8	7.6	140	480	760	1,900
7-09-00 1930	7-10-00 0230	6.6	.90	.60	15	99	92	260
7-16-00 0000	7-16-00 0445	4.9	1.0	1.2	12	70	86	200
7-27-00 0345	7-27-00 1500	13	1.5	2.8	46	170	220	410
9-15-00 0615	9-15-00 1500	28	6.6	4.2	110	390	980	1,400

Table 6. Constituent loads for sampled storms, lower Charles River Watershed, Massachusetts—*Continued*

Start date and time	End date and time	Biochemical oxygen demand, 5-day (kg)	Coliform, fecal, membrane filter (TCFU)	Enterococcus, membrane filter (TCFU)	Dissolved solids (kg)	Suspended solids (kg)	Nitrate, total (kg as N)	Nitrogen, ammonia, total (kg as N)
Multifamily land use (01104673)								
1-10-00 1445	1-10-00 2200	4.6	0.10	0.40	157	40.8	0.60	0.30
4-09-00 0145	4-09-00 0815	--	.004	.10	56.1	26.6	.004	.10
5-18-00 1845	5-18-00 2030	8.8	.10	.20	75.9	22.6	.50	.005
6-02-00 1730	6-03-00 0245	8.4	.30	.10	122	20.9	.80	.70
6-06-00 0800	6-07-00 1430	--	.50	1.5	2,330	506	13	2.2
7-09-00 1845	7-10-00 0200	8.1	.10	.10	152	34.6	1.4	.50
7-16-00 0000	7-16-00 0745	19	.40	.40	615	92.3	.60	.80
7-27-00 0215	7-27-00 1830	16	.80	1.6	251	54	1.1	.70
9-15-00 0615	9-15-00 1800	--	--	--	--	--	--	--
Commercial land use (01104677)								
1-10-00 1445	1-10-00 2200	3.2	0.02	0.10	41.1	25.1	0.50	0.30
4-09-00 0145	4-09-00 0815	--	.01	.03	42.8	42.3	.50	.20
5-18-00 1845	5-19-00 2145	35	.20	.30	224	104	1.6	.30
6-02-00 1730	6-03-00 0245	9.5	.20	.10	80.4	29.5	1.2	.90
6-06-00 0730	6-07-00 1430	--	.40	.50	230	98.5	1.3	.50
7-09-00 1915	7-10-00 0100	19	.04	.10	164	78.4	1.8	.60
7-16-00 0000	7-16-00 0945	17	.30	.30	49.5	89.8	1.0	.40
7-27-00 0215	7-27-00 1800	6.4	.50	1.1	83.4	353	.40	.30
9-15-00 0630	9-15-00 1430	--	--	--	--	--	--	--
Muddy River (01104683)								
1-10-00 1445	1-11-00 1500	390	2.7	3.5	13,200	2,350	76	32
4-09-00 0015	4-09-00 2330	--	2.5	2.8	9,090	3,440	42	11
5-18-00 1745	5-19-00 2330	310	9.6	3.8	10,600	1,260	45	13
6-02-00 1530	6-03-00 0830	770	17	6.3	13,500	2,910	65	35
6-06-00 0945	6-07-00 1445	--	170	140	56,100	32,400	290	65
7-09-00 1915	7-10-00 0900	430	3.7	.60	7,680	1,150	48	25
7-16-00 0000	7-16-00 1645	280	12	6.1	317	1,140	14	12
7-27-00 0245	7-28-00 0000	410	50	40	14,200	6,510	61	38
9-15-00 0815	9-15-00 2115	--	14	--	14,700	12,700	120	74
Stony Brook (01104687)								
1-10-00 1445	1-10-00 1145	640	27	12	16,800	4,330	170	34
4-09-00 0015	4-09-00 2045	--	16	6.9	15,000	10,900	63	13
5-18-00 1600	5-19-00 2330	290	7.6	2.9	13,400	1,190	67	13
6-02-00 1530	6-03-00 0730	1,700	41	16	8,870	17,700	75	49
6-06-00 0800	6-07-00 1715	--	290	280	107,000	42,000	570	130
7-09-00 2000	7-10-00 0930	1,400	100	15	14,000	9,010	80	38
7-16-00 0000	7-16-00 1200	730	81	13	4,470	5,480	40	24
7-27-00 0345	7-27-00 2330	1,300	39	32	18,700	14,700	100	24
9-15-00 0815	9-16-00 0000	--	45	--	14,800	13,200	130	39

Start date and time	End date and time	Nitrogen, total Kjeldahl (kg as N)	Phos-phorus, total (kg)	Cadmium, total (g)	Chromium, total (g)	Copper, total (g)	Lead, total (g)	Zinc, total (g)
Multifamily land use (01104673)								
1-10-00 1445	1-10-00 2200	1.3	0.20	0.60	6.4	65	73	170
4-09-00 0145	4-09-00 0815	1.3	.20	.90	7.0	60	49	190
5-18-00 1845	5-18-00 2030	1.4	.20	.20	4.4	53	47	130
6-02-00 1730	6-03-00 0245	1.7	.40	.40	7.1	87	74	190
6-06-00 0800	6-07-00 1430	14	2.5	4.9	77	500	670	1,600
7-09-00 1845	7-10-00 0200	2.0	.30	.30	5.1	100	110	200
7-16-00 0000	7-16-00 0745	1.7	.50	.60	7.7	74	120	180
7-27-00 0215	7-27-00 1830	4.1	.40	.60	13	120	100	230
9-15-00 0615	9-15-00 1800	--	--	--	--	--	--	--
Commercial land use (01104677)								
1-10-00 1445	1-10-00 2200	1.0	0.20	0.40	3.2	54	130	160
4-09-00 0145	4-09-00 0815	1.2	.20	.60	6.3	94	140	190
5-18-00 1845	5-19-00 2145	5.0	.60	.80	14	240	210	400
6-02-00 1730	6-03-00 0245	2.7	.30	.40	5.4	200	170	260
6-06-00 0730	6-07-00 1430	2.7	.40	1.1	15	170	310	400
7-09-00 1915	7-10-00 0100	3.5	.30	1.3	9.5	310	260	390
7-16-00 0000	7-16-00 0945	2.9	.30	.60	8.2	93	130	220
7-27-00 0215	7-27-00 1800	2.4	.30	1.2	17	160	830	490
9-15-00 0630	9-15-00 1430	--	--	--	--	--	--	--
Muddy River (01104683)								
1-10-00 1445	1-11-00 1500	100	14	19	290	1,900	2,200	6,800
4-09-00 0015	4-09-00 2330	130	14	40	320	2,200	2,700	7,400
5-18-00 1745	5-19-00 2330	90	10	10	580	1,600	910	5,100
6-02-00 1530	6-03-00 0830	140	24	15	350	3,000	2,500	6,900
6-06-00 0945	6-07-00 1445	580	92	140	2,700	14,000	18,000	43,000
7-09-00 1915	7-10-00 0900	91	8.6	9.6	140	2,500	1,200	3,800
7-16-00 0000	7-16-00 1645	51	7.3	16	95	1,000	790	1,900
7-27-00 0245	7-28-00 0000	190	26	110	900	4,500	4,800	11,000
9-15-00 0815	9-15-00 2115	310	63	39	980	6,700	8,700	16,000
Stony Brook (01104687)								
1-10-00 1445	1-10-00 1145	130	28	27	390	1,700	3,800	7,500
4-09-00 0015	4-09-00 2045	130	45	52	730	2,900	9,000	15,000
5-18-00 1600	5-19-00 2330	77	10	10	100	820	990	2,900
6-02-00 1530	6-03-00 0730	300	57	82	1,300	5,100	17,000	20,000
6-06-00 0800	6-07-00 1715	990	180	250	4,100	13,000	33,000	57,000
7-09-00 2000	7-10-00 0930	230	37	46	510	3,600	7,800	11,000
7-16-00 0000	7-16-00 1200	130	21	23	270	1,700	3,800	5,300
7-27-00 0345	7-27-00 2330	230	58	59	960	4,900	16,000	16,000
9-15-00 0815	9-16-00 0000	310	59	49	890	5,000	12,000	27,000

Table 7. Stormwater volume for 3-month and 1-year design storms, lower Charles River Watershed, Massachusetts

[ft^3, cubic foot]

Station name	Volume (ft^3)	
	3-month	1-year
Charles River at Watertown	80,000,000	200,000,000
Single-family land use	280,000	440,000
Laundry Brook	2,100,000	3,500,000
Faneuil Brook	580,000	1,000,000
Faneuil Brook Subbasin[1]	970,000	1,600,000
Multifamily land use	120,000	210,000
Commercial land use	100,000	160,000
Muddy River	6,900,000	13,000,000
Muddy River Subbasin[1, 2]	10,000,000	18,000,000
Stony Brook	7,000,000	13,000,000
Stony Brook Subbasin[1, 3]	7,900,000	15,000,000

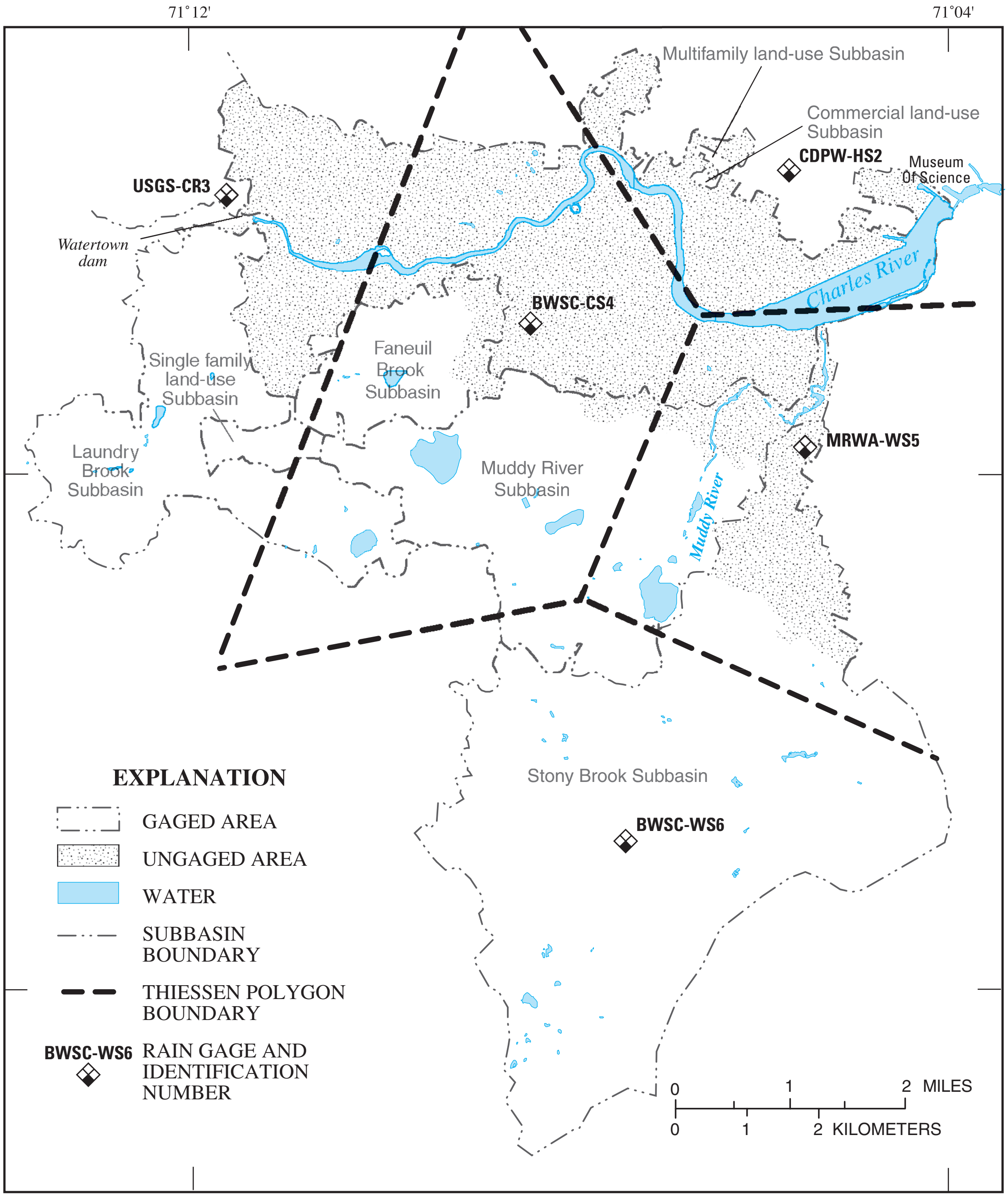
[1]Includes ungaged portions of gaged subbasin, respectively.
[2]Includes Muddy River conduit.
[3]Includes Stony Brook overflow and volume of combined sewage.

Rainfall-Data Analysis

In New England, rainfall across a drainage basin can be highly variable, especially during the summer. Summer thunderstorms can produce an inch of rain in one part of a watershed and no rain in other parts, adding to the difficulties of storm sampling. This problem is compounded in that the present study area encompasses more than 38 mi^2. Fortunately, several rain gages are operated by city, State, and Federal governmental agencies in the lower Charles River Watershed. Rain gages were assigned to each water-quality sampling station on the basis of Thiessen polygons determined with ARC/INFO geographic information system (GIS) software (fig. 5; Environmental Research Institute, Inc., Version 7.11). Rain gages within the same polygon as one of the stations were assigned to that station. Data from these gages were used to determine antecedent conditions of the approximately 90 storms during WY 2000 (table 5). Statistics for antecedent conditions and rainfall characteristics were calculated by means of the SYNOP computer program, developed by the USEPA for use in the National Urban Runoff Program (NURP) (fig. 6).

The above observations and reported rainfall and antecedent characteristics were based on a particular set of conditions that were used to define a "storm." In this study, a storm was defined as any measurable rain (greater than 0.1 in.) with at least a 12-hr antecedent dry period. In other words, there must be no measurable precipitation 12 hr prior to the start of any new storm. For example, if a break in precipitation during a storm lasted less than 12 hr, the entire period of precipitation was considered one storm, but if the break in precipitation lasted longer than 12 hr, the two rainfall periods were considered as two storms. This definition is important, because different definitions of a storm will produce different rainfall statistics. These different statistics may explain discrepancies between rainfall statistics calculated here and those determined by others.

Characteristics of sampled storms were biased compared to the total population of storms. This bias is an artifact of storm-sampling criteria: sampled storms had to produce rainfall amounts greater than about 0.5 in. and had to be preceded by at least 72 hr of little to no rainfall (a maximum allowed amount of 0.15 in.). However, WY 2000 was about average in terms of storm size, characteristics, and variation of characteristics when compared with 26 years (1970 to 1995) of rainfall data recorded at Logan International Airport (fig. 6). An unpaired t-test showed no statistical difference between means of these characteristics measured for WY 2000 and means measured at Logan International Airport from 1970 to 1995 at the 95-percent significance level. Two exceptions were the mean greater than 0.5 and greater than 1.0 in. antecedent dry periods that showed slight differences at the 95-percent significance level. Water Year 2000 was also about average in terms of total annual rainfall compared to long-term averages recorded at Logan International Airport (42.8 and 42.2 in., respectively), mean number of storms with total rainfall between 1 and 2 in. (2.1 and 3.3 in., respectively), and the mean number of storms with total rainfall greater than 2 in. (9 and 8.33 in., respectively).



Map modified from Zarriello and Barlow, 2002

Figure 5. Thiessen polygons used to assign rain gages to subbasins in the lower Charles River Watershed, Massachusetts.

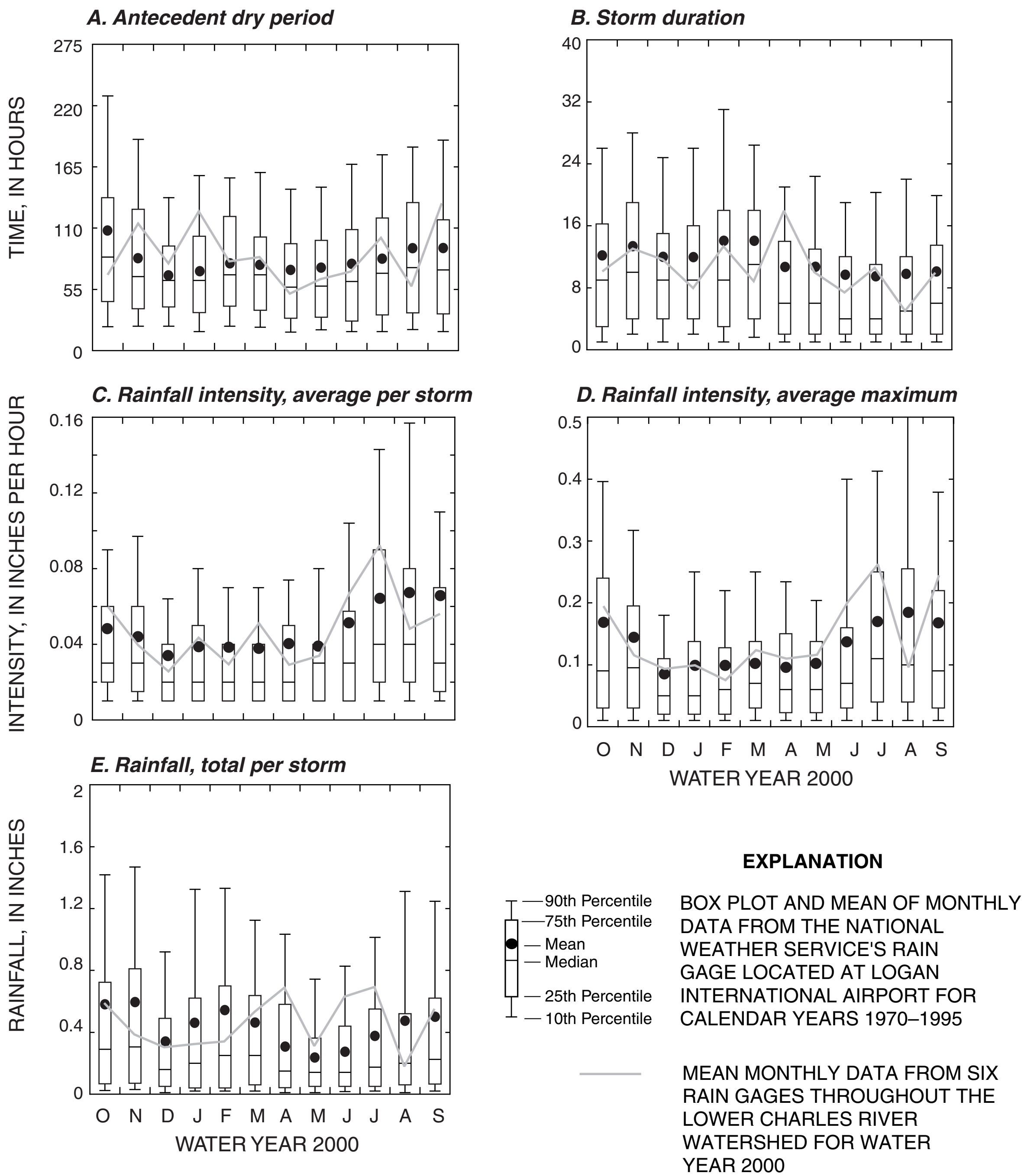


Figure 6. Summary statistics of rainfall characteristics and antecedent conditions for individual storms in the lower Charles River Watershed during Water Year 2000 and at Logan International Airport, Boston, Massachusetts from 1970 to 1995.

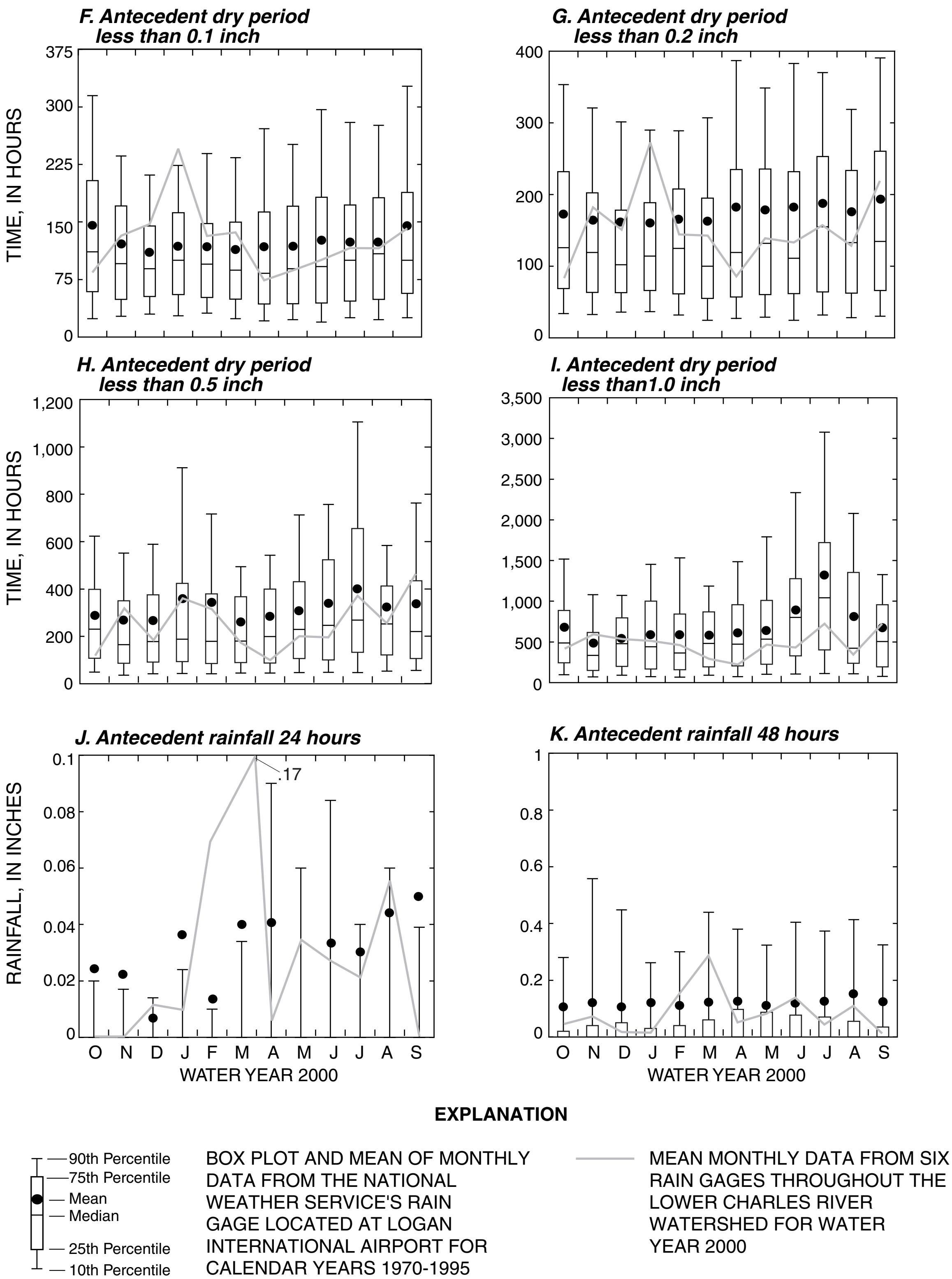


Figure 6. Summary statistics of rainfall characteristics and antecedent conditions for individual storms in the lower Charles River Watershed during Water Year 2000 and at Logan International Airport, Boston, Massachusetts from 1970 to 1995—*Continued*.

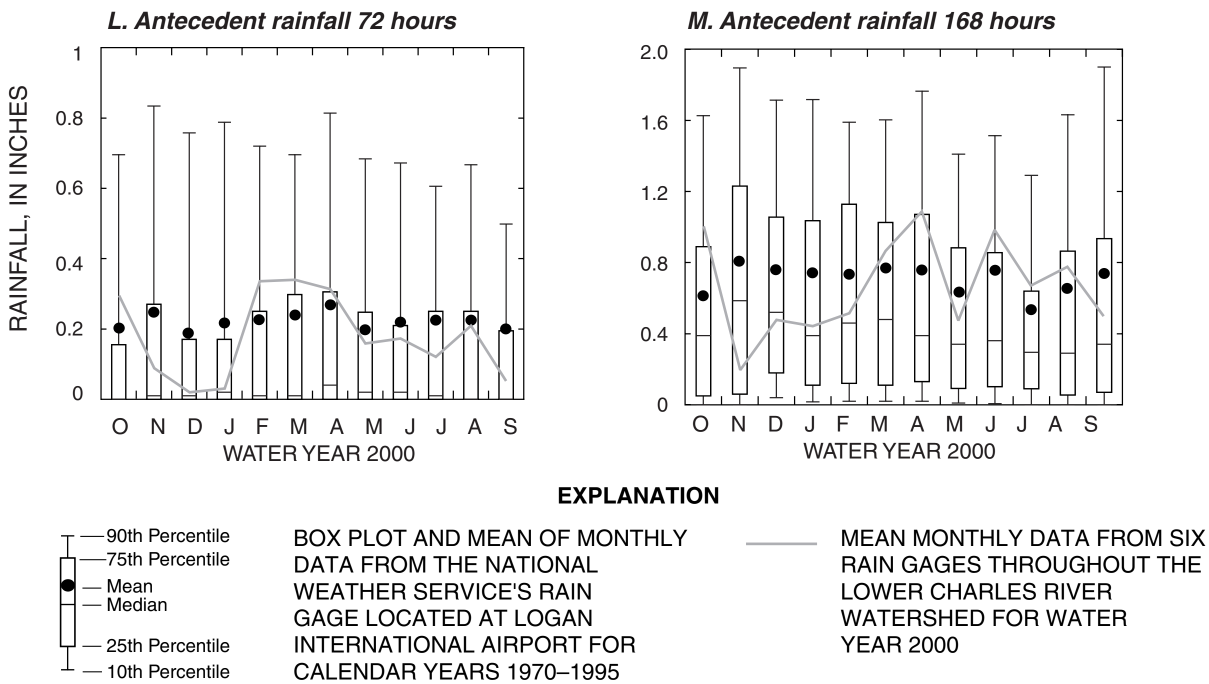


Figure 6. Summary statistics of rainfall characteristics and antecedent conditions for individual storms in the lower Charles River Watershed during Water Year 2000 and at Logan International Airport, Boston, Massachusetts from 1970 to 1995—*Continued*.

QUALITY ASSURANCE

Water-quality data are subject to bias (or systematic error) and variability (or random error) during sample collection, processing, and analysis. The magnitude of bias and variability can be determined by analysis of quality-assurance samples, which include field blanks, laboratory blanks, and split replicates. Inspection of field-blank data showed that sample collection and processing were not a source of contamination bias. Analytical bias was assessed through laboratory sample-blank data. The statistical techniques are described in detail by Mueller (1998). Briefly, expected contamination bias was determined by ranking blank data and determining the concentration that can be expected in a specified percentage (90 percent was chosen for this study) of environmental samples with an acceptable degree of confidence. Sampling variability was assessed by analysis of split field replicates, that is, water-quality samples split into subsamples in the field. Variability was estimated by visual inspection of scatter plots with LOWESS (locally weighted scatterplot smoother; SAS Institute Inc., 1998). The plots show replicate-sample standard deviation plotted as a function of the arithmetic mean concentration of each replicate set (Mueller, 1998). LOWESS smoothing of scatter plots enhances patterns that might otherwise be obscured (SAS Institute Inc., 1998). A change in slope of the LOWESS plot was considered to mark the boundaries among low, middle, and high concentration ranges (table 8).

The maximum potential contamination bias in at least 90 percent of all samples is estimated (at various levels of confidence; table 8) to be less than the minimum reporting level (MRL) for all constituents with the exception of TDS, TKN, Cr, Cu, and Zn (table 2). Contamination bias of these constituents averaged less than about 25 percent of the overall dry-weather means and stormwater EMCs, with a few exceptions. Contamination bias of Cr and Cu on average was 73 and 35 percent of the overall dry-weather means, respectively. Consequently, dry-weather Cr and Cu loads may be elevated as a result of analytical error.

Table 8. Contamination bias expected in 10 percent of the environmental samples collected during the study of the lower Charles River Watershed, Massachusetts

[**MRL:** Minimum reporting level. CFU/100mL, colony-forming units per 100 milliliters; µg/L, micrograms per liter; mg/L, milligrams per liter; <, less than value shown; --, not determined]

Constituent	Number of blank samples	MRL	Number of blank samples greater than MRL	Concentration expected in 10 percent of environmental samples	Confidence level
Biochemical oxygen demand, 5-day (mg/L)	19	2	0	<2	86
Coliform, fecal, membrane filter (CFU/100mL)	0	10	--	--	--
Enterococcus, membrane filter (CFU/100mL)	0	10	--	--	--
Dissolved solids (mg/L)	11	10	2	19	69
Suspended solids (mg/L)	11	10	0	<5	69
Nitrate plus nitrite (mg/L as N)	0	0.023	--	--	--
Nitrogen, ammonia (mg/L as N)	23	0.075	0	<.075	91
Nitrogen, total Kjeldehl (mg/L as N)	30	0.15	17	.28	96
Phosphorus (mg/L)	11	0.01–0.1	0	<.05	69
Cadmium (µg/L)	13	0.05–0.5	0	<.5	75
Chromium (µg/L)	13	0.2–5	9	1	75
Copper (µg/L)	13	0.2	7	2.4	75
Lead (µg/L)	13	0.05	0	<.2	75
Zinc (µg/L)	13	2–10	1	1.7	75

Concentration variability is shown in table 9. These data can be used to determine the maximum potential error for individual measurements of each constituent and water-quality property. The variability of the sample sets is assumed to represent the variability of the entire population. The error of an individual measurement can be estimated by means of either equation (2) for the low and high concentration ranges or equation (3) for concentrations in the middle concentration range. The equations are as follows:

$$C_i = C \pm 1.645 \times \sigma, \qquad (2)$$

where

C_i is the concentration interval, in the appropriate units;

C is the concentration of the sample, in the appropriate units;

σ equals the standard deviation of the replicate pairs, in the appropriate units; and

1.645 represents the percentage points of the t-distribution for infinite degrees of freedom and a 90-percent confidence interval;

or

$$C_i = C \pm 1.645 \times \left(\frac{\sigma}{100}\right), \qquad (3)$$

where

C_i is the concentration interval, in the appropriate units;

C is the concentration of the sample, in the appropriate units;

σ is the relative standard deviation of the replicate pairs, in percent; and

1.645 represents the percentage points of the t-distribution for infinite degrees of freedom and a 90-percent confidence interval.

For example, the dry-weather fecal coliform concentration sampled at Charles River at Watertown (01104615) on July 19, 1999, was 270 CFUs/100 mL. This concentration is within the low range; by means of equation 2, we can state with 90-percent confidence that the actual value is between 210 and 330 CFUs/100 mL.

Table 9. Standard deviations of replicate samples collected in this study of the lower Charles River Watershed, Massachusetts

[CFU/100mL, colony-forming units per 100 milliliters; µg/L, micrograms per liter; mg/L, milligrams per liter; ð, less than or equal to value shown; >, greater than value shown; --, not determined]

Constituent	Low concentration range		Middle concentration range		High concentration range	
	Concen-tration	Standard deviation (units)	Concen-tration	Relative standard deviation (percent)	Concen-tration	Standard deviation (units)
Biochemical oxygen demand, 5-day (mg/L)	ð5	0.2	>5	13.1	--	--
Coliform, fecal, membrane filter (CFU/100mL)	ð500	37	501–5,000	9.5	>5,000	2,800
Enterococcus, membrane filter (CFU/100mL)	ð250	13	251–2,500	10.7	>2,500	5,100
Dissolved solids (mg/L)	ð300	9.4	>300	2.6	--	--
Suspended solids (mg/L)	ð25	.2	>25	14.4	--	--
Nitrate plus nitrite (mg/L as N)	ð1	.01	>1	4.0	--	--
Nitrogen, ammonia (mg/L as N)	ð1.2	.02	--	--	--	--
Nitrogen, total Kjeldehl (mg/L as N)	ð1.5	.08	>1.5	3.9	--	--
Phosphorus (mg/L)	ð0.3	.01	>0.3	1.9	--	--
Cadmium (µg/L)	--	--	--	--	--	--
Chromium (µg/L)	ð3	.05	>3	2.9	--	--
Copper (µg/L)	ð10	.87	>10	2.4	--	--
Lead (µg/L)	ð10	.08	>10	2.6	--	--
Zinc (µg/L)	ð25	4.00	>25	1.8	--	--

Additionally, variability in mean concentrations can be used to determine the potential error associated with dry-weather and stormwater load estimates for loads determined by use of mean concentrations. Equation (4) is used for concentrations in the low- and high-concentration ranges and equation (5) is used for concentrations in the middle-concentration range; the equations are given as

$$C_i = \overline{C} \pm 1.645 \times \left(\frac{\sigma}{\sqrt{n}}\right), \quad (4)$$

where

C_i is the concentration interval, in the appropriate units;
$\overline{C}$ is the mean concentration, in the appropriate units;
σ is the standard deviation of the replicate pairs, in the appropriate units;
n is the number of samples; and,
1.645 represents the percentage points of the t-distribution for infinite degrees of freedom and a 90-percent confidence interval;

and

$$C_i = \overline{C} \pm 1.645 \times \left(\frac{\frac{\sigma}{100}}{\sqrt{n}}\right), \quad (5)$$

where

C_i is the concentration interval, in the appropriate units;
$\overline{C}$ is the mean concentration, in the appropriate units;
σ is the standard deviation of the replicate pairs, in percent;
n equals the number of samples; and,
1.645 represents the percentage points of the t-distribution for infinite degrees of freedom and a 90-percent confidence interval.

For example, the mean stormwater fecal coliform EMC measured from Stony Brook (01104687) was 66,000 CFUs/100 mL (n=9). This concentration is within the high-concentration range; therefore, by means of equation 4, we can say with 90-percent confidence that the actual value is somewhere between 64,500 and 67,500 CFUs/100 mL.

STREAMFLOW

As in most highly urbanized areas, streamflow in the lower Charles River Watershed is extremely variable or “flashy.” Streamflow in the lower Charles River Watershed is affected by the impervious character of the land surface throughout the watershed, flood-control structures, and CSOs. In contrast, streamflow upstream of the Charles River at Watertown station (01104615) is strikingly different from that measured at the other gaging stations in the study area. Generally, discharge increases within 1/2 hr after the onset of rainfall, peaks, and slowly decreases. Discharge may not return to pre-storm values for days or even weeks after large storms. The reasons for these differences likely include urbanized land use and impervious area; more than 11.5 mi^2 of wetlands, which moderate streamflow by dampening higher stormflows and maintaining base flow during dry weather; and Mother Brook, an upstream diversion used for flood control. Although originally intended to bring water power to mills, the Mother Brook diversion—built in 1640—presently diverts as much as one-third of the flow from the Charles River upstream of the Watertown gaging station to prevent flooding of the lower Charles River Watershed. Water from Mother Brook is discharged into the Neponset River. The annual hydrographs for each gaging station, river or brook in the study area are shown in figure 4.

Charles River at Watertown (01104615)

Streamflow at station 01104615 ranged from 24 to 1,350 ft^3/s with a mean discharge of 483 ft^3/s during WY 2000 (fig. 7). Streamflow during this time equaled or exceeded 165 ft^3/s 90 percent of the time (fig. 8). The mean dry-weather discharge was 456 ft^3/s and the mean stormwater

Figure 7. Upstream view of footbridge located at U.S. Geological Survey gaging station Charles River at Watertown, Massachusetts (01104620).

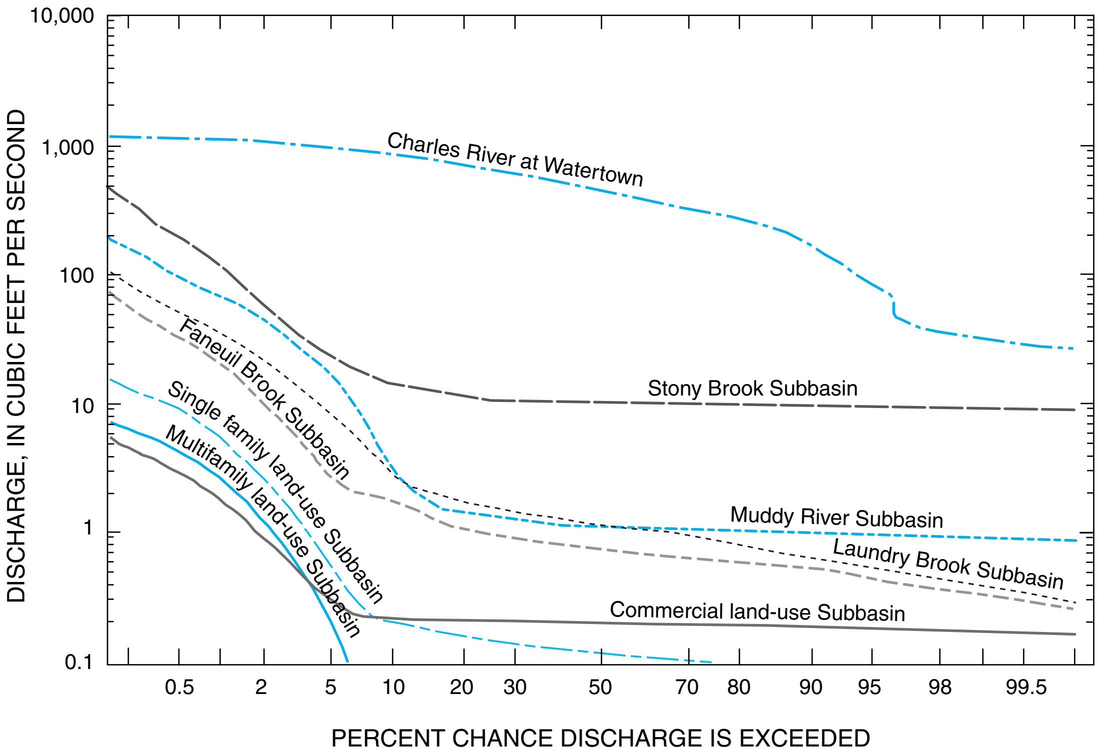


Figure 8. Flow-duration curves of simulated 15-minute flow values for tributary and uniform land-use subbasins, and the flow-duration curve of observed 15-minute flow values at Charles River at Watertown (01104615), lower Charles River Watershed, Massachusetts, Water Year 2000.

discharge was about 559 ft^3/s. The total volume of water discharged to the lower Charles River from areas upstream of Watertown in WY 2000 was about 10,600 million ft^3 for dry-weather flow and 4,640 million ft^3 for stormwater flow (table 4).

Upstream flow at the Watertown gaging station categorized as "stormwater" is likely local stormwater runoff from highly urban areas just upstream of the gaging station rather than stormwater runoff from the entire upstream drainage basin, whereas upstream flows categorized as "dry-weather" likely include some stormwater runoff from the upper parts of the drainage basin. Stormwater from upstream is difficult to distinguish from dry-weather flows because of the unique characteristics of the upstream drainage basin.

Single-Family Land-Use Station (01104630)

Streamflow at the single-family land-use gaging station (01104630) ranged from 0.001 ft^3/s to 79 ft^3/s with a mean discharge of 0.3 ft^3/s during WY 2000 (fig. 9). Streamflow during this time equaled or

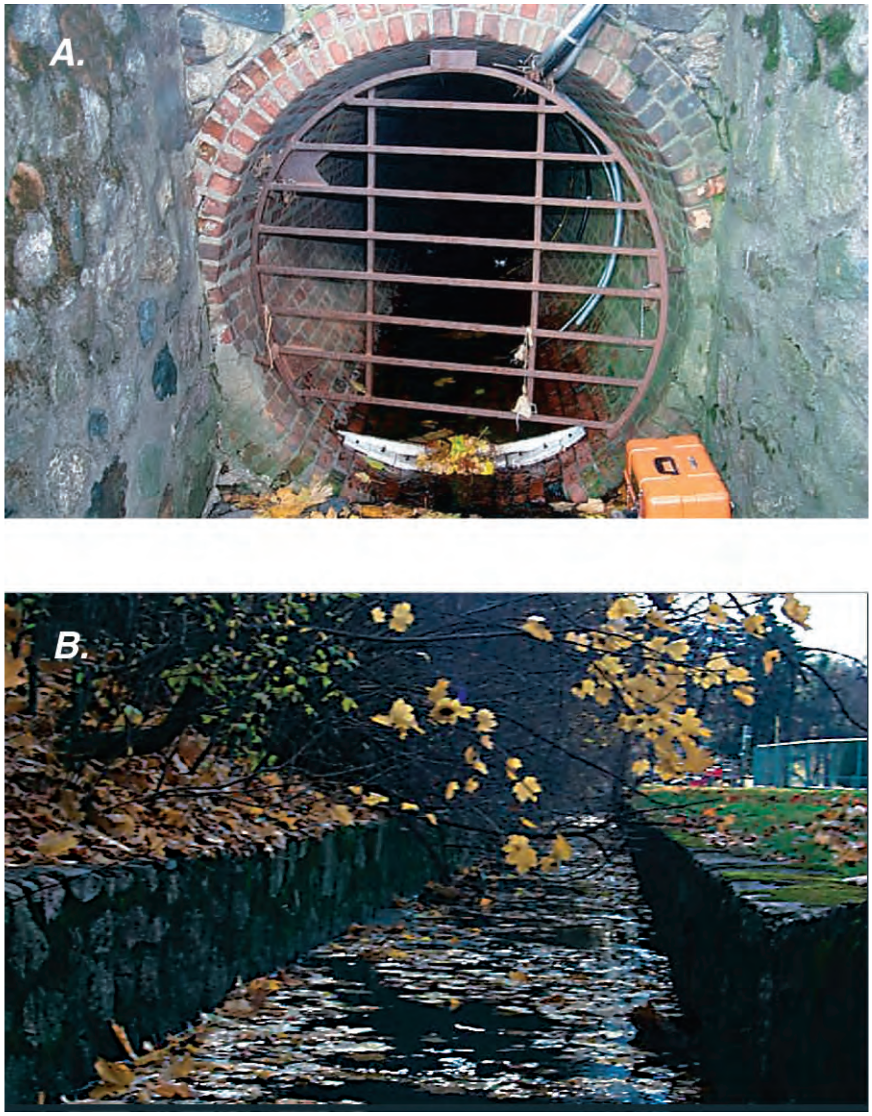


Figure 9. U.S. Geological Survey gaging station single-family land-use (01104630), Newton Center, Massachusetts, (*A*) upstream and (*B*) downstream views.

exceeded 0.07 ft^3/s 90 percent of the time (fig. 8). The mean dry-weather discharge was 0.11 ft^3/s and the mean stormwater discharge was about 1.95 ft^3/s. Streamflow at the single-family land-use station (01104630) can change from a trickle to a torrent almost immediately after it begins raining.

Figure 10. U.S. Geological Survey gaging station Laundry Brook (01104640), Watertown, Massachusetts, (*A*) upstream and (*B*) downstream views.

Laundry Brook Station (01104640)

Streamflow at the Laundry Brook station (01104640) ranged from 0.36 to 194 ft^3/s with a mean discharge of 2.6 ft^3/s during WY 2000 (fig. 10). Streamflow during this time equaled or exceeded 0.62 ft^3/s 90 percent of the time (fig. 8). The mean dry-weather discharge was 1.07 ft^3/s

and the mean stormwater discharge was about 7.81 ft^3/s. Streamflow at Laundry Brook sometimes was observed to increase just prior to the storm, probably because of the regulation of Bulloughs Pond in Newton. As a means of flood control, the city of Newton lowers the water level in the pond just prior to large storms by discharging pond water directly into Laundry Brook. The total volume of water from Laundry Brook discharged to the lower Charles River was about 26 million ft^3 for dry-weather flow in WY 2000 and 56.3 million ft^3 for stormwater flow (this includes some of the water released from Bulloughs Pond).

Faneuil Brook Subbasin

Streamflow for Faneuil Brook Subbasin, including its ungaged portion, ranged from 0.001 to 171 ft^3/s with a mean discharge of 1.6 ft^3/s during WY 2000 (fig. 11). Streamflow during this time equaled or exceeded 0.54 ft^3/s 90 percent of the time (fig. 8). The mean dry-weather discharge was 0.7 ft^3/s and the mean stormwater discharge was about 4.2 ft^3/s. The total volume of water from the Faneuil Brook Subbasin, including its ungaged portion, that discharged to the lower Charles River in WY 2000 was estimated as 16.6 million ft^3 for dry-weather flow and 32.5 million ft^3 for stormwater flow (table 4).

Figure 11. U.S. Geological Survey gaging station Faneuil Brook (01104660), Brighton, Massachusetts, (*A*) upstream view and (*B*) above manhole

Multifamily Land-Use Station (01104673)

Streamflow at the multifamily land-use gaging station (01104673) ranged from less than 0.001 to 25.5 ft^3/s with a mean discharge of 0.096 ft^3/s during WY 2000 (fig. 12). Streamflow during this time equaled or exceeded 0.001 ft^3/s 90 percent of the time (fig. 8). The mean dry-weather discharge was 0.007 ft^3/s and the mean stormwater discharge was about 1.18 ft^3/s. The total volume of water from the multifamily land-use subbasin that discharged to the lower Charles River during WY 2000 was estimated as 0.2 million ft^3 for dry-weather flow and 2.84 million ft^3 for stormwater flow.

Figure 12. U.S. Geological Survey gaging station multifamily land use (01104673), Cambridge, Massachusetts.

Commercial Land-Use Station (01104677)

Streamflow at the commercial land-use gaging station (01104677) ranged from less than 0.001 to 19 ft^3/s with a mean discharge of 0.26 ft^3/s during WY 2000 (fig. 13). Streamflow during this time equaled or exceeded 0.2 ft^3/s 90 percent of the time (fig. 8). The mean dry-weather discharge was 0.2 ft^3/s and the mean stormwater discharge was about 1.17 ft^3/s. The total volume of water from the commercial land-use subbasin that discharged to the lower Charles River in WY 2000 was estimated as 5.98 million ft^3 for dry-weather flow and 2.13 million ft^3 of stormwater flow. The finding that the dry-weather flow is larger than the stormwater flow suggests that there is a source of water, and possibly contaminants, to this drain other than normal dry-weather base flow. After the completion of the field effort for this study, the city of Cambridge's chief engineer notified the USEPA that the increased base flow likely results from dewatering activities by the Massachusetts Bay Transit Authority (MBTA).

Muddy River Subbasin

Streamflow for Muddy River Subbasin, including its ungaged portion, ranged from less than 0.5 to 639 ft^3/s, with a mean discharge of 4.51 ft^3/s during WY 2000 (fig. 14).

Figure 13. U.S. Geological Survey gaging station commercial land use (01104677), Cambridge, Massachusetts.

Figure 14. U.S. Geological Survey gaging station Muddy River (01104683), Brookline, Massachusetts, upstream view.

Streamflow during this time equaled or exceeded 1.04 ft^3/s 90 percent of the time (fig. 8). The mean dry-weather discharge was 1.17 ft^3/s and the mean stormwater discharge was about 25.8 ft^3/s. Dry-weather streamflow at Muddy River (01104683) displays a semi-diurnal pattern that mimics the tidal cycle, although the river has not been hydraulically connected to the harbor since 1908 when the Old Charles River Dam was constructed (fig. 1). However, it is hydraulically connected to the lower Charles River Basin which is managed to create a near-constant water elevation. The Basin is allowed to drain during low tide and refill with upstream flow between low tides. This draining and refilling affects water levels in the Muddy River. Prior to or during rainstorms, the Muddy River's stage often drops sharply as the Basin's stage is artificially lowered by large pumps at the New Charles River Dam.

The total volume of water from the Muddy River Subbasin discharged to the lower Charles River in WY 2000 was estimated as about 92.6 million ft^3 for dry-weather flow and 248 million ft^3 for stormwater flow (table 4). A portion of the upstream flow is diverted through the Muddy River conduit; this diversion bypasses the Back Bay Fens and minimizes flooding there (fig. 1). The total volume of water from the Muddy River conduit discharged to the lower Charles River in WY 2000 was estimated as about 60.6 million ft^3 for dry-weather flow and 137 million ft^3 for stormwater flow (table 4).

Occasionally during large storms, Stony Brook and the Old Stony Brook discharge overflow into the Back Bay Fens at the Boston Gatehouses 1 and 2, respectively. The overflow volume was about 11.3 million ft^3 for WY 2000 (fig. 15).

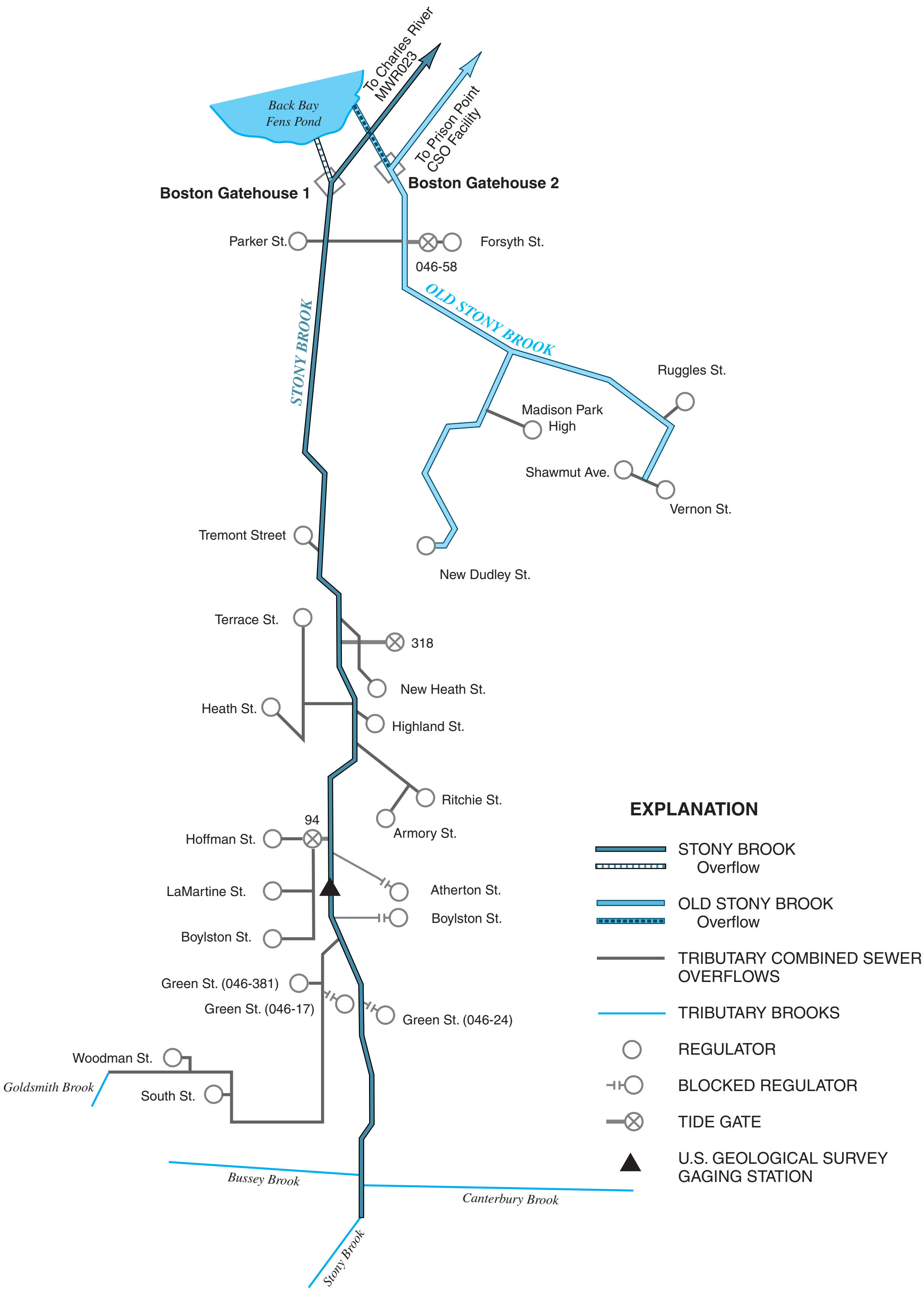


Figure 15. Location of the U.S. Geological Survey gaging station Stony Brook (01104687), lower Charles River Watershed, Massachusetts (modified from Metcalf and Eddy, 1994).

Stony Brook Subbasin

Streamflow for the Stony Brook Subbasin, including its ungaged portions, ranged from 10.3 to 688 ft^3/s with a mean discharge of 15.5 ft^3/s during WY 2000 (fig. 16). Streamflow during this time equaled or exceeded 10.3 ft^3/s 90 percent of the time (fig. 8). The mean dry-weather discharge was 10.8 ft^3/s and the mean stormwater discharge was about 29.5 ft^3/s. Streamflow at Stony Brook (01104687) also has a cyclic pattern during dry weather. In contrast to the Muddy River, however, this pattern is based on a 24-hr cycle and appears unrelated to operations at the Charles River Dam. The reason for the cyclic pattern observed at Stony Brook is unknown but could result from the

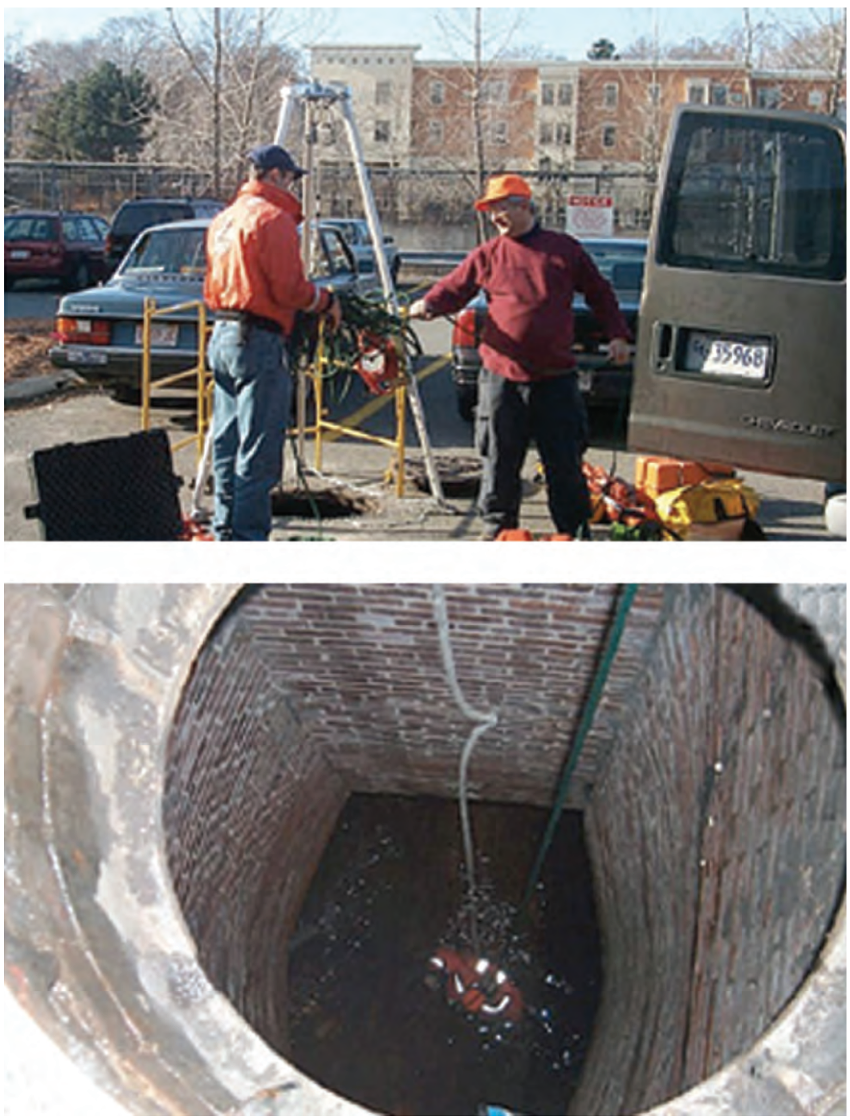


Figure 16. U.S. Geological Survey gaging station Stony Brook (01104687), Boston, Massachusetts.

controlled release of cooling water into Stony Brook. Increases in streamflow are accompanied by increased temperature and decreased specific conductance. During storms that produce more than 0.5 in. of rain, discharge in Stony Brook is frequently augmented by CSOs. Six of the nine sampled storms produced CSO discharge (Massachusetts Water Resources Authority, written commun., 2001). As much as 15 million ft^3 of CSO was discharged into Stony Brook during calendar year (CY) 2000 (Massachusetts Water Resources Authority, written commun., 2001). The CSO discharges to Stony Brook affect both the volume and quality of the flow through Stony Brook. The total volume of water discharged from the Stony Brook Subbasin to the lower Charles River in WY 2000, including the CSO discharges, was estimated to be 255 million ft^3 for dry-weather flow and 234 million ft^3 for stormwater flow (table 4).

WATER QUALITY

The quality of dry-weather and stormwater flows in the tributary streams of the lower Charles River Watershed is typical of highly urbanized areas. Constituent levels are elevated above background levels because of a variety of sources (table 10), including contaminated urban runoff, illicit sanitary-sewer connections, and in the case of one major tributary, CSOs. Constituent concentrations also vary over time at individual sampling sites and among sites for any given storm or dry-weather period.

Indicator Bacteria

Water draining from urban areas commonly contains a wide variety of disease-causing microorganisms, bacteria, viruses and other potential pathogens. Some microorganisms are introduced by fecal contamination from warm-blooded animals. Ingestion or contact with these pathogens can cause a variety of sicknesses including gastroenteritis, respiratory infections, eye and ear infections, skin rashes, hepatitis, and other diseases. Because isolation and measurement of disease-causing viruses and pathogens is impractical, bacterial indicators such as fecal coliform are often used as proxies. In other words, the presence of these bacteria in a stream or river suggests a higher potential for adverse human health effects because the bacteria indicate the presence of disease-causing microorganisms. For example, studies have shown that about 4 percent of people who had swum in areas with high fecal coliform densities within the previous 9 to 14 days developed one or more of the following: fever, chills, earache, skin rash, nausea, stomach pain, coughing, and sore throat (U.S. Environmental Protection Agency, 2001).

Fecal coliform bacterial densities measured from samples collected at Charles River at Watertown, Laundry Brook, Faneuil Brook, Muddy River, and Stony Brook varied widely and between dry-weather and storm conditions (tables 22 and 23). The highest mean dry-weather fecal coliform density (66,000 CFUs/100 mL) was found in samples collected at Faneuil Brook (01104660); large dry-weather mean fecal coliform concentrations measured at Faneuil Brook probably indicate the presence of illicit sanitary cross-connections in the Faneuil Brook Subbasin. The lowest mean densities were found in samples collected at Stony Brook (01104687) and Charles River at Boston Science Museum (01104710) (fig. 17; table 25) (47 and 33 CFUs/100 mL, respectively).

The lowest mean stormwater fecal coliform density was found in samples collected at Charles River at Watertown (01104615) with a mean of 4,300 CFU/100 mL. Stony Brook (01104687) and Faneuil Brook (01104660) had the highest mean stormwater concentrations (68,000 and 65,000 CFU/100 mL, respectively). Although the sources of the elevated concentrations at Faneuil Brook Subbasin are unknown, the high concentrations from Stony Brook Subbasin can be partially attributed to known CSO discharges upstream of the sampling station.

Among samples collected from the uniform land-use stations [single-family land use (01104630), commercial land use (01104677), and multifamily land use (01104673)], samples collected from the single-family land-use station had the highest mean stormwater fecal coliform densities (30,000 CFU/100 mL), compared to16,000 CFU/100 mL from the multifamily land-use station and 9,900 CFU/100 mL from the commercial land-use station.The difference in fecal coliform densities in samples collected from the single-family land-use station and those collected from the multifamily land-use station were not statistically significant (at the $p = 0.1$ level; table 11) based on a nonparametric paired-comparison test (the Sign Test; Helsel and Hirsch, 1992).

Table 10. Sources and environmental importance of selected constituents and water-quality properties

[**Source:** Modified from Paulson and others, 1993]

Constituent or property	Common sources	Environmental importance
Specific conductance	A measure of the electrical conductivity of water; varies with the quantity of dissolved solids and is used to approximate the dissolved-solids content.	Dissolved solids can cause water to be unsuitable for public supply, agriculture, and industry; can harm aquatic organisms.
Turbidity	Caused by natural or human-induced suspended matter; components include clay, silt, fine organic and inorganic matter, soluble colored organic compounds, and microscopic aquatic organisms.	Can be detrimental to aquatic organisms; can cause water to be unsuitable for recreation, industry, and public supply.
Biochemical oxygen demand, 5-day	A measure of the amount of oxygen that is removed from aquatic environments by the life process of microorganisms; can be affected by effluent from sewage-treatment plants and aquatic biota (dead fish, algae, fecal pellets, and algal exudates) and oxygen-demanding materials from bottom sediment (Bowie and others, 1985)	Oxygen is necessary for aquatic life; deficiency can result from assimilation of organic wastes and decay of algae.
Coliform, fecal, membrane filter	Sources include effluent from sewage-treatment plants and runoff from pastures, feedlots, and urban areas.	Presence indicates contamination of water by wastes from humans or other warm-blooded animals.
Enterococcus, membrane filter	Do.	Do.
Dissolved solids	A result of rock weathering; also in agricultural runoff and industrial discharge.	In excess, can cause water to be unsuitable for public supply, agriculture, and industry; can harm aquatic organisms.
Suspended sediment	A result of rock erosion; also induced by disturbances of land cover because of fires, floods, and human activities such as mining, logging, construction, and agriculture.	Can be detrimental to aquatic organisms; can fill reservoirs and impair recreational use of water.
Nitrate plus nitrite	Nonpoint sources are agricultural and urban runoff; a major point source is wastewater discharge.	Plant nutrient that, in excess, can cause algal blooms and excessive growth of higher aquatic plants in bodies of water; can cause water to be unsuitable for public supply.
Nitrogen, ammonia	Do.	Do.
Nitrogen, total Kjeldahl	Do.	Do.
Phosphorus	Occurs in some rocks and sediments; also in runoff and seepage from phosphate-rock mines, agricultural and urban runoff, and industrial and municipal runoff, and industrial and muncipal wastewater discharge.	Plant nutrient that, in excess quantity, can cause algal blooms and excessive growth of higher aquatic plants in bodies of water.
Trace elements	See table 16.	Trace elements can be toxic to aquatic organisms at low concentrations.

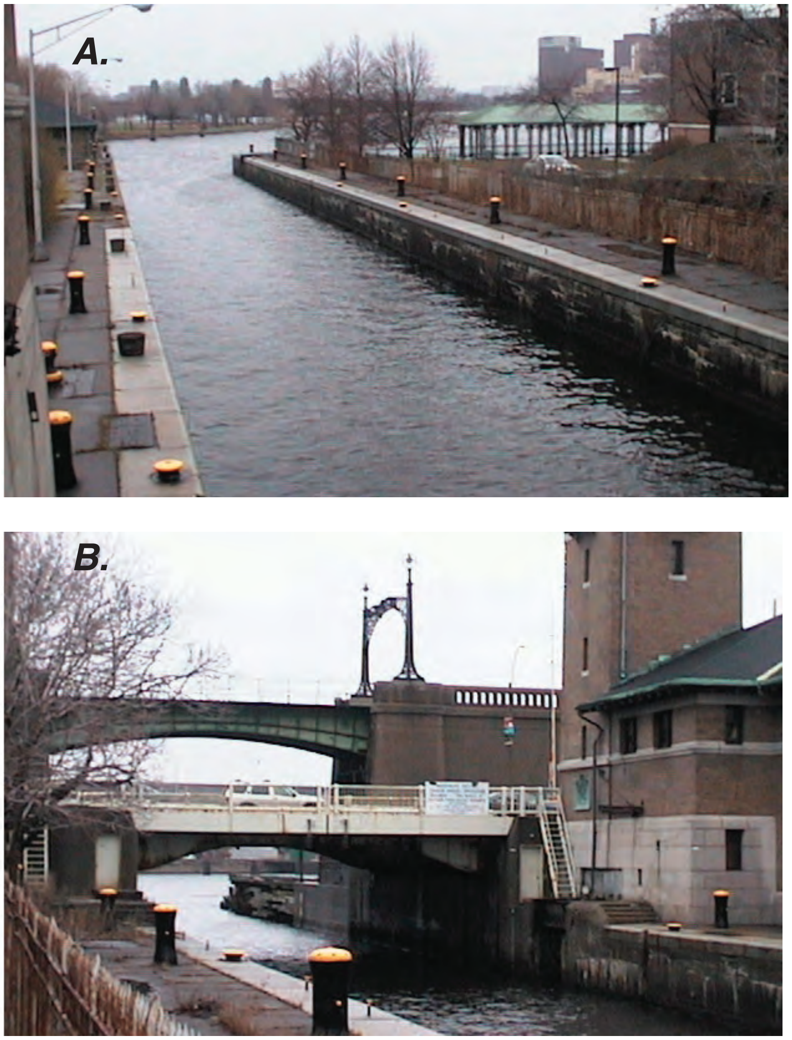


Figure 17. U.S. Geological Survey water-quality sampling station Charles River at Boston Science Museum, Massachusetts (01104710), (*A*) upstream and (*B*) downstream views.

Enterococcus densities in samples collected from upstream and the tributary subbasins showed a similar pattern to that of fecal coliform bacteria, although *Enterococcus* densities were somewhat lower than concurrent fecal-coliform densities. The highest mean dry-weather and stormwater *Enterococcus* densities (16,000 and 34,000 CFU/100 mL, respectively) were found in samples collected from Faneuil Brook (01104660); the lowest dry-weather densities (10 to 17 CFU/100 mL) were found in samples collected from Stony Brook (01104687) and Charles River at Boston Science Museum (01104710) (table 22). The lowest mean stormwater *Enterococcus* density (2,700 CFU/100 mL) was found in samples collected from Charles River at Watertown (01104615).

Among samples collected from the uniform land-use stations, the samples collected from the single-family land-use station (01104630) had the highest mean stormwater *Enterococcus* density (34,000 CFU/100 mL), compared to 22,000 CFU/100 mL for the multifamily land-use station (01104673) and 14,000 CFU/100 mL for the commercial land-use station (01104677). Generally, *Enterococcus* densities were highest in samples collected from the single-family land-use station and lowest in samples collected from the commercial land-use station. The differences given by the Sign Test are not statistically significant (at $p = 0.1$) between results from the single-family land-use station and from the multifamily land-use station and between results from single-family land-use station and from the commercial land-use station (table 11). Stormwater *Enterococcus* densities were generally greater than concurrent fecal coliform bacteria densities at the uniform land-use stations, in contrast to the pattern observed in samples collected from the tributary subbasins and upstream. These data suggest that sources of fecal contamination to the land-use stations are possibly different than sources to the tributary subbasins, or that fecal coliform survival is limited at the uniform land-use stations.

The Commonwealth of Massachusetts has established statewide maximum fecal coliform standards for

Table 11. Results of Sign Test between paired stormwater event mean concentrations for sampled storms at uniform land-use stations, lower Charles River Watershed, Massachusetts

[**Results: CM**, commercial land use; **MF**, multifamily land use; **SF**, single-family land use. (+), More than half of the storm event mean concentrations (EMCs) from SF were greater than those from MF (column 1), more than half of the storm EMCs from SF were greater than those from CM (column 2), or more than half of the storm EMCs from MF were greater than those from CM (column 3); (-), Less than half of the storm EMCs from SF were greater than those from MF (column 1), less than half of the storm EMCs from SF were greater than those from CM (column 2), or less than half of the storm EMCs from MF were greater than those from CM (column 3); CFU/100mL, colony-forming units per 100 milliliters; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L milligrams per liter; µg/L, micrograms per liter; >, greater than; =, equal; Bold, statistically significant (p<0.1); --, Tie]

Constituent	Results			Rank
	SF compared to MF (1)	SF compared to CM (2)	MF compared to CM (3)	
Specific conductance (µS/cm)	--	**0.008 (-)**	**0.008 (-)**	CM > SF = MF
Turbidity (NTU)	**0.004 (+)**	**.063 (+)**	.227 (-)	SF > CM > MF
Biochemical oxygen demand, 5-day (mg/L)	.500 (+)	.188 (+)	.656 (-)	SF > CM > MF
Coliform,fecal, membrane filter (CFU/100 mL)	.144 (+)	**.035 (+)**	**.035 (+)**	SF > MF > CM
Enterococcus, membrane filter (CFU/100 mL)	.144 (+)	.144 (+)	**.004 (+)**	SF > MF > CM
Dissolved solids (mg/L)	.363 (-)	--	**.035 (+)**	MF > SF = CM
Suspended solids (mg/L)	**.035 (+)**	.144 (+)	.144 (-)	SF > CM > MF
Nitrate (mg/L)	.363 (+)	.227 (+)	.363 (-)	SF > CM > MF
Nitrogen, ammonia (mg/L as N)	.227 (+)	**.035 (+)**	--	SF > CM = MF
Nitrogen, total Kjeldahl (mg/L as N)	.144 (+)	**.063 (+)**	.144 (-)	SF > CM > MF
Phosphorus (mg/L)	**.016 (+)**	**.035 (+)**	.109 (+)	SF > MF > CM
Cadmium (µg/L)	.344 (-)	.109 (-)	--	MF = CM > SF
Chromium (µg/L)	.227 (+)	**.063 (+)**	.500 (-)	SF > CM > MF
Copper (µg/L)	**.004 (-)**	**.004 (-)**	**.035 (-)**	CM > MF > SF
Lead (µg/L)	--	**.035 (-)**	**.035 (-)**	CM > MF = SF
Zinc (µg/L)	**.035 (-)**	**.035 (-)**	**.035 (-)**	CM > MF > SF

swimming and boating. The swimming standards state that the geometric mean (or the geomean) from a particular water-quality station shall not exceed 200 CFUs/100 mL; no more than 10 percent of the samples collected should exceed 400 CFUs/100 mL. The boating standards state that the geomean from a particular water-quality station shall not exceed 1,000 CFUs/100 mL; no more than 10 percent of the samples collected should exceed 2,000 CFUs/100 mL. Geomeans were defined as the geomean of the discrete bacterial samples collected at each site for each sampled storm; censored data were set to one-half the detection limit.

Dry-weather samples for four of the nine stations had geomeans for fecal coliform greater than the swimming standard. The geomean for samples from Faneuil Brook (01104660) (35,000 CFUs/100mL) was nearly 200 times the swimming standard (200 CFUs/100 mL). The fecal coliform geomean (180 CFUs/100 mL) for the samples from Charles River at Watertown (01104615) was just below the swimming standard. In contrast, fecal coliform geomeans for samples from only two stations [Faneuil Brook and the multifamily land-use station (01104673)] were greater than the boating standard (1,000 CFUs/100 mL) during dry weather. Although samples from only four stations had fecal coliform geomeans above the swimming standard, more than 10 percent of the samples collected from seven of the nine stations had fecal coliform densities in excess of 400 CFUs/100 mL, including Charles River at Watertown (01104615) (15.4 percent). Charles River at Boston Science Museum (01104710) and Stony Brook (01104687) had no dry-weather samples with fecal coliform densities greater than the swimming and boating standards. More than 10 percent of the fecal coliform densities measured in samples from four stations [single-family land use (01104630), Laundry Brook (01104640), Faneuil

Brook (01104660), and the multifamily land use (01104673)] were greater than the boating standard of 2,000 CFUs/100 mL. Fewer than 10 percent of the samples collected at Charles River at Watertown, however, had fecal coliform densities greater than 2,000 CFUs/100 mL.

In contrast to dry weather, stormwater samples exceeded the swimming and boating fecal colifom standards at every station. The exception was Charles River at Boston Science Museum (01104710), from which a few stormwater bacterial samples were collected. More than 10 percent of the samples collected at all of the stations, with the exception of Charles River at Boston Science Museum, had fecal coliform densities in excess of 400 CFUs/100 mL and 2,000 CFUs/100 mL, including Charles River at Watertown (01104615; 78 and 37 percent, respectively). The failure of samples from most of the water-quality stations in this study to meet the minimum water-quality standards necessary to support swimming and boating after rainstorms strongly indicate sources such as urban runoff, illicit sewage discharges, and CSOs.

It is useful to discuss *Enterococcus* bacterial densities in dry-weather samples and stormwater samples because the USEPA is recommending the use of *Enterococcus* as an indicator of fecal contamination (Gray, 2000). *Enterococcus* bacterial densities can be correlated with gastrointestinal illness, whereas fecal coliform concentrations do not always correlate well with the levels of pathogenic bacteria and viruses in waters (Joyce, 2000; Gray, 2000). The pattern of fecal coliform density exceedences of the swimming standard, however, are almost identical to the pattern of *Enterococcus* exceedences of the proposed *Enterococcus* guideline of 61 CFUs/100 mL.

Nutrients

In urban areas like the lower Charles River Watershed, human activities, including the use of fertilizer, the combustion of fossil fuels, and the discharge of untreated and treated sewage, can increase nutrient concentrations above background concentrations in streams and rivers. For example, mean concentrations of phosphorus in 75 percent of the streams in urban and agricultural areas sampled by the USGS National Water-Quality Assessment Program (NAQWA) were greater than the USEPA guideline (0.1 mg/L) for phosphorus (Fuhrer and others, 1999). The highest nitrogen concentrations sampled by NAQWA were also found in urban areas (Fuhrer and others, 1999).

Nutrient enrichment tends to stimulate phytoplankton blooms and the growth of higher aquatic plants or macrophytes (Smith, 1990). When caused by human activities, excessive plant growth is termed cultural eutrophication. Cultural eutrophication interferes with recreational uses of a river including boating, swimming, and fishing. Problems often associated with increased nutrient loading include:

- boating hazards from decreased navigability as waterways become choked by macrophytes;
- swimming hazards because phytoplankton concentrated in the upper layers of the water reduces water clarity. The Commonwealth of Massachusetts requires there to be no “lack of clarity” for safe swimming; and,
- degraded water quality for fish and other aerobic aquatic organisms; dead and dying biomass fuels bacterial decay that depletes oxygen in bottom waters and sediment.

The highest mean dry-weather nutrient concentration measured in upstream samples and in samples collected from the tributary subbasins were found at Faneuil Brook (01104660), with the exception of TKN, which was highest at Muddy River (01104683) (1.8 mg/L; table 25). Under storm conditions, the highest mean concentrations of ammonia (0.4 mg/L), phosphorus (0.4 mg/L), and TKN (2.3 mg/L) were found at Stony Brook (01104687) and nitrate plus nitrite (1.1 mg/L) at Faneuil Brook. The discharge of untreated sewage is the likely source of these high nutrient concentrations, although the high dry-weather TKN values at Muddy River are not accompanied by high fecal coliform densities, as might be expected.

Among the samples collected from the uniform land-use stations, samples collected from the single-family land-use station (01104630) had the highest mean stormwater concentration of ammonia (0.5 mg/L), nitrate plus nitrite (0.8 mg/L), TKN (2.3 mg/L), and phosphorus (0.4 mg/L), compared to samples collected from the multifamily land-use station (01104673) and the commercial land-use station (01104677). Stormwater nutrient concentrations were generally highest at the single-family land-use station and lowest at the multifamily land-use station, except for phosphorus, which was lowest at commercial land-use station. Although many of these differences were not statistically significant at the

$p = 0.1$ level, phosphorus concentrations were significantly different at two of the three uniform land-use stations ($p < 0.05$; table 11).

Phosphorus concentrations in dry-weather samples were greater than USEPA phosphorus guidelines about 50 percent of the time, on average. In contrast, most stormwater phosphorus concentrations exceeded the phosphorus guideline. Most notable is that the concentrations of phosphorus measured at Charles River at Watertown (01104615) exceed the phosphorus guideline more than 44 percent of the time. Moreover, stormwater concentrations of phosphorus at the two largest tributaries, [Stony Brook (01104687) and Muddy River (01104683)], were greater than the phosphorus guideline for every storm sampled.

These data suggest that there is an ample supply of nutrients to cause the regular algae blooms and eutrophication observed in the lower Charles River during the summer months. In addition, these eutrophic conditions likely exacerbate low dissolved-oxygen levels in the bottom waters as a result of organic loading and increased sediment oxygen demand (SOD), as heterotrophic bacteria decompose the large supply of organic carbon.

Trace Metals

Trace metals are a primary concern in the lower Charles River Watershed, because they are common in urban stormwater and have accumulated in the bed sediment of the lower Charles River (Breault and others, 2000b). Urban runoff contains a complex mixture of trace metals derived from weathering and erosion of soil and rocks (natural sources), atmospheric deposition, vehicles, paved surfaces, and many other human sources. The order-of-magnitude concentrations for naturally produced trace metals and likely human sources of most trace metals that are likely to be present in urban stormwater are shown in table 12.

The highest mean dry-weather trace-metal concentrations measured in samples collected from upstream and the tributary subbasins, with the exception of those for chromium, were found in samples collected from Faneuil Brook (01104660); dry-weather chromium concentrations (2.0 µg/L) were highest in samples collected from Charles River at Watertown (01104615). Under storm conditions, all of the trace elements were found in the highest concentration in samples collected from Stony Brook (01104687). Charles River at Watertown had the lowest mean stormwater trace-element concentrations (table 25).

Among samples from the uniform land-use stations, samples collected from the commercial land-use station (01104677) had the highest mean stormwater concentration of cadmium (0.4 µg/L), copper (100 µg/L), lead (140 µg/L), and zinc (180 µg/L), in comparison with samples collected from the single-family land-use (01104630) and the multifamily land-use (01104673) stations. With the exception of chromium, all of the selected trace elements had stormwater concentrations greater in samples collected from the multifamily land-use station than from the single-family land-use station. Samples from single-family land-use station had the highest mean stormwater chromium concentrations (8.2 µg/L). Stormwater trace-element concentrations, with the exceptions of those for cadmium and chromium, were generally highest in samples collected from the commercial land-use station and lowest in samples collected from the single-family land-use station; many of these differences are statistically significant (table 11). Cadmium and chromium EMCs were statistically similar between samples collected from the land-use stations, with the exception of chromium concentration differences between the single-family land-use station and the commercial land-use station ($p = 0.063$).

Historically, the USEPA has recommended that whole-water trace-metal concentrations be used as an indication of bioavalibility (U.S. Environmental Protection Agency, 1986). There are, however, no universal and robust methods to relate whole-water trace-metal concentrations to ecosystem effects. More recently, the USEPA has recommended the use of dissolved (filtered) trace-metal concentrations, in addition to whole-water concentrations, to provide more reliable correlations with toxicity (U.S. Environmental Protection Agency, 1992). Consequently, exceedences of trace-metal standards are not discussed herein. It is important to point out that whole-water trace-metal concentrations were chosen for this study because of the high concentrations found throughout the bottom sediment of the lower Charles River (Breault and others, 2000b) and the need for detailed information concerning total trace-metal loading patterns.

Table 12. Characteristics of selected major and trace elements of potential interest to studies of urban and highway runoff

[Modified from Breault and Granato, 2000. **Crust:** Sources: Lide and Frederikse (1997). Crustal abundance is the estimated abundance in the continental earth crust. **Soils:** Sources: Shacklette and Boerngen (1984). Soil abundance is the average from analysis of about 1,300 soil samples taken throughout the contermi-nous United States. **Freshwaters:** Brownlow (1979); Drever (1988); Appelo and Postma (1993). Freshwater abundance is an order of magnitude estimate of the elemental abundance in unpolluted fresh waters of the United States based on older literature values. **Potential highway source(s):** Source: Bourcier and others (1980); Falahi-Ardakani (1984); Kobriger and Geinopolos (1984); Hodge and Stallard (1986); Smith and Lord (1990); Hildemann and others (1991); Armstrong (1994); Hee (1994); Granato (1996); Helmers (1996); Farago and others (1997); Pearce and others (1997). mg/kg, milligrams per kilogram; mg/L, milligrams per liter; ppm, parts per million; ~ , about; --, not available]

Element name (abbreviation)	Natural abundance (ppm)			Potential highway source(s)
	Crust (mg/kg)	Soils (mg/kg)	Freshwaters	
Aluminum (Al)	8.23×10^{4}	7.2×10^{4}	$\sim 10^{-2}$	Auto exhaust, brakes
Antimony (Sb)	2×10^{-1}	6.6×10^{-1}	$\sim 10^{-3}$	Auto exhaust, brakes
Arsenic (As)	1.8×10^{0}	7.2×10^{0}	$\sim 10^{-3}$	
Barium (Ba)	4.25×10^{2}	5.8×10^{2}	$\sim 10^{-3}$	Auto exhaust, brakes, fuel
Beryllium (Be)	2.8×10^{0}	9.2×10^{-1}	--	
Bismuth (Bi)	8.5×10^{-3}	--	--	
Boron (B)	1.0×10^{1}	3.3×10^{1}	$\sim 10^{-1}$	Auto exhaust, deicers
Bromide (Br)	2.4×10^{0}	8.5×10^{-1}	$\sim 10^{-2}$	Auto exhaust, deicers, fuel
Cadmium (Cd)	1.5×10^{-1}	--	--	Auto wear, insecticide application, lubricants, tire wear
Calcium (Ca)	4.15×10^{4}	2.4×10^{4}	$\sim 10^{1}$	Auto exhaust, brakes, deicers
Carbon (C)	2.00×10^{2}	2.5×10^{4}	$\sim 10^{2}$	Auto exhaust, fuel
Cerium (Ce)	6.65×10^{1}	7.5×10^{1}	$\sim 10^{-5}$	Catalytic converters
Chloride (Cl)	1.45×10^{2}	--	$\sim 10^{1}$	Brakes, deicers
Chromium (Cr)	1.02×10^{2}	5.4×10^{1}	$\sim 10^{-3}$	Auto exhaust, auto wear, brakes
Cobalt (Co)	2.5×10^{1}	9.1×10^{0}	$\sim 10^{-4}$	Auto exhaust
Copper (Cu)	6.0×10^{1}	2.5×10^{1}	$\sim 10^{-3}$	Auto exhaust, auto wear, brakes, deicers
Fluoride (F)	5.85×10^{2}	4.3×10^{2}	$\sim 10^{-1}$	Deicers
Gold (Au)	4×10^{-3}	--	$\sim 10^{-6}$	
Iodine (I)	4.5×10^{-1}	1.2×10^{0}	$\sim 10^{-3}$	
Iron (Fe)	5.63×10^{4}	2.6×10^{4}	$\sim 10^{-2}$	Auto exhaust, auto rust and wear, brakes, deicers
Lead (Pb)	1.4×10^{1}	1.9×10^{1}	$\sim 10^{-3}$	Auto exhaust, bearing wear, deicers, lubricants, tire wear
Lithium (Li)	2.0×10^{1}	2.4×10^{1}	$\sim 10^{-2}$	Auto exhaust
Magnesium (Mg)	2.33×10^{4}	9.0×10^{3}	$\sim 10^{0}$	Auto exhaust, brakes, deicers
Manganese (Mn)	9.5×10^{2}	5.5×10^{2}	$\sim 10^{-2}$	Engine wear, fuel additive
Mercury (Hg)	8.5×10^{-2}	9.0×10^{-2}	$\sim 10^{-5}$	
Molybdenum (Mo)	1.2×10^{0}	9.7×10^{-1}	$\sim 10^{-4}$	Brakes
Nitrogen (N)	1.9×10^{1}	--	$\sim 10^{0}$	Auto exhaust, deicers, roadside fertilizer
Nickel (Ni)	8.4×10^{1}	1.9×10^{1}	$\sim 10^{-3}$	Auto exhaust, wear, asphalt, deicers, fuel, lubricants
Palladium (Pd)	1.5×10^{-2}	--	--	Catalytic converters
Phosphorus (P)	1.05×10^{3}	4.3×10^{2}	$\sim 10^{-1}$	Auto exhaust, fuel, lubricants
Platinum (Pt)	5×10^{-3}	--	--	Auto exhaust, catalytic converters
Potassium (K)	2.09×10^{4}	1.5×10^{4}	$\sim 10^{0}$	Auto exhaust, deicers
Rhodium (Rh)	1×10^{-3}	--	--	Catalytic converters
Selenium (Se)	5×10^{-2}	3.9×10^{-1}	$\sim 10^{-4}$	Auto exhaust
Silicon (Si)	2.82×10^{5}	3.1×10^{5}	$\sim 10^{1}$	Auto exhaust, brakes, deicers

Table 12. Characteristics of selected major and trace elements of potential interest to studies of urban and highway runoff—*Continued*

Element name (abbreviation)	Natural abundance (ppm)			Potential highway source(s)
	Crust (mg/kg)	Soils (mg/kg)	Freshwaters	
Silver (Ag)	$7.5x10^{-2}$	--	$\sim10^{-4}$	
Sodium (Na)	$2.36x10^{4}$	$1.2x10^{4}$	$\sim10^{1}$	Auto exhaust, deicers
Strontium (Sr)	$3.70x10^{2}$	$2.4x10^{2}$	$\sim10^{-2}$	Auto exhaust, deicers
Sulfur (S)	$3.5x10^{2}$	$1.6x10^{3}$	$\sim10^{-4}$	Auto exhaust, deicers, fuel, roadway beds
Tellurium (Te)	$1x10^{-3}$	--	--	
Titanium (Ti)	$5.65x10^{3}$	$2.9x10^{3}$	$\sim10^{-2}$	Studded tires
Tin (Sn)	$2.3x10^{0}$	$1.3x10^{0}$	--	Brakes
Tungsten (W)	$1.25x10^{0}$	--	$\sim10^{-5}$	Studded tires
Vanadium (V)	$1.20x10^{2}$	$8.0x10^{1}$	$\sim10^{-3}$	Auto exhaust, deicers
Zinc (Zn)	$7.0x10^{1}$	$6.0x10^{1}$	$\sim10^{-3}$	Auto exhaust, brakes, tire wear, lubricants

Water-Quality Properties

Water-quality properties, such as specific conductance, turbidity, BOD-5, TSS, and TDS, are usually used as indicators of the overall health of a stream or river. These properties can be affected by a variety of geological, chemical, biological, and hydrologic processes within the watershed and the river. During dry weather, mean concentrations and values of the selected water-quality properties in samples collected from upstream and the tributary subbasins were highest at Faneuil Brook (01104660) (table 25). Under storm conditions, mean EMCs for BOD-5 (15 mg/L), TSS (107 mg/L), and turbidity (64 NTU) were highest in samples collected from Stony Brook (01104687). Mean TDS concentrations (188 mg/L) and specific conductance (330 µS/cm) during storm conditions were highest in samples collected from Faneuil Brook. Among samples collected from the uniform land-use stations, the samples collected from the single-family land-use station (01104630) had the highest mean stormwater values of BOD-5 (13 mg/L), TSS (92 mg/L), and turbidity (50 NTU), compared to samples collected from the multifamily land-use station (01104673) and the commercial land-use station (01104677). In contrast, specific conductance values were highest (310 µS/cm) in samples collected from the commercial land-use station, and mean TDS concentrations highest (165 mg/L) in samples collected from the multifamily land-use station.

Comparison between Stormwater Concentrations from This Study and Those from Other Studies

Mean stormwater EMCs of selected constituents from the lower Charles River Watershed were compared to stormwater concentrations from other studies (fig. 18 and table 13). These studies include stormwater data collected from 23 cities between 1978 and 2000 by many different agencies and municipalities. Differences between the EMCs of this study and other studies are expressed as magnitudes and relative percent differences (RPD). It is important to note that differences in reported water-quality values between this study and other studies may be the result of one or more dissimilarities, including sampling, processing, preservation, and analytical and statistical procedures. In addition, spatial and temporal variability can also be responsible for observed differences. The environmental setting, local land use, traffic characteristics, drainage characteristics, and other features are recognized as potential sources of spatial variation (Gupta and others, 1981; Young and others 1996).

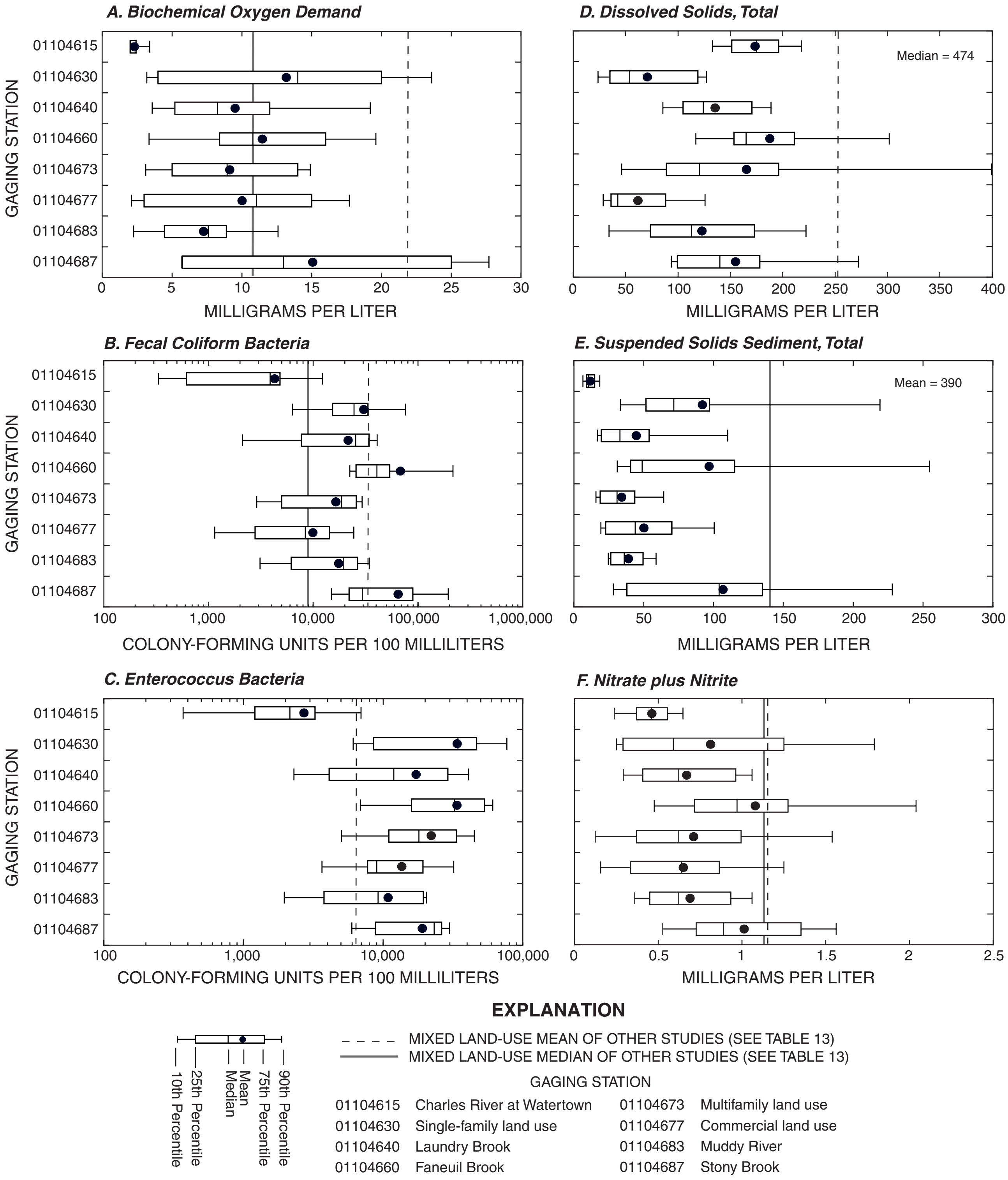


Figure 18. Comparison between stormwater event mean concentrations measured in samples from the lower Charles River Watershed, Massachusetts, Water Year 2000, and stormwater concentrations from other studies.

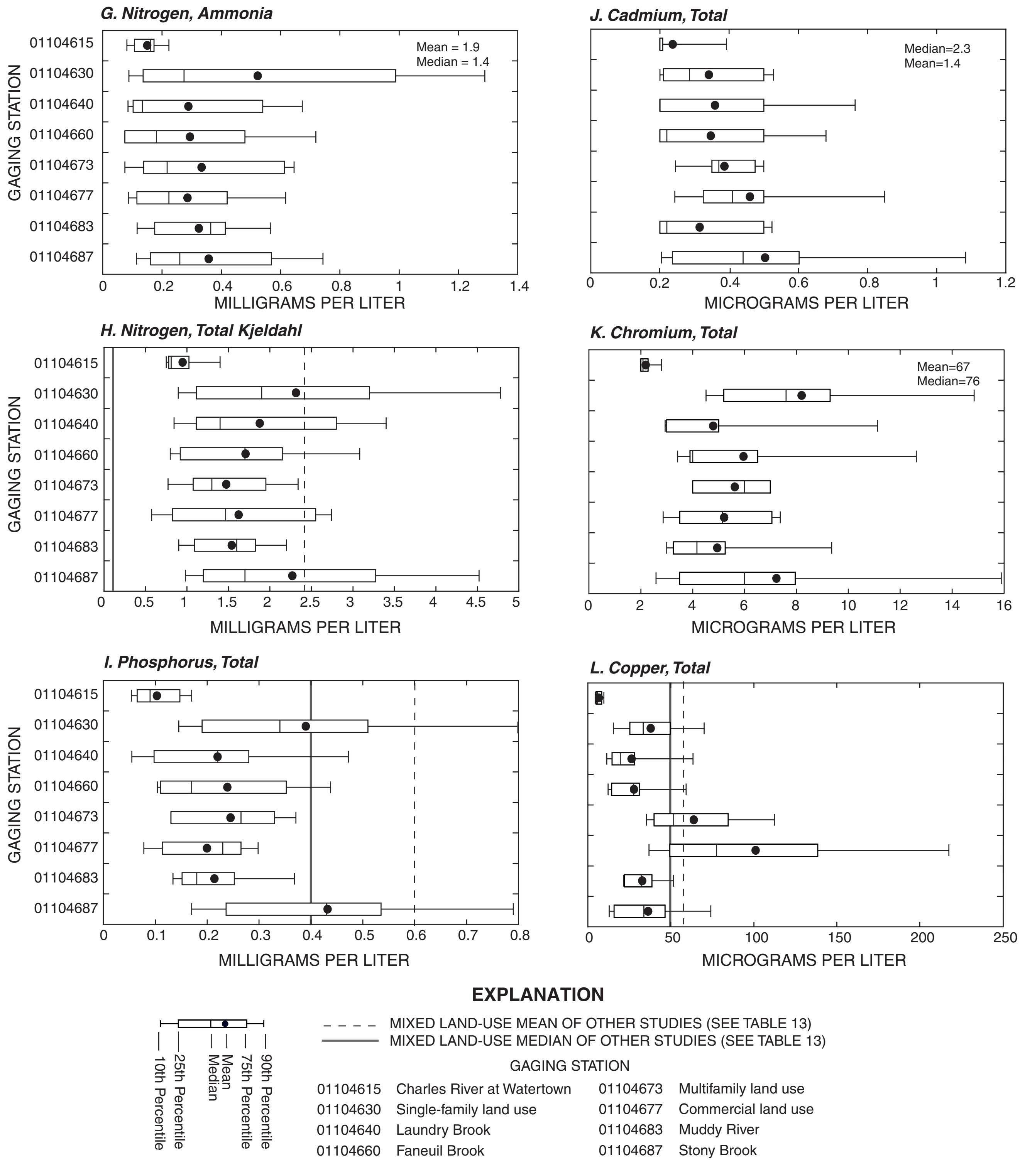


Figure 18. Comparison between stormwater event mean concentrations measured in samples from the lower Charles River Watershed, Massachusetts, Water Year 2000, and stormwater concentrations from other studies—*Continued*.

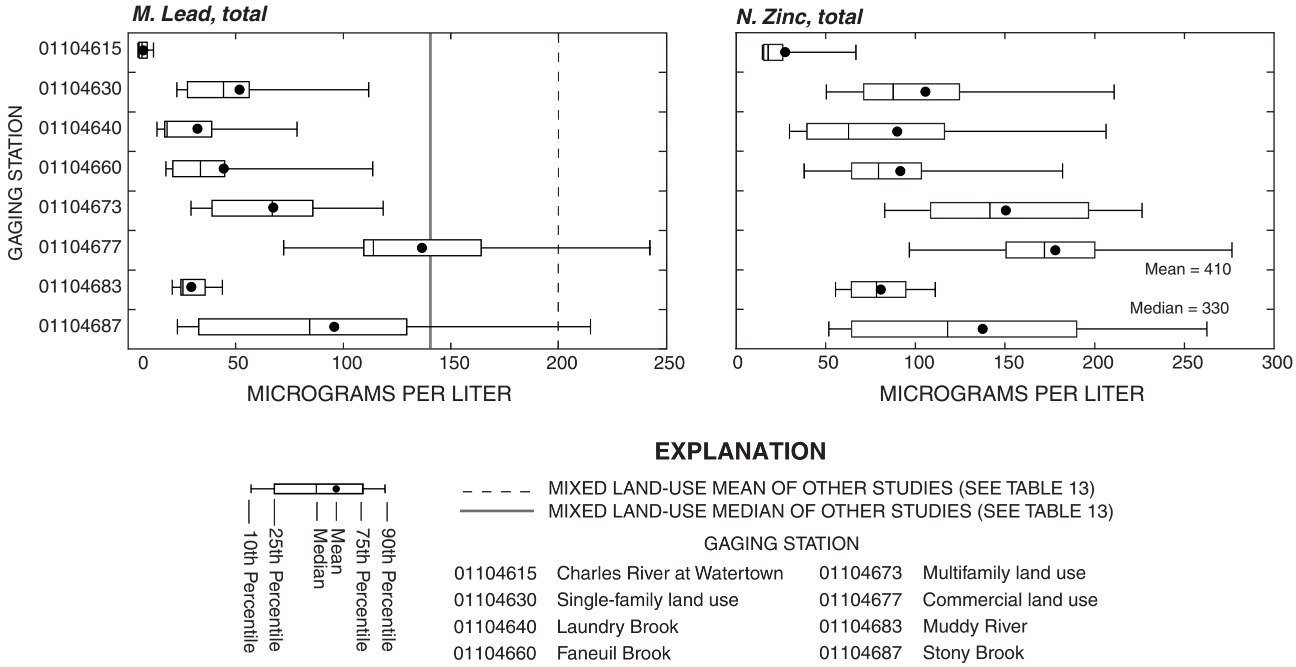


Figure 18. Comparison between stormwater event mean concentrations measured in samples from the lower Charles River Watershed, Massachusetts, Water Year 2000, and stormwater concentrations from other studies—*Continued.*

Table 13. Summary statistics for selected stormwater constituents from other studies

[Data from Hardee and others (1979); Mattraw and Miller (1981); Malmquist (1983); Athayde and others (1983); Eddins and Crawford (1984); Lopez and Giovannelli (1984). Heaney (1986); Brabets (1986); Hall and Anderson (1988); Marsalek and Schroeter (1988); SCCWRP (1988); Gannon and Busse (1989); Bicknell (1990); Ishaq (1992); Focazio (1995); Cooke and others (1995); Guimaraes (1995); Kjelstrom (1995); Lopes and others (1995); McCarthy (1996); Bell and others (1996); Kerr and Lee (1996); Woodward and Curran (1998); Lee and Bang (2000). CFU/100 mL, colony-forming units per 100 milliliters; µg/L, micrograms per liter; mg/L, milligrams per liter; --, not available]

Constituents	Mean				Median			
	Mixed	Multi-family	Resi-dential	Commer-cial	Mixed	Multi-family	Resi-dential	Commer-cial
Biochemical oxygen demand (mg/L)	22	73	12	18	11	39	9.8	110
Coliform, fecal, membrane filter (CFU/100 mL)	34,000	3,000	29,000	3,900	9,300	6,700	24,000	4,000
Enterococcus, membrane filter (CFU/100 mL)	6,400	--	--	23	--	--	--	--
Dissolved solids (mg/L)	253	69	209	152	474	53	139	175
Suspended solids (mg/L)	390	135	196	151	145	56.7	89.1	107
Nitrate plus nitrite (mg/L as N)	1.1	.60	1.5	.80	1.1	.20	.60	.70
Nitrogen, ammonia, total (mg/L)	1.9	4.0	2.5	.20	1.4	.20	--	.40
Nitrogen, total Kjeldahl (mg/L as N)	2.4	1.9	2.1	--	.20	--	1.1	1.4
Phosphorus (mg/L)	.60	1.3	28	.30	.40	.20	.40	.20
Cadmium (µg/L)	1.4	5.9	7	2.8	2.3	2.7	6.4	2.1
Chromium (µg/L)	67	13	17	2.8	76	10	7.0	38
Copper (µg/L)	60	46	56	48	48	11	29	37
Lead (µg/L)	200	100	330	210	140	50	140	140
Zinc (µg/L)	410	180	320	430	330	100	130	260

Historical changes, such as the ban on leaded gasoline, can affect the data comparability of different studies (Young and others, 1996; U.S. Environmental Protection Agency, 1999). Seasonality also is a major issue for runoff studies. Determining the magnitude of these factors is beyond the scope of this study; therefore, the following comparisons are for purposes of illustration only.

In general, mean concentrations of the selected constituents and water-quality properties measured in samples collected from Charles River at Watertown (01104615), Laundry Brook (01104640), Faneuil Brook (01104660), Muddy River (01104683), and Stony Brook (01104687) were less than those measured by other studies, with the exception of *Enterococcus* bacteria (fig. 18), for which there have been little data in the literature. On average, mean concentrations of constituents and water-quality properties measured in samples collected from upstream and the tributary subbasins in this study were between 1.5 and 16 times less than concentrations measured in samples collected in other studies. In contrast, concentrations of *Enterococcus* bacteria were, on average, about 1.3 times greater in samples collected from upstream and the tributary subbasins compared to those collected in other studies. Comparison of median values showed similar results, with the exception of fecal coliform bacteria and TKN. Fecal coliform bacteria and TKN median concentrations measured in samples collected from upstream and the tributary subbasins in this study were about 1.3 and 7.3 times greater than those collected in other studies, respectively (fig. 18).

About 69 percent of the mean concentrations of the selected constituents and water-quality properties measured in samples collected from the uniform land-use stations [single-family land use (01104630), multi-family land use (01104673), and commercial land use (01104677)] were less than those measured by other studies. The few exceptions include fecal coliform bacteria (RPD of +4), BOD-5 (+6), and TKN (+11) at the single-family land-use station; fecal coliform (+138), *Enterococcus* bacteria (+82), nitrate plus nitrite (+20), and Cu (+32) at the multifamily land-use station; and ammonia (+18), Cr (+61), Cu (+71), fecal coliform (+88) and *Enterococcus* bacteria (+199) at the commercial land-use station. About 51 percent of the median concentrations and water-quality properties measured in samples collected from the uniform land-use subbasins were less than those measured in other studies.

These results indicate that stormwater quality in the study area is generally similar to or better than that reported in studies of other areas of the United States. Despite these findings, the water quality of the lower Charles River becomes impaired after rainstorms (Thomas Faber, U.S. Environmental Protection Agency, written commun., 2001). This finding suggests that the poor water quality of the river after rainstorms may be more a function of the river's inability to assimilate large loads of these contaminants, relative to its size, rather than the discharge of overly contaminated stormwater.

CONTAMINANT LOADS AND YIELDS

Loads for 14 of the 16 water-quality constituents and properties were determined by means of both direct-computation (arithmetic and flow-weighted means) and regression approaches. Dry-weather and stormwater data collected during the 1999–2000 period (tables 22 and 23) were used to compute dry-weather and stormwater loads directly for sampled storms for each water-quality sampling station. Multiple linear-regression equations (relating rainfall characteristics, antecedent conditions, and stormwater EMCs) were used to estimate stormwater EMCs for approximately 90 storms in WY 2000. Dry-weather and stormwater volumes for load determination were obtained from calibrated, continuous rainfall-runoff models, except for the Charles River at Watertown (01104615), where observed flow values were used (Zarriello and Barlow, 2002).

Separating dry-weather and stormwater flow periods and assigning the corresponding EMC value was straightforward for the tributary subbasins because of the large differences between dry-weather and stormwater flows. Distinguishing dry-weather and stormwater flows for the Charles River at Watertown (01104615), however, was more difficult. Fortunately, a clear first flush and peak due to local urban runoff could generally be observed, followed by a more gradual recession, which was often followed by another dampened peak. This second peak likely represents stormwater drainage of the upper and mid-Charles

River Watershed. Bacterial concentrations were found to be notably higher in the local-urban-runoff portion of the hydrograph and quickly returned to pre-storm values early in the hydrograph recession (fig. 19). Consequently, stormwater EMC values for the Charles River at Watertown were assigned to the initial peak. Dry-weather contaminant EMCs were assigned to the recession and the subsequent peak. Because this "second peak" likely contained stormwater runoff from the upper and mid-Charles River Watershed, the overall flow-weighted dry-weather mean was deemed more appropriate than the arithmetic mean for the calculation of the dry-weather upstream load. This choice was a factor in determining the percentage of the total stormwater and dry-weather loads attributable to upstream sources.

EMCs predicted by the multiple linear-regression equations showed good agreement with measured values (fig. 20). Antecedent dry period, generally, was the most important explanatory variable for the constituents and water-quality properties studied (table 26). This result is consistent with buildup-washoff models that are often utilized to simulate stormwater contaminant EMCs. In other words, longer antecedent dry periods allow more time for contaminants to "build up" on roof tops, streets, parking lots, and other impervious surfaces and for bacteria to grow in protected reservoirs (for example, pipes; Marino and Gannon, 1991). Storm duration also explains some of the EMC variability; however, storm duration was inversely related to EMCs. The relation between storm duration and contaminant EMC makes sense physically. More rain tends to dilute flow-composited contaminant concentrations over time; more "clean" water is collected after the bulk of contaminants are washed away. Maximum rainfall intensity was also an important explanatory variable for contaminant EMCs, especially for trace elements and water-quality properties at two water-quality sampling stations, Charles River at Watertown (01104615) and Stony Brook (01104687). The positive relation between contaminant EMCs and maximum intensity also makes sense physically, but for two contrasting reasons at the two stations. It is likely that intense

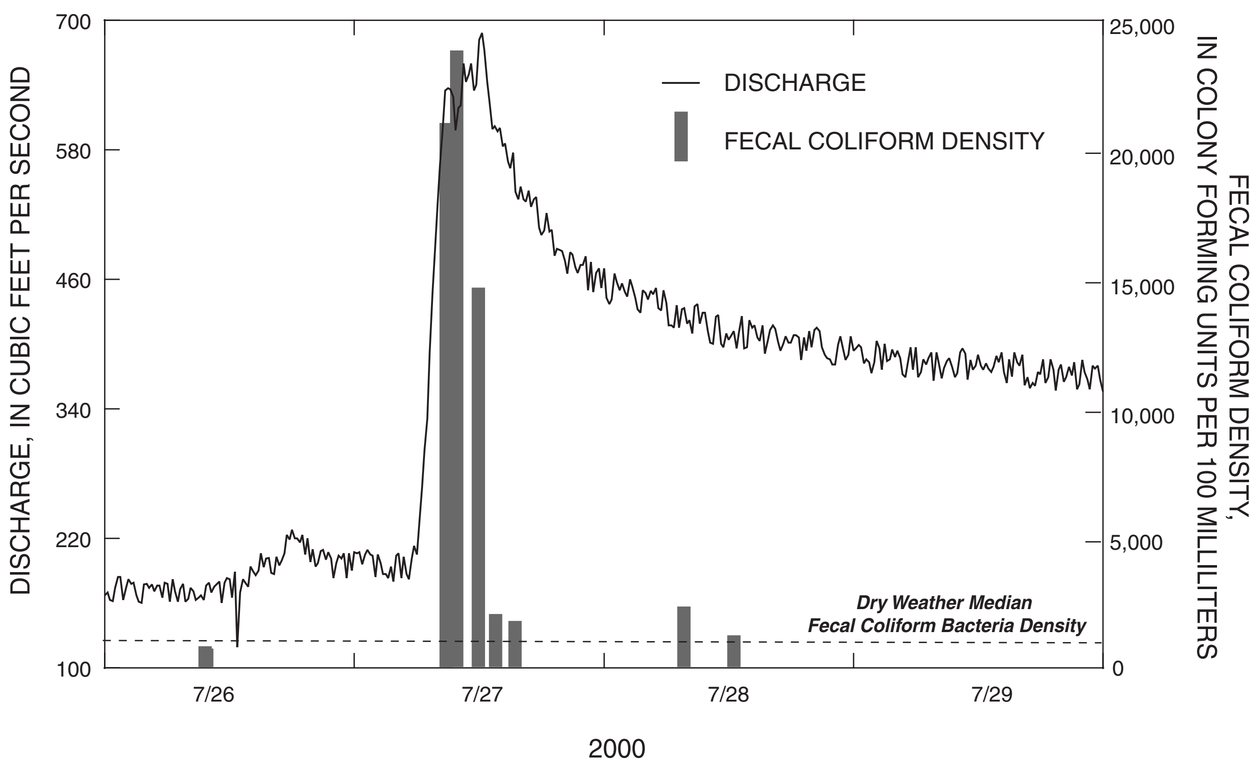


Figure 19. Characteristic stormwater hydrograph and pattern of fecal coliform bacterial density before, during, and after a storm at the U.S. Geological Survey gaging station at Charles River at Watertown (01104615), lower Charles River Watershed, Massachusetts, July 26–30, 2000.

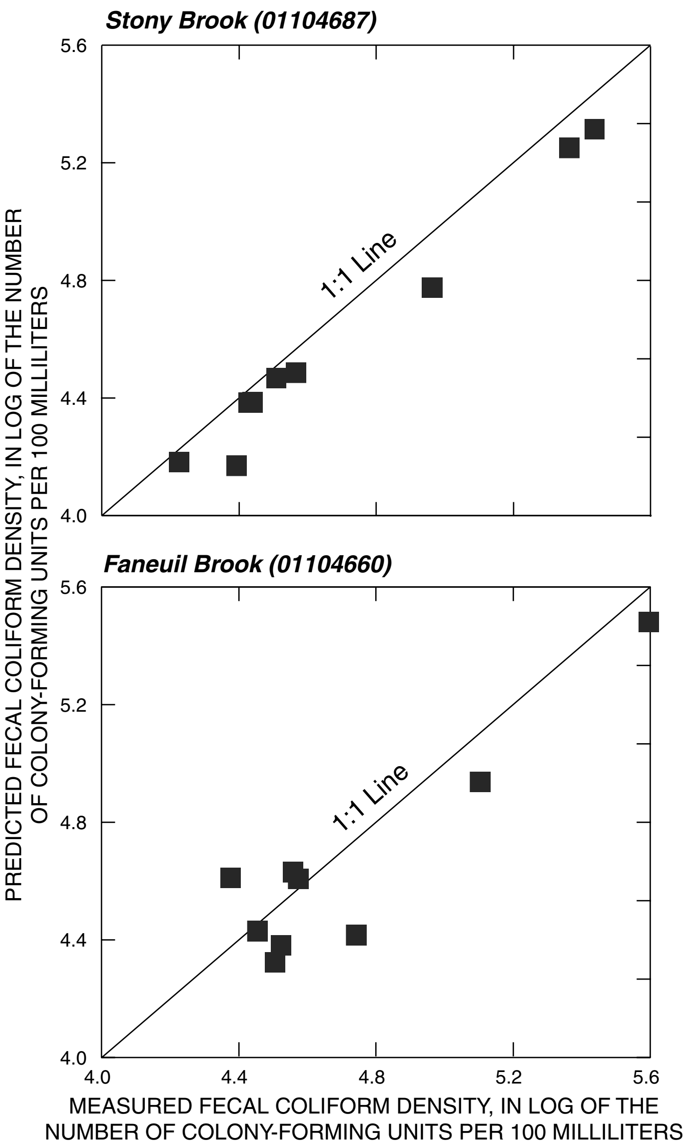


Figure 20. Goodness of fit between measured and predicted event mean concentrations of fecal coliform bacteria at two U.S. Geological Survey gaging stations in the lower Charles River Watershed, Massachusetts.

storms in the upstream subbasin mobilize upland soils that may be contaminated with trace elements and ultimately affect water-quality properties. In addition, more intense storms increase the likelihood of CSO activation compared to less intense storms of similar size in the Stony Brook Subbasin.

The regression equations discussed in the study are spatially and temporally specific. Spatially, the unique environment presented by each individual subbasin requires that a different set of equations be produced for each. For example, CSOs are present in the Stony Brook Subbasin but absent in the other subbasins. Temporally, the regression equations were developed for present conditions, and will likely change in the future as planned conditions are realized (for example, sewer separation or improved stormwater management practices). A good example is the lining of sanitary sewers in the Laundry Brook Subbasin, a change that is expected to greatly reduce inputs of sewage contaminants into storm drains. It is likely that infrastructure improvements such as sewer lining will affect the relation between rainfall and water quality, especially with respect to fecal coliform bacteria; as a result, the equations are likely to change for this subbasin. The spatial and temporal variability of water quality in the lower Charles River demonstrates the need for continued monitoring and reevaluation. Finally, water-quality samples collected at Muddy River (01104683) and Stony Brook (01104687) may not accurately reflect concentrations at the mouth, particularly in the case of Stony Brook, because several CSOs discharge downstream of the USGS gaging station. This factor was taken into account in estimating the density of fecal coliform and other contaminants concentrations after sewer separation in the Stony Brook Subbasin.

Annual Loads

In this section of the report, *dry-weather load* indicates loading during dry-weather conditions for a particular subbasin, *stormwater load* indicates loading during storms for a particular subbasin, and *annual load is* the sum of dry-weather and stormwater loads for a particular subbasin. *Total dry-weather load* is the sum of dry-weather loads, *total stormwater load* is the sum of stormwater loads, *total annual load* is the sum of both dry-weather and stormwater loads, and *upstream load* is load calculated for the Charles River at Watertown (01104615) gaging station. All loads are calculated by means of the regression equations (when appropriate) or overall dry-weather mean or mean EMC concentration. One exception is upstream dry-weather loads that were calculated by means of the overall flow-weighted mean. Finally, loads for subbasins with ungaged areas may be underestimated because EMCs measured at upstream stations may not be indicative of the EMCs that otherwise would have been measured at the mouth. For example, Zarriello and Barlow (2002) reported that the percent impervious area increases as one approaches the lower Charles River, where the subbasins are more urbanized; thus, water samples collected at the mouth might have higher contaminant EMCs than water samples collected at the gage.

Fecal Coliform Bacteria

About 44 percent (table 14) of the total annual fecal coliform load is contributed to the lower Charles River from the Stony Brook Subbasin, compared to 24 percent from upstream, which is the next largest contributor (fig. 21). Almost all of the annual Stony Brook Subbasin fecal coliform load (99.9 percent) is contributed by storms, whereas less than 1 percent is contributed during dry weather (table 15). The pattern of fecal coliform loading from upstream is different; more than 63 percent of the annual upstream load occurs during dry weather. In general, however, most fecal coliform loading can be attributed to stormwater. Stormwater fecal coliform loads to the lower Charles River are proportionally largest from the Stony Brook Subbasin (54 percent of total stormwater load) and the Muddy River Subbasin (17 percent). The total annual fecal coliform load to the lower Charles River is about 7,900 trillion colony forming units (TCFU).

Enterococcus Bacteria

The annual *Enterococcus* bacterial load comes mostly from upstream (58 percent); the upstream load is more than 3 times greater than the next largest contributor of annual *Enterococcus* load, Stony Brook Subbasin (table 14; fig. 21). Like fecal coliform, *Enterococcus* loading for the most part occurs during storms (93 percent of total annual load). Moreover, more than half of the total stormwater *Enterococcus* bacteria load comes from upstream. The difference between fecal coliform and *Enterococcus* loading patterns may be caused by different sources and survival characteristics of the bacteria. *Enterococcus*, once released by the host organism to a stream or river, generally survive longer than fecal coliform (Ronald Stoner, Massachusetts Department of Environmental Protection, oral commun., 2002). Viruses and other pathogens may also have different survival characteristics compared to the bacterial indicators (fecal coliform and *Enterococcus*). The percentage of the total stormwater *Enterococcus* load contributed by the Stony Brook Subbasin (20 percent) is about double the Muddy River Subbasin percentage (12 percent). Dry-weather loads of *Enterococcus* generally come from upstream (90 percent). This finding is consistent with the longer residence time of upstream water and the longer-lived character of the *Enterococcus* indicator.

Nitrogen

The largest total annual nitrate, ammonia, and TKN loads enter the lower Charles River from upstream sources (table 14; fig. 21). Upstream sources account for about 87, 82, and 86 percent of the total WY 2000 load of nitrate, ammonia, and TKN, respectively. Upstream annual dry-weather nitrogen loads are larger than the corresponding upstream stormwater loads by a ratio of about two to one (table 15). In addition to being the largest dry-weather contributor of total nitrogen to the lower Charles River for WY 2000, upstream sources of nitrogen also account for the largest percentage of stormwater nitrate, ammonia, and TKN loads (81, 71, and 73 percent, of the WY 2000 stormwater load, respectively).

Phosphorus

As with nitrogen, upstream sources contribute most (81 percent) of the annual total phosphorus load to the lower Charles River (table 14; fig. 21). Most of this load (70 percent) is discharged during dry weather (table 15). Similarly, during storms, upstream sources also are the major contributor to stormwater phosphorus loading (64 percent).

Trace Metals

The selected trace metals (cadmium, chromium, copper, lead, and zinc) exhibit similar loading patterns (tables 14 and 15; fig. 21). The major trace-metal contributor on an annual basis is the upstream watershed (between 53 and 89 percent of the total trace-metal annual load). Almost all of the dry-weather trace-metal load (93 to 98 percent) for WY 2000 can be attributed to upstream sources. Similarly, the largest stormwater trace-metal load for WY 2000 for a single subbasin (34 to 80 percent) can also be attributed to upstream sources.

Table 14. Percentages of dry-weather, stormwater, and total loads of each constituent contributed to the lower Charles River at each station in the Lower Charles River Watershed, Massachusetts, Water Year 2000

[All constituents are in percent. Calculated on the basis of unrounded data]

Station name	Biochemical oxygen demand, 5-day	Coliform, fecal, membrane filter	Enterococcus membrane filter	Dissolved solids	Suspended solids	Nitrate, total (as N)	Nitrogen, ammonia, total (as N)	Nitrogen, total Kjeldahl (as N)	Phosphorus, total	Cadmium, total	Chromium, total	Copper, total	Lead, total	Zinc, total
Water Year 2000 Dry-Weather Load														
Charles River at Watertown (01104615)[1]	95.1	80.0	89.6	92.3	95.8	90.4	88.6	93.3	91.9	96.6	97.8	93.0	95.8	97.3
Laundry Brook (01104640)	.31	.74	.53	.33	.15	.57	.15	.22	.26	.19	.12	.43	.17	.11
Faneuil Brook[2]	.52	16.9	8.23	.40	.78	.63	.69	.33	.36	.18	.10	.33	.31	.24
Muddy River[3]	1.44	.79	.56	1.42	1.29	1.18	2.89	1.99	1.25	.68	.44	1.62	1.21	.57
Stony Brook[4]	1.67	.19	.14	4.54	1.30	5.93	6.36	3.04	5.37	1.83	1.24	3.36	1.77	1.40
Ungaged area	1.00	1.34	.95	1.02	.71	1.25	1.34	1.08	.85	.53	.34	1.23	.71	.38
Water Year 2000 Stormwater Load														
Charles River at Watertown (01104615)[1]	64.3	10.9	53.9	88.6	79.4	80.8	71.3	73.1	64.0	72.0	79.6	50.1	33.8	52.0
Laundry Brook (01104640)	2.53	1.76	1.26	.79	1.11	1.18	1.05	1.73	1.84	.87	1.25	1.74	2.48	3.38
Faneuil Brook[2]	1.75	6.28	5.43	.54	1.44	.89	.88	.95	1.12	.96	.90	1.01	1.99	1.42
Muddy River[3]	6.79	17.1	11.5	3.19	4.43	5.47	6.72	5.75	9.71	7.30	5.68	21.9	17.1	13.9
Stony Brook[4]	16.6	54.2	20.1	3.98	9.55	7.10	14.9	12.5	15.6	14.1	7.81	12.1	32.5	16.6
Ungaged area	8.13	9.79	7.79	2.87	4.08	4.62	5.12	5.96	7.81	4.76	4.77	13.2	12.1	12.6
Water Year 2000 Total Load														
Charles River at Watertown (01104615)[1]	80.0	23.9	58.2	91.2	82.3	87.3	81.9	85.4	81.1	87.9	89.3	66.0	53.3	84.5
Laundry Brook (01104640)	1.39	1.56	1.17	.47	.93	.76	.50	.81	.87	.43	.65	1.26	1.75	1.04
Faneuil Brook[2]	1.12	8.28	5.77	.44	1.33	.72	.77	.57	.65	.46	.47	.76	1.46	.57
Muddy River[3]	4.05	14.1	10.2	1.97	3.87	2.56	4.37	3.46	4.51	3.02	2.87	14.4	12.1	4.36
Stony Brook[4]	8.94	44.0	17.6	4.37	8.07	6.30	9.66	6.73	9.31	6.18	4.29	8.85	22.8	5.70
Ungaged area	4.48	8.20	6.96	1.59	3.48	2.34	2.80	2.99	3.54	2.03	2.40	8.75	8.54	3.86

[1]Charles River at Watertown dry-weather loads were calculated using the flow-weighted average.
[2]Includes ungaged areas of gaged subbasin.
[3]Includes Muddy River conduit and ungaged areas of gaged subbasin.
[4]Includes Stony Brook overflow and ungaged areas of gaged subbasin.

Table 15. Percentages of dry-weather and stormwater loads of each constituent at each station in the lower Charles River Watershed, Massachusetts, Water Year 2000

[**Charles River–Watertown:** Dry-weather loads were calculated by means of the flow-weighted average. **Faneuil Brook:** Includes ungaged areas of gaged subbasin. **Muddy River:** Includes Muddy River Conduit and ungaged areas of gaged subbasin. **Stony Brook:** Includes Stony Brook conduit and ungaged areas of gaged subbasin. All constituents are in percent. Calculated on the basis of unrounded data]

Constituent	Charles River at Watertown (01104615)		Laundry Brook (01104640)		Faneuil Brook		Muddy River		Stony Brook		Ungaged area	
	Dry weather	Storm-water	Dry weather	Storm-water	Dry weather	Storm-water	Dry weather	Storm-water	Dry weather	Storm-water	Dry weather	Storm-water
Biochemical oxygen demand, 5-day	60.76	39.24	11.46	88.54	23.80	76.20	18.14	81.86	9.58	90.42	11.41	88.59
Coliform, fecal, membrane filter	62.99	37.01	8.82	91.18	38.40	61.60	1.06	98.94	.08	99.92	3.06	96.94
Enterococcus membrane filter	18.71	81.29	5.47	94.53	17.36	82.64	.66	99.34	.09	99.91	1.67	98.33
Dissolved solids	69.95	30.05	48.41	51.59	62.17	37.83	49.97	50.03	71.82	28.18	44.27	55.73
Suspended solids	20.85	79.15	2.85	97.15	10.55	89.45	5.98	94.02	2.88	97.12	3.67	96.33
Nitrate, total (as N)	70.20	29.80	50.31	49.69	60.09	39.91	31.13	68.87	63.73	36.27	36.27	63.73
Nitrogen, ammonia, total (as N)	66.40	33.60	18.34	81.66	55.47	44.53	40.60	59.40	40.42	59.58	29.37	70.63
Nitrogen, total Kjeldahl (as N)	66.65	33.35	16.42	83.58	35.52	64.48	35.13	64.87	27.55	72.45	22.15	77.85
Phosphorus, total	69.58	30.42	18.33	81.67	33.87	66.13	17.01	82.99	35.46	64.54	14.78	85.22
Cadmium, total	71.02	28.98	28.42	71.58	25.59	74.41	14.47	85.53	19.15	80.85	16.91	83.09
Chromium, total	58.56	41.44	10.16	89.84	11.37	88.63	8.12	91.88	15.42	84.58	7.63	92.37
Copper, total	52.09	47.91	12.55	87.45	16.00	84.00	4.15	95.85	14.03	85.97	5.20	94.80
Lead, total	56.53	43.47	3.07	96.93	6.73	93.27	3.14	96.86	2.44	97.56	2.63	97.37
Zinc, total	82.54	17.46	7.60	92.40	29.89	70.11	9.34	90.66	17.64	82.36	6.99	93.01

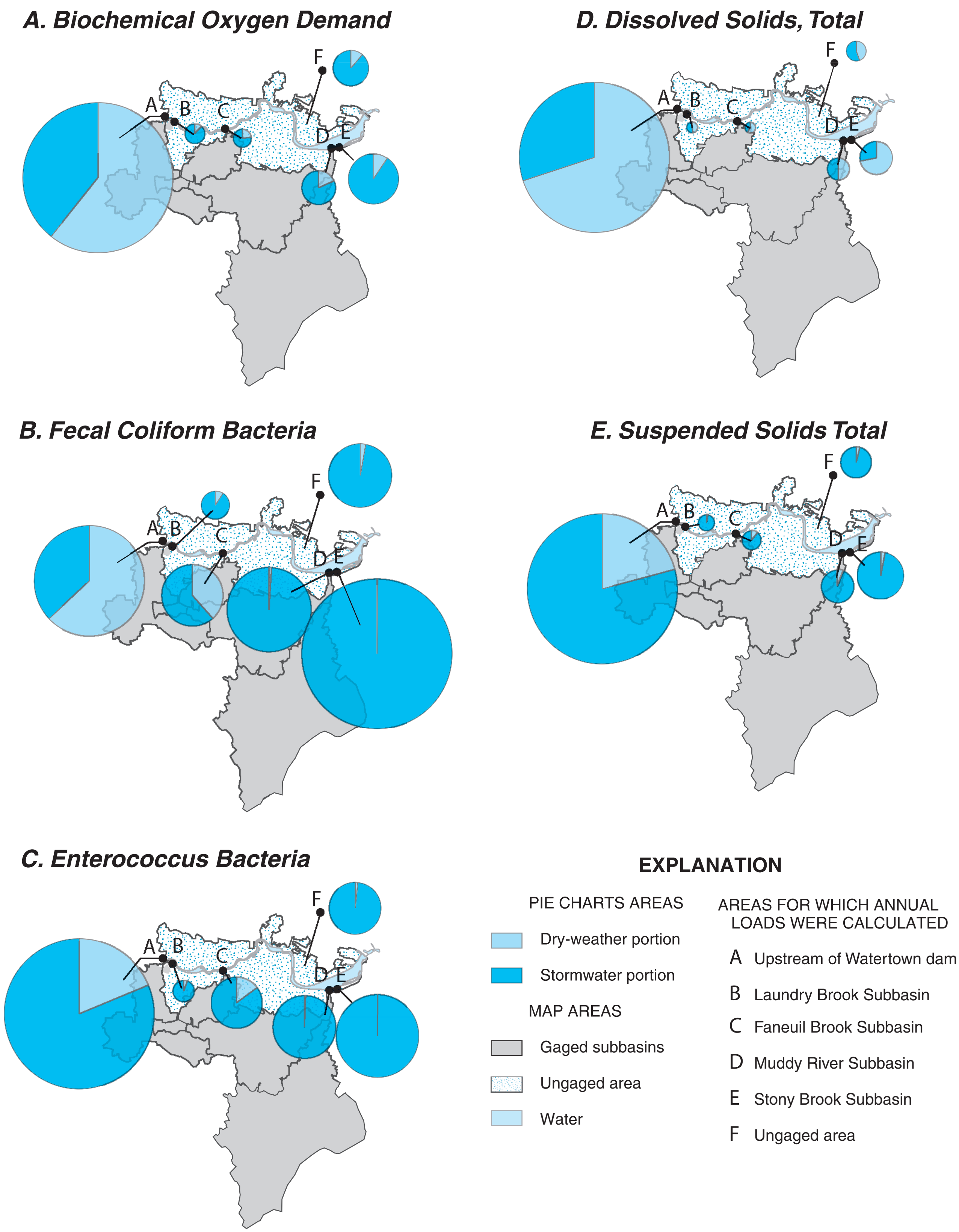


Figure 21. Spatial distribution of annual loads for the tributary subbasins and for the ungaged area, lower Charles River Watershed, Massachusetts, Water Year 2000.

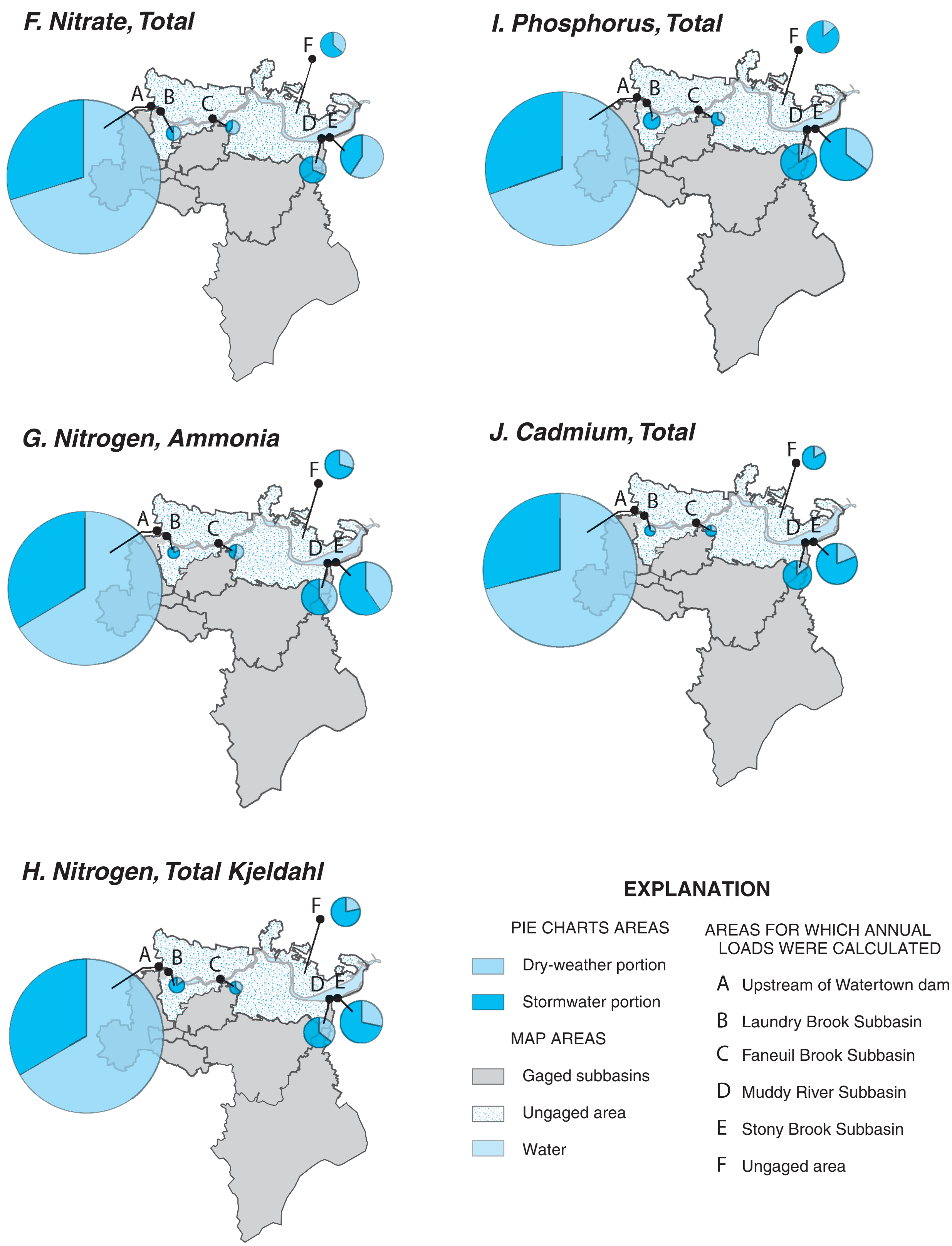


Figure 21. Spatial distribution of annual loads for the tributary subbasins and for the ungaged area, lower Charles River Watershed, Massachusetts, Water Year 2000—*Continued*.

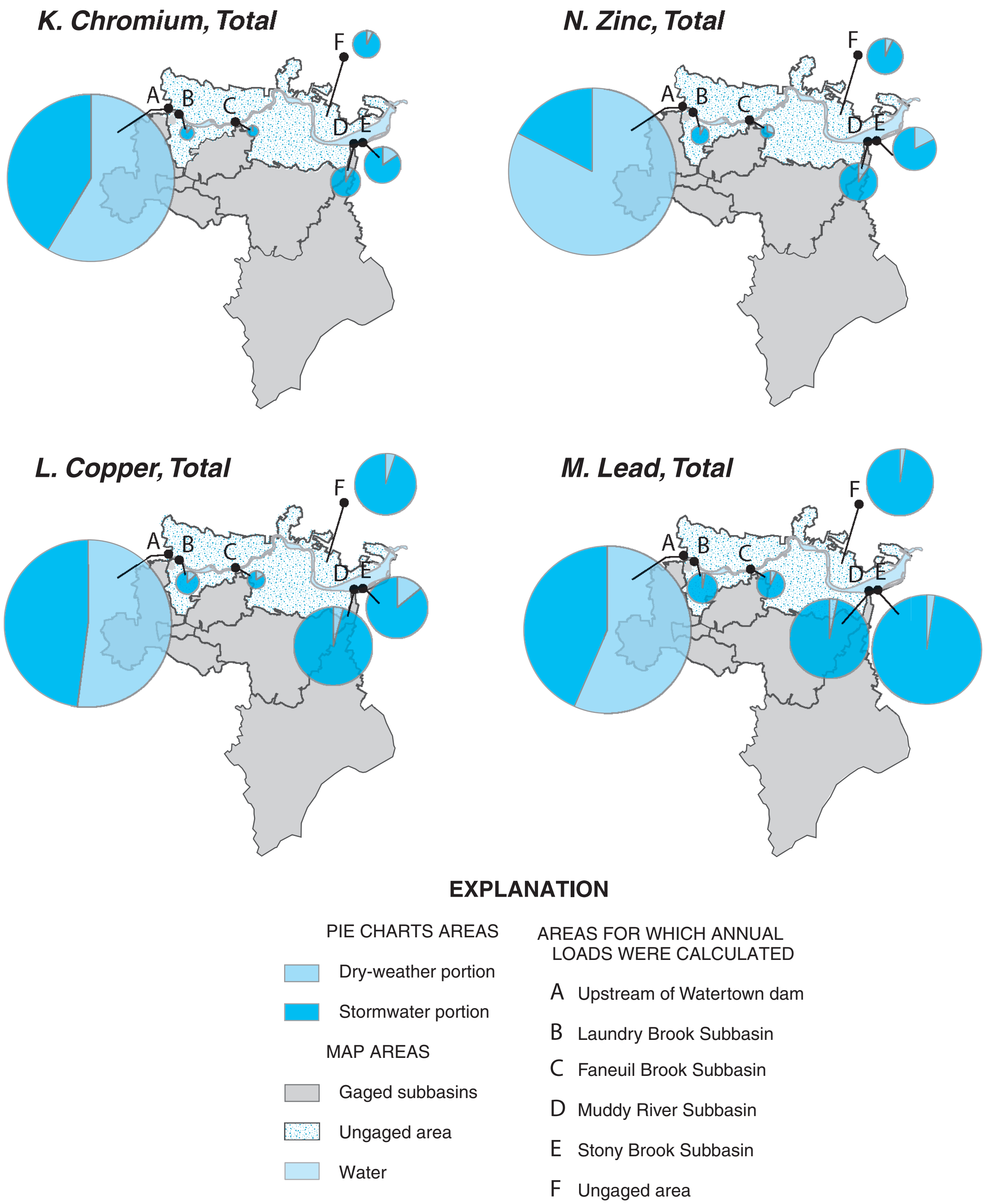


Figure 21. Spatial distribution of annual loads for the tributary subbasins and for the ungaged area, lower Charles River Watershed, Massachusetts, Water Year 2000—*Continued*.

Biochemical Oxygen Demand

Upstream BOD-5 sources contributed about 80 percent of the total annual BOD-5 load to the lower Charles River during WY 2000; of this total annual load, 61 percent was contributed during dry weather (tables 14 and 15; fig. 21). Moreover, the upstream sources accounted for 95 percent of the total dry-weather BOD-5 load. Most of the annual stormwater BOD-5 load (64 percent) was also accounted for by upstream sources.

Total Dissolved Solids

Dry-weather and stormwater loads of TDS to the lower Charles River during WY 2000 were largest from upstream sources (tables 14 and 15; fig. 21). Upstream sources accounted for about 90 percent of both total dry-weather and total stormwater TDS loads. Most of the TDS load (70 percent) was contributed to the lower Charles River during WY 2000 from upstream sources during dry weather. Similarly, dry-weather loads account for a greater proportion of the annual TDS load than do stormwater TDS loads for all of the tributary subbasins (fig. 21).

Total Suspended Solids

TSS loading patterns contrast with those of TDS (tables 14 and 15; fig. 21). For example, most of TSS loading occurs during storms. Almost the entire TSS load (96 percent) during dry weather and 79 percent during wet weather comes from upstream sources. Annually, more than 80 percent of the total annual TSS load to the lower Charles River comes from upstream. Although much of the sediment that enters the lower Charles River comes from upstream, this sediment probably contains less contamination than sediment that enters the lower Charles River from the tributary subbasins. In other words, upstream sources may not be mainly responsible for the highly contaminated bed sediment found in the lower Charles River; upstream sediment may dilute sediment from the tributary subbasins (Breault and others, 2000b).

Annual Yields

To compare results among subbasins of different sizes and land use (table 16), it is useful to normalize load values to subbasin area. Loads per unit area are known as yields. Although yields can give insight into whether a subbasin is contributing a disproportionate amount of a particular constituent, yields do not give any information about the quality of water or sediment that comes from a given subbasin. In other words, low contaminant yields do not necessary indicate low contaminant concentrations. For example, small amounts of heavily contaminated suspended sediment would result in low contaminant yields, whereas large amounts of slightly contaminated sediment would result in high contaminant yields. In order to generate this type of information, water-quality sampling strategies must include more specific analysis of different matrix types, including suspended sediment and dissolved (filtered) water samples. In this study, it is useful to compare yields from upstream and the tributary subbasins to one another and from the uniform land-use sites to each other.

Charles River at Watertown

It is not surprising that the upstream subbasin contributes the largest proportion of the total annual load to the lower Charles River for most of the selected constituents and water-quality properties. The upstream subbasin has an area of 268.02 mi^2, which is about 20 times larger than the largest tributary subbasin (Stony Brook, 13.84 mi^2; table 16). In contrast, upstream yields were among the smallest for all of the water-quality properties and constituents, with the exception of TDS (table 17). Upstream yields of BOD-5, fecal coliform bacteria, *Enterococcus* bacteria, copper, and lead were the smallest among all subbasins. These data indicate that although large loads can be attributed to upstream sources, these loads generally are proportionate to the size of the upstream contributing area.

Laundry Brook Subbasin

Laundry Brook yields were among the lowest compared to the other subbasins (table 17). In particular, yields of BOD-5, TDS, TSS, nitrate, ammonia, TKN, P, Cd, Cr, and Zn were lowest from the Laundry Brook Subbasin. These results, in combination with the small size of the subbasin, indicate that the Laundry Brook Subbasin is generally contributing a small portion of the constituents with respect to the other tributary subbasins of similar size.

Table 16. Land use in the lower Charles River Watershed, Massachusetts

[Land use is in percent. Percentages do not total 100 percent because of rounding. **Muddy River:** Includes Muddy River Conduit. mi^2, square mile; --, not determined]

Land use	Tributary subbasins										Uniform land-use subbasins		
	Charles River at Watertown (01104615)	Laundry Brook (01104640)	Faneuil Brook (01104660)		Muddy River (01104683)		Stony Brook (01104687)		Charles River Boston Science Museum (01104710)	Ungaged area	Single-family land use (01104630)	Multi-family land use (01104673)	Commercial land use (01104677)
			Gage	Mouth	Gage	Mouth	Gage	Mouth					
Commercial	1.90	7.56	4.98	9.44	7.38	6.87	6.62	6.86	2.80	14.69	0	0	76.36
Cropland	3.51	0	0	0	.84	.80	1.11	.99	3.14	0	0	0	0
Forest	41.05	10.71	4.40	3.89	6.99	6.39	12.17	10.98	36.93	.50	.02	0	0
Industrial	1.89	.21	0	.56	0	0	.79	.91	1.92	6.03	0	0	0
Mining	.60	0	0	0	0	0	0	0	.53	0	0	0	0
Open land	2.10	.21	.73	.56	.30	.32	1.07	.99	1.93	.76	0	0	0
Parks, cemeteries, public and institutional greenspace	3.14	8.61	10.84	9.44	10.13	13.42	12.79	13.26	4.27	13.50	.83	21.63	0
Participation recreation	1.43	.42	7.94	6.67	4.77	6.39	8.32	7.77	1.87	3.09	0	0	0
Pasture	1.26	0	0	0	0	0	.58	.53	1.13	0	0	0	0
Residential, 1/4–1/2 acre	9.75	13.24	3.07	2.22	9.86	8.95	1.99	1.83	9.10	1.23	23.87	0	0
Residential less than 1/4 acre	6.39	50.84	50.48	41.11	22.80	21.09	32.50	30.64	9.33	25.97	73.64	0	0
Residential greater than 1/2 acre	16.55	2.52	0	0	13.31	12.14	.65	.61	14.87	0	0	0	0
Residential–multifamily	.84	.21	11.82	21.11	14.95	14.54	14.05	16.92	2.33	12.29	0	78.37	23.64
Spectator recreation	.70	2.52	3.29	2.78	3.03	3.04	1.84	1.98	.96	4.11	1.64	0	0
Transportation	1.47	1.26	.34	.56	.70	1.12	1.97	2.52	1.69	7.16	0	0	0
Waste disposal	.33	0	0	0	0	0	.76	.69	.32	.09	0	0	0
Water	2.44	.84	1.65	1.11	4.92	4.95	.19	.15	2.63	10.25	0	0	0
Water-based recreation	.02	0	.48	.56	0	0	0	0	.03	.19	0	0	0
Wetland	4.29	.84	0	0	0	0	.37	.30	3.81	.14	0	0	0
Woody perennial	.34	0	0	0	.02	0	2.26	2.06	.39	0	0	0	0
Percent impervious	--	11	--	14	--	42	--	19	--	--	17	73	86
Total (mi^2)	268.02	4.76	1.42	1.78	5.44	6.26	11.80	13.10	304.63	9.68	.36	.04	.02

Faneuil Brook Subbasin

The highest fecal coliform bacteria, *Enterococcus* bacteria, and TSS yields were measured from the Faneuil Brook Subbasin (table 17). In addition, BOD-5, TDS, nitrate, and ammonia yields from this subbasin were among the largest from all subbasins. As mentioned previously, illicit sanitary cross-connections are likely responsible for the large annual yields of these contaminants. Because of its small size (1.78 mi^2), however, the Faneuil Brook Subbasin is not contributing a large portion of the total load to the lower Charles River. This subbasin, however, is producing a disproportionate amount of fecal coliform bacteria and *Enterococcus* bacteria (table 17) in relation to its size.

Muddy River Subbasin

Yields of many of the constituents and measures of water-quality properties (including TKN, P, Cd, Cr, Cu, Pb, and Zn) were largest from the Muddy River Subbasin (table 17). Yields of the remaining constituents studied were among the largest from all subbasins. The large yields from the Muddy River Subbasin compared to the other tributary subbasins indicate that this subbasin is contributing disproportionately large loads to the lower Charles River, relative to its size. This result is not surprising because the amount of impervious area in this subbasin (42 percent) is more than twice that of the next most impervious of the tributary subbasins—Stony Brook (19 percent) (table 16).

Stony Brook Subbasin

BOD-5, nitrate, ammonia, and Cd yields were the largest from the Stony Brook Subbasin (table 17). Yields of the remaining constituents were among the largest from all subbasins. Large yields in combination with the large size of the subbasin indicate that Stony Brook is contributing disproportionately large loads of these constituents to the lower Charles River. The effect of CSOs in the Stony Brook Subbasin is evident from yields of the selected constituents and measures of water-quality properties. Sewer separation planned for the Stony Brook Subbasin is expected to reduce contaminant yields from Stony Brook. These yields include contributions of the Stony Brook overflow to the Back Bay Fens. Although these loads eventually discharge to the lower Charles River through the Muddy River, they do originate from the Stony Brook Subbasin. Therefore, the Stony Brook overflow loads were included with the Stony Brook Subbasin loads in the calculation of contaminant yields from this subbasin.

Ungaged Areas

If mean dry-weather and stormwater constituent concentrations of the Laundry Brook and Muddy River Subbasins are considered appropriate for estimating loads from the ungaged areas, then the corresponding yields of the constituents and measures of water-quality properties analyzed would be among the lowest compared to the tributary subbasins. Copper and zinc yields for the ungaged areas were slightly greater than the average compared to the tributary subbasins (table 17).

Uniform Land-use Subbasins

Generally, constituent yields were largest from the commercial land-use subbasin and smallest from the single-family land-use subbasin (table 17). Again, this result demonstrates the effect of impervious area, particularly paved streets, in accumulating contaminants between storms. This commercial land-use subbasin has the largest percentage of impervious area (86 percent), whereas the multifamily land-use subbasin has the second highest (73 percent), and the single-family land-use subbasin has the smallest (17 percent; table 16).

Design-Storm Loads

In order to compare stormwater-contaminant loading patterns from upstream sources, tributaries, and CSOs, and between current and future infrastructure conditions, stormwater loads were estimated for two historical “design storms” with recurrence intervals of approximately 3 months (known as the “3-month storm”) and 1 year (the “1-year storm;” fig. 22). As noted previously, however, EMCs measured at upstream stations may not be representative of EMCs at the mouth of each tributary. This relation is particularly important for Stony Brook. The MWRA has estimated that about 0.18 million ft^3 and 0.57 million ft^3 of combined sewage discharged to Stony Brook during the 3-month and 1-year design storms, respectively; about half of this volume entered downstream of the USGS gaging station (table 18).

Table 17. Constituent yields for 3-month and 1-year design storms, and Water Year 2000, lower Charles River Watershed, Massachusetts

[g/mi^2, grams per square mile; kg/mi^2, kilograms per square mile; TCFU/mi^2, trillion colony-forming units per square mile; --, model inappropriate]

Stations	Bio-chemical oxygen demand, 5-day (kg/mi^2)	Coliform, fecal, membrane filter (TCFU/mi^2)	Entero-coccus, membrane filter (TCFU/mi^2)	Dissolved solids (kg/mi^2)	Sus-pended solids (kg/mi^2)	Nitrate plus nitrite (kg/mi^2 as N)	Nitrogen, ammonia, total (kg/mi^2 as N)
3-month design storm							
Mixed land use							
Charles River at Watertown (01104615)	16	0.04	0.20	1,480	109	4.5	1.3
Laundry Brook (01104640)	140	.60	.30	1,560	420	8.0	.70
Faneuil Brook[1]	100	6.6	5.2	2,670	1,490	9.4	2.4
Muddy River[1,3]	--	5.0	4.9	5,540	1,760	28	12
Stony Brook[1,4,5]	180	7.0	23	2,240	1,570	15	4.5
Ungaged area[2]	98	1.5	1.6	1,670	528	8.5	3.5
Uniform land use							
Single-family land use (01104630)	310	6.7	7.5	1,300	2,000	6	4.5
Multifamily land use (01104673)	820	15	20	15,000	3,100	64	29
Commercial land use (01104677)	1,300	13	9.5	7,800	6,500	84	37
1-year design storm							
Mixed land use							
Charles River at Watertown (01104615)	40	0.10	0.60	3,750	354	12	3.2
Laundry Brook (01104640)	350	1.0	.30	2,570	691	13	1.0
Faneuil Brook[1]	170	11	8.8	4,500	2,520	5.7	6.9
Muddy River[1,3]	--	9.1	8.9	10,100	3,200	51	21
Stony Brook[1,4,5]	370	15	5.6	4,200	2,970	29	9.7
Ungaged area[2]	160	2.4	2.5	2,660	841	14	5.3
Uniform land use							
Single-family land use (01104630)	500	11	12	2,000	3,200	3.2	7.2
Multifamily land use (01104673)	1,400	.80	34	26,000	5,300	110	50
Commercial land use (01104677)	2,000	21	15	12,000	10,000	130	57
Water Year 2000							
Mixed land use							
Charles River at Watertown (01104615)	2,500	8.7	16	297,000	23,100	910	220
Laundry Brook (01104640)	2,500	32	18	86,500	14,800	450	74
Faneuil Brook[1]	5,300	450	240	217,000	56,000	1,100	310
Muddy River[1,3]	5,400	220	120	272,000	46,000	1,100	490
Stony Brook[1,4]	5,500	310	96	276,000	43,900	1,300	500
Ungaged area[2]	3,900	83	54	144,000	27,000	680	210
Uniform land use							
Single-family land use (01104630)	6,100	190	180	170,000	46,000	850	760
Multifamily land use (01104673)	20,000	210	470	480,000	73,000	2,000	460
Commercial land use (01104677)	65,000	640	250	5,100,000	210,000	9,400	2,300

[1]Includes ungaged portions of gaged subbasins.
[2]Does not include ungaged portions of gaged subbasins.
[3]Includes Muddy River conduit.
[4]Includes Stony Brook overflow.
[5]Calculated by means of equations 6 and 7.

Stations	Nitrogen, total Kjeldahl (kg/mi^2 as N)	Phos-phorus, total (kg/mi^2)	Cadmium, total (g/mi^2)	Chromium, total (g/mi^2)	Copper, total (g/mi^2)	Lead, total (g/mi^2)	Zinc, total (g/mi^2)
3-month design storm							
Mixed land use							
Charles River at Watertown (01104615)	8.6	0.90	0.001	0.02	0.10	0.10	0.20
Laundry Brook (01104640)	27	2.9	.002	.10	.30	.40	.80
Faneuil Brook[1]	22	2.8	.003	.10	.30	.70	1.0
Muddy River[1,3]	58	9.7	.01	.20	1.2	1.3	3.6
Stony Brook[1,4,5]	31	5.9	.008	.11	.50	1.4	2.0
Ungaged area[2]	18	2.9	.003	.10	.30	.4	1.1
Uniform land use							
Single-family land use (01104630)	32	8.1	.01	.20	.60	1.1	1.6
Multifamily land use (01104673)	130	22	.02	.50	.30	4.5	11
Commercial land use (01104677)	150	26	.10	.70	3.5	18	20
1-year design storm							
Mixed land use							
Charles River at Watertown (01104615)	26	2.3	0.003	0.04	0.10	0.30	0.80
Laundry Brook (01104640)	59	4.8	.002	.10	.40	.70	1.4
Faneuil Brook[1]	37	4.7	.01	.20	.50	1.1	1.6
Muddy River[1,3]	83	18	.02	.40	2.1	2.3	6.6
Stony Brook[1,4,5]	61	12	.014	.20	1.0	2.7	3.9
Ungaged area[2]	23	4.7	.01	.10	.60	.60	1.7
Uniform land use							
Single-family land use (01104630)	50	13	.01	.30	.90	1.8	2.5
Multifamily land use (01104673)	220	38	.04	.90	.40	7.8	19
Commercial land use (01104677)	230	--	.10	1.0	--	27	25
Water Year 2000							
Mixed land use							
Charles River at Watertown (01104615)	1,200	120	0.20	4.4	6.8	5.9	45
Laundry Brook (01104640)	660	73	.10	1.8	7.2	11	31
Faneuil Brook[1]	1,300	150	.20	3.5	12	25	46
Muddy River[1,3]	2,100	290	.30	6.0	63	57	99
Stony Brook[1,4,5]	1,900	270	.30	4.1	18	49	59
Ungaged area[2]	1,200	150	.10	3.3	25	26	57
Uniform land use							
Single-family land use (01104630)	1,800	200	.20	4.3	20	26	54
Multifamily land use (01104673)	3,400	590	.60	12	11	140	330
Commercial land use (01104677)	9,000	4,300	1.9	22	430	440	890

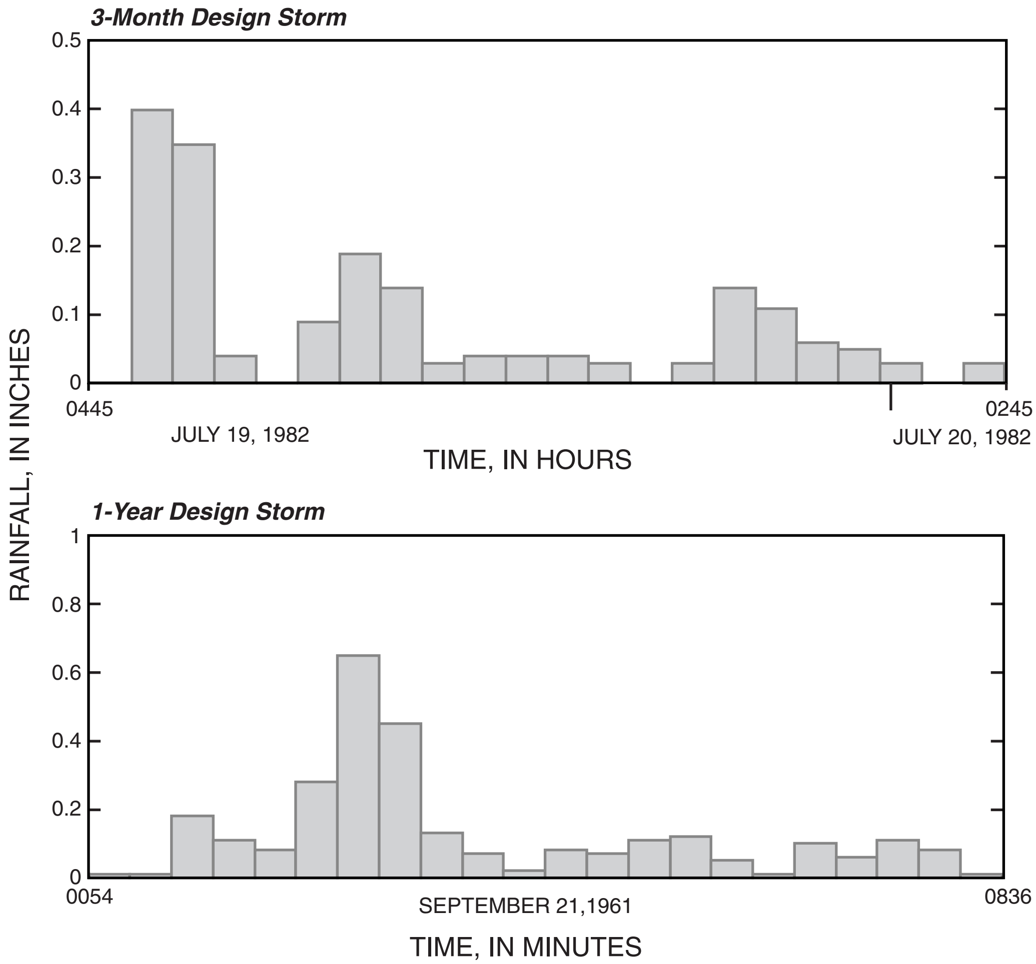


Figure 22. The 3-month design (hourly) storm and 1-year design storms (21 minutes), lower Charles River, Massachusetts.

Consequently, design-storm loads for Stony Brook were calculated by means of equation 6, which takes into account the added effect of downstream CSOs, and is given as

$$L_{i,j} = (sw\overline{C}_i \times (V_j - V_{cso,j})) + (C_i \times V_{cso,j}) \quad , \quad (6)$$

where

$L_{i,j}$ equals the load for constituent i for storm j;

$sw\overline{C}_i$ equals the average concentration of constituent i in stormwater without CSO effect (see equation 7);

V_j equals the total volume for storm j (table 7);

C_i equals the typical concentration of constituent i in combined sewage (table 19); and,

$V_{cso,j}$ equals the total volume of CSO for storm j (table 18).

In order to estimate the design-storm loads, (1) the volume of CSO discharged, (2) typical concentrations of constituents in combined sewage (a mixture of stormwater and raw sewage), and (3) non-CSO stormwater EMCs must be known. The MWRA has determined that CSOs tributary to Stony Brook activated (discharged) 32 times during calendar year 2000,

Table 18. Estimated volume of combined sewage overflow to Stony Brook, lower Charles River Watershed, Massachusetts

[Massachusetts Water Resources Authority, written commun., 2001. **Date and time:** Date is in month, day, and year. Time is eastern standard time. CY, calendar year; USGS, U.S. Geological Survey; ft^3, cubic foot; --, unknown]

Start date and time	End date and time	Upstream of USGS gage (ft^3)	Total (ft^3)
1-10-00 1445	1-10-00 1145	84,200	134,000
4-09-00 0015	4-09-00 2045	0	0
5-18-00 1600	5-19-00 2330	0	0
6-02-00 1530	6-03-00 0730	0	0
6-06-00 0800	6-07-00 1715	1,650,000	4,160,000
7-09-00 2000	7-10-00 0930	9,360	368,000
7-16-00 0000	7-16-00 1200	211,000	434,000
7-27-00 0345	7-27-00 2330	218,000	--
9-15-00 0815	9-16-00 0000	127,000	134,000
CY 2000		5,410,000	14,900,000
January–October 2000		4,110,000	9,340,000
3-month[1]		--	181,000
1-year[1]		--	570,000
Design year[1]		--	4,180,000
3-month[2]		--	48,100
1-year[2]		--	190,000
Design year[2]		--	1,000,000

[1]Before proposed sewer separation.
[2]After proposed sewer separation.

and that about 15 million ft^3 of combined sewage was discharged; of this volume, 5.4 million ft^3 of combined sewage discharged upstream of the USGS gaging station (Massachusetts Water Resources Authority, written commun., 2001). The MWRA has estimated that about 5.2 million ft^3 of combined sewage discharged to Stony Brook during the nine storms sampled in this study, about half of which (2.3 million ft^3) came in upstream of the USGS gaging station (table 18). Given the volume of CSO discharge to Stony Brook upstream of the gage, the concentrations of constituents in combined sewage (table 19), and known loads of each constituent in samples collected at the gaging station, EMCs for stormwater without the presence of the combined sewage (or non-CSO EMCs) can be estimated (table 20) from:

Table 19. Mean concentrations of selected constituents and water-quality properties in combined sewage

[Modified from Metcalf & Eddy, 1994. CFU/100 mL, colony-forming unit per 100 milliliters; µg/L, micrograms per liter; mg/L, milligrams per liter]

Constituent	Sample size	Arithmetic mean	Standard deviation
Biochemical oxygen demand, 5-day (mg/L)	807	78	76
Coliform, fecal, membrane filter (CFU/100 mL)	221	538,000	1,375,000
Suspended solids (mg/L)	869	140	246
Nitrate plus nitrite (mg/L as N)	170	3.4	9.8
Nitrogen, ammonia, total (mg/L as N)	205	3.1	3.7
Nitrogen, total Kjeldahl (mg/L as N)	182	5.9	5.8
Phosphorus, total (mg/L)	181	3.1	10.5
Copper, total (µg/L)	206	63	52
Zinc, total (µg/L)	199	210	180

$$swC_{i,j} = \frac{L'_{i,j} - [(V'_{cso,j} \times C_i)]}{V'_j - V'_{cso,j}} , \qquad (7)$$

where

$swC_{i,j}$ equals the stormwater EMC of constituent i for storm j without CSO effect;

$L'_{i,j}$ equals the total load of constituent i for storm j at the gaging station (table 6);

$V'_{cso,j}$ equals the volume of CSO discharged upstream of the gaging station for storm j (table 18);

C_i equals the typical concentration of constituent i in combined sewage (table 19); and,

V'_j equals the discharge measured at the Stony Brook gaging station (01104687) for storm j (table 3).

Stormwater EMCs were determined for each of the nine storms and then averaged to obtain a representative value ($sw\overline{C}_i$). The July 10th storm was omitted because it is considered an outlier. It appears that this sample was heavily affected by combined sewage, although the MWRA estimated that only a small amount of combined sewage discharged upstream of the gaging station during this storm (table 18). As a

Table 20. Projected constituent event mean concentrations for Stony Brook, lower Charles River Watershed, Massachusetts, under conditions of complete sewer separation

[CFU/100 mL, colony-forming units per 100 milliliters; μg/L micrograms per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units]

Constituent	Concentration
Biochemical oxygen demand, 5-day (mg/L)	9.6
Coliform, fecal, membrane filter (CFU/100 mL	32,000
Enterococcus, membrane filter (CFU/100 mL)[1]	8,500
Dissolved solids (mg/L)[2]	138
Suspended solids (mg/L)	96
Nitrate plus nitrite (mg/L as N)	.85
Nitrogen, ammonia, total (mg/L as N)	.21
Nitrogen, total Kjeldahl (mg/L as N)	1.9
Phosphorus, total (mg/L)	.30
Cadmium, total (μg/L)[3]	.47
Chromium, total (μg/L)[3]	6.6
Copper, total (μg/L)	31
Lead, total (μg/L)[3]	89
Zinc (μg/L)	120

[1]Combined sewage concentrations were estimated by means of the ratio of fecal coliform in stormwater at Faneuil Brook and combined sewage to the concentration of *Enterococcus* in stormwater.

[2]Estimated.

[3]Combined sewage concentrations were estimated by means of the ratio of zinc in stormwater at Laundry Brook (01104640) and combined sewage to the concentration of each metal in stormwater.

result, the ratio of upstream to downstream contributions of CSO for this storm is lower than for other storms. In cases where the concentration of a constituent or water-quality property in combined sewage was not given, estimates of constituent concentrations in combined sewage were used (table 20).

Generally, estimated loading patterns among the subbasins for the 3-month and 1-year design storms were similar to patterns for annual loads (table 27). The proportion of the total stormwater load calculated to come from the Stony Brook Subbasin, however, was larger and upstream loads lower than for the annual stormwater loads. The greater load from the Stony Brook Subbasin during the design storms probably resulted from CSO effects, whereas not every storm during a typical year causes CSO activation. The annual load was also calculated by means of equation 6 and there was little difference between these loads and those calculated using the regression equations (average difference of 0.97 percent).

Estimated Stony Brook Subbasin Loads after Sewer Separation

The effects of sewer separation on design-storm and WY 2000 loads from the Stony Brook Subbasin were also estimated. These estimates depend upon the following variables, which were either measured by the USGS or provided by the MWRA: (1) the volume of CSO discharged to Stony Brook before and after separation (table 18), (2) typical constituent concentrations in combined sewage (table 19), (3) non-CSO stormwater EMCs (equation 7), and (4) the increases in stormwater discharge after separation.

There is a certain amount of stormwater mixed with raw sewage that presently is transported out of the subbasins directly to the MWRA's Deer Island Treatment Plant (fig. 23). After sewer separation, however, this stormwater will no longer be transported to the treatment plant but rather be discharged directly to Stony Brook; consequently, stormwater flow will increase. The MWRA has estimated that sewer separation will result in 816,000 ft^3 and 1.38 million ft^3 increases in stormwater discharge to Stony Brook for the 3-month and 1-year design storms, respectively (Massachusetts Water Resources Authority, written commun., 2001). The estimated annual increase is about 52 million ft^3 after sewer separation in the Stony Brook Subbasin. The MWRA has also estimated that, after sewer separation, there will still be a small volume of combined sewage discharge (0.05 million ft^3, and 0.19 million ft^3) during the 3-month and 1-year design storms, respectively, and 1.0 million ft^3 for the design[2] year (table 18) (Massachusetts Water Resources Authority, written commun., 2001). Non-CSO stormwater EMCs (table 20) were multiplied by projected stormwater flows and added to the remaining

[2]The design year is a modified hyetograph from 1992 that includes a range of storm sizes which are considered typical for an average year (Metcalf and Eddy, Inc., 1994).

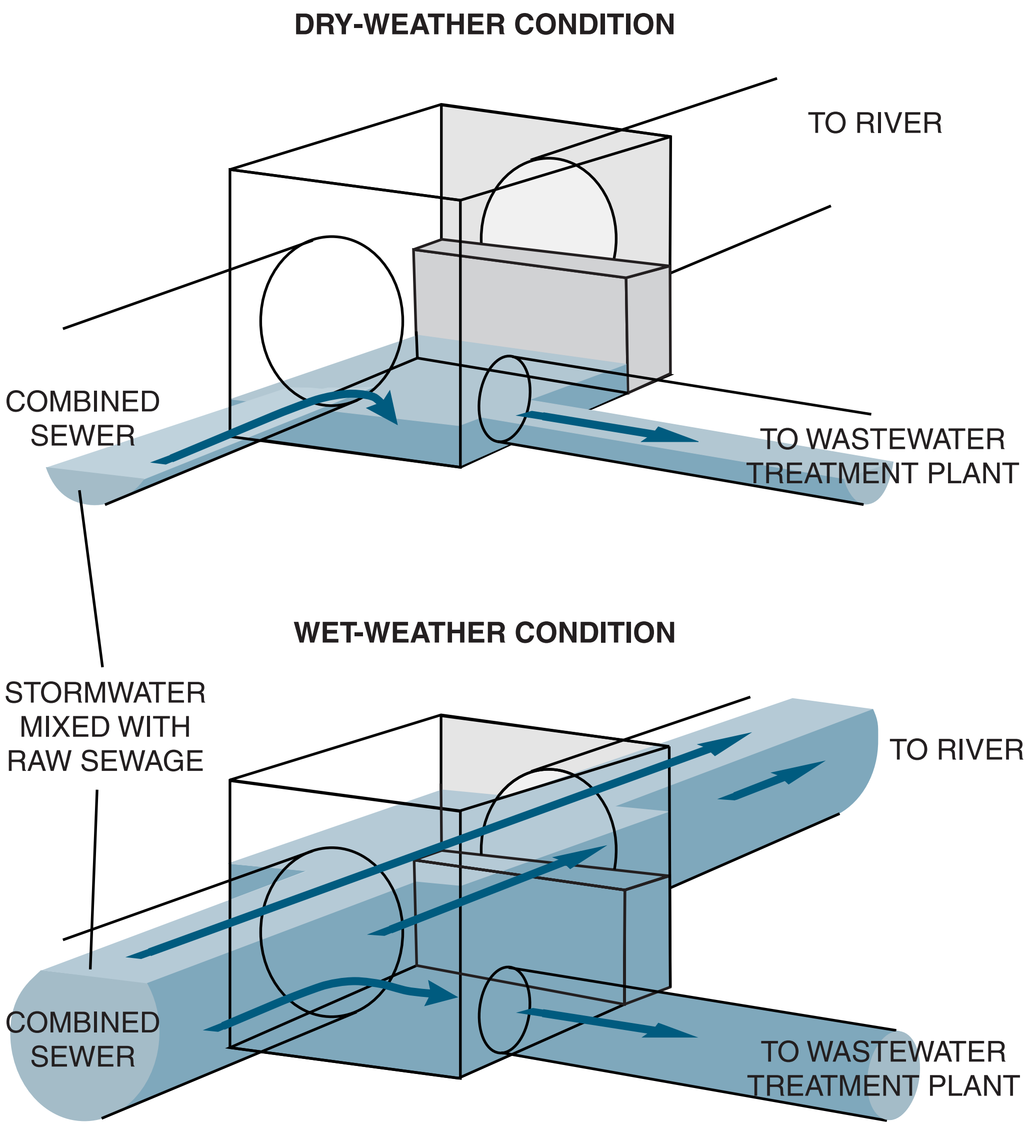


Figure 23. A typical combined sewer.

CSO load after separation to determine the annual (WY 2000) and design storm loads for the Stony Brook Subbasin after sewer separation:

$$L''_{i,j} = sw\overline{C}_i \times [(V_j - V_{cso,j}) + \Delta V_j] \ , \qquad (8)$$

where

$L''_{i,j}$ equals the load for constituent i after sewer separation for storm j;

$sw\overline{C}_j$ equals the average concentration of constituent i in stormwater (see equation 7);

V_j equals the total volume for storm j after sewer separation (table 7);

$V_{cso,j}$ equals the total volume of CSO (table 18) for storm j; and,

ΔV_j equals the increase in stormwater for storm j after sewer separation.

Annual loads (WY 2000) for all of the trace metals, nitrate (plus nitrite), TKN, TSS, and TDS showed slight to moderate increases after sewer separation, whereas the rest of the constituents decreased (fig. 24 and table 21). In particular, fecal coliform loads are projected to decrease about 30 percent, or 1,500 TCFU, annually. The 3-month and 1-year storms are projected to produce a similar pattern of relative change in constituent loading after separation. Under this scenario, constituents associated with street runoff (trace metals) are projected to increase and constituents associated with sewage (BOD-5, bacteria, ammonia, and phosphorus) are projected to decrease after separation.

Environmental Implications of Loads

The environmental implications of the different contaminant loads depend upon the contaminant under consideration. The effect of bacterial loading is likely to be controlled by the short-term rate at which bacteria enter the lower Charles River (or loading intensity; fig. 25) and the location of the discharge points along the river reach. For example, as bacteria are introduced into the lower Charles River, they tend to be diluted; the extent of their dilution depends on the geometry of the river reach. The bacteria also begin to die off as soon as they are released to the environment at a rate that is a function of both time and toxicity. Therefore, loading intensity and local reach geometry and chemistry are critical factors that affect a river's capacity to assimilate bacteria and meet the fecal coliform standards.

Considered in isolation, the bacteria loads from Stony Brook and Muddy River would appear to be most responsible for the numerous exceedences of the fecal coliform standard in the lower Charles River during storms. However, both Stony Brook and Muddy River discharge to the wide part of the river downstream of Boston University Bridge, where most of the volume of the lower Charles River water is found. Dilution of stormwater by cleaner water (water with lower constituent concentrations) in the lower reaches of the Charles River may explain why wet-weather fecal coliform concentrations are often lower downstream than upstream, even though most of the bacteria enter the lower Charles River here during storms. In contrast, upstream reaches of the lower Charles River are much smaller in volume than downstream reaches, and, therefore, upstream reaches are affected more by stormwater loading. Spatial and temporal differences in bacterial loading patterns and the physical environment complicate bacterial dynamics of the lower Charles River. Simulation of these dynamics is an objective of a concurrent receiving-water-modeling investigation by the MWRA.

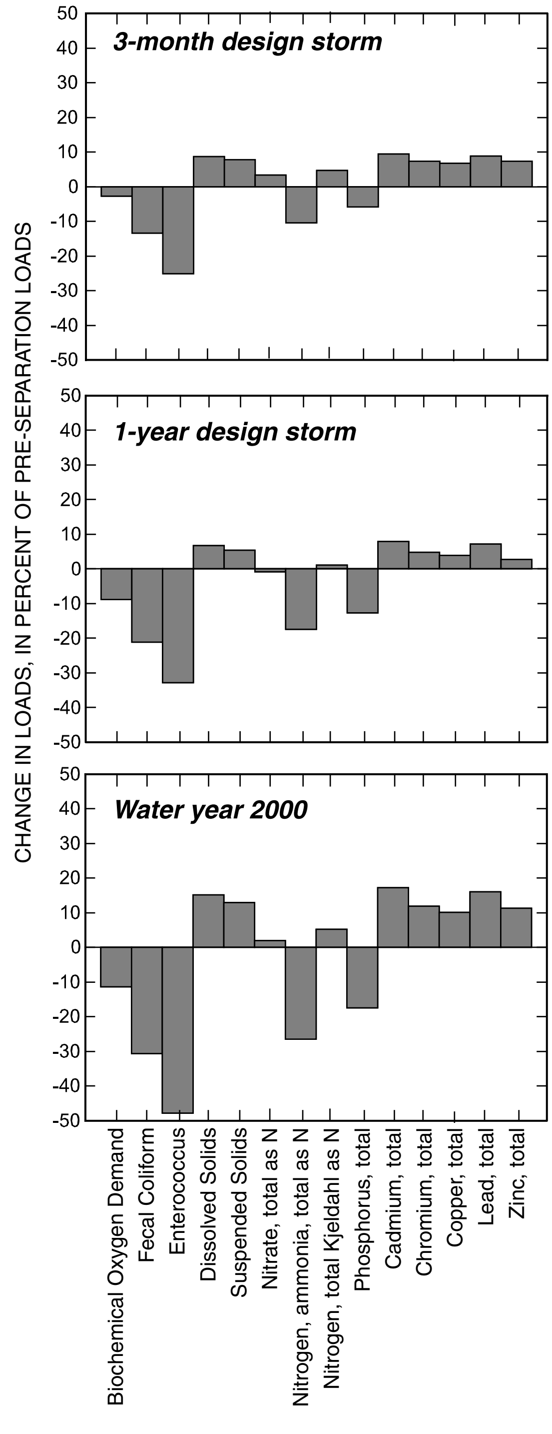


Figure 24. Changes in constituent loads after sewer separation relative to pre-separation loads in the Stony Brook Subbasin, lower Charles River Watershed, Massachusetts. Water Year 2000 includes dry-weather loads and estimated design-storm combined-sewer-overflow loads.

Table 21. Estimated stormwater loads to Stony Brook after sewer separation for design storms and Water Year 2000, Lower Charles River Watershed, Massachusetts

[**Annual and design storm loads:** Includes load from Stony Brook overflow and load based on increase in stormwater for the "design year" after sewer separation. WY, water year; g, gram; kg, kilogram; TCFU, trillion colony-forming units]

Annual and design storm loads	Biochemical oxygen demand, 5-day (kg)	Coliform, fecal, membrane filter (TCFU)	Entero-coccus, membrane filter (TCFU)	Dissolved solids (kg)	Suspended solids (kg)	Nitrate, total (kg as N)	Nitrogen, ammonia, total (kg as N)
3-month storm[1]	2,400	76	2	33,400	23,200	210	51
1-year storm[1]..................	4,700	170	5.2	62,100	43,400	390	110
WY 2000 stormwater[2]	82,000	2,800	700	1,200,000	801,000	7,100	1,800

Annual and design storm loads	Nitrogen, total Kjeldahl (kg as N)	Phosphorus, total (kg)	Cadmium, total (g)	Chromium, total (g)	Copper, total (g)	Lead, total (g)	Zinc, total (g)
3-month storm[1]	450	72	110	1,600	7,400	21,000	31,000
1-year storm[1]	850	150	210	3,000	14,000	40,000	55,000
WY 2000 stormwater[2]	15,000	2,600	3,900	56,000	200,000	740,000	1,000,000

[1]Calculated by means of equation 6.

[2]Calculated by means of regression equations.

Seasonal nitrogen and phosphorus loading affects the lower Charles River by stimulating growth of algae and macrophytes. The lower Charles River can be considered an impoundment or freshwater lake, especially during low-flow conditions in the summer. It is during the summer that nutrient loading is particularly problematic and the river is expected to be most used for recreation, especially for boating and swimming. In addition to low flows, the warmer temperatures and longer hours of sunlight during the summer months promote algae growth. The problems associated with large nutrient loads may be increased by the presence of the "salt wedge" that enters the lower Charles River from Boston Harbor during peak periods of recreational boating in summer (Breault and others, 2000a). The proliferation of algae can lead to low dissolved oxygen concentrations in the bottom water, fish kills, odors, and reduced water-column clarity. Therefore, the unique environment of the lower Charles River increases the environmental effects of seasonal nutrient loading.

Trace-metal loading to the lower Charles River potentially poses a threat to both aquatic organisms and benthic organisms living in and on the bottom sediment. It has been shown that trace-metal contamination is generally greater in lower Charles River surficial sediment than sediment from other urbanized, free-flowing rivers in the United States (Breault and others, 2000b). The lower Charles River is characterized by low hydaulic gradients, a lack of tidal flushing, and a lack of uncontaminated sediment (from erosion of upstream soils) that typically dilutes contaminated urban sediment. The anoxic, sulfide-rich zone within the salt wedge may also be a factor contributing to high trace-metal concentrations in the sediment (Breault and others, 2000a). Consequently, although concentrations of trace metals in dry-weather and stormwater samples may be low compared to aquatic-life criteria and to concentrations determined in other studies, and although annual trace-metal loads may be comparatively modest, the impounded conditions of the lower Charles River amplify the potential environmental effects of the trace-metal loading to the lower Charles River.

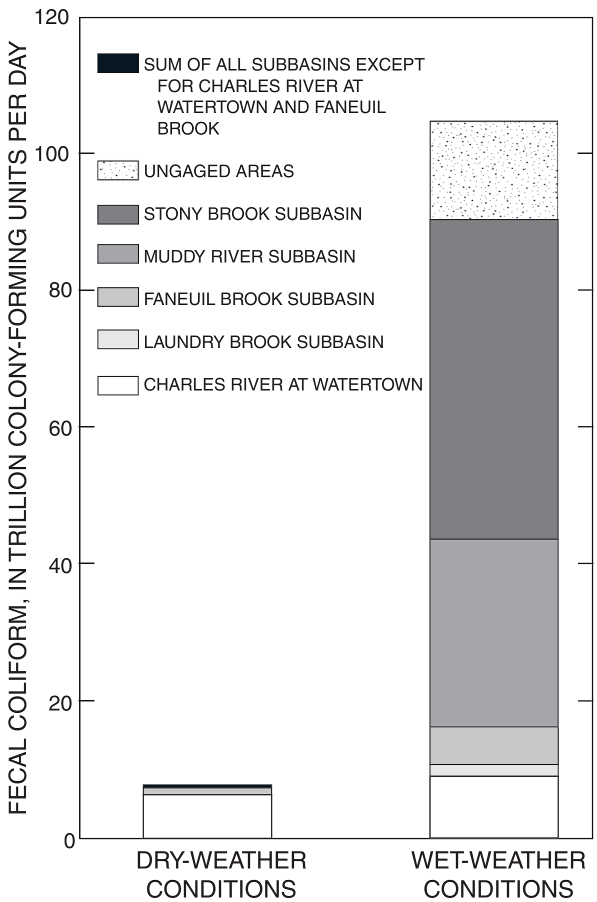


Figure 25. Average daily loading intensity of fecal coliform bacteria from upstream and selected tributary subbasins, lower Charles River Watershed, Massachusetts, Water Year 2000.

SUMMARY

The lower Charles River has been impaired by point and non-point pollution sources for many decades. In response to this impairment, the USEPA Region I has designated the lower Charles River as a priority water body, and has set the goal of achieving consistently “fishable and swimmable” water-quality conditions in the entire River by 2005. In 1999, the USEPA, MADEP, MWRA, and the USGS began a cooperative effort to identify the major pathways and magnitudes of constituent loads contributing to the impaired water quality of the lower Charles River after storms.

Water-quality samples were collected between June 1999 and July 2000 at one USGS streamflow-gaging station on the main stem of the Charles River, at four streams that drain tributary subbasins, and at three small subbasins with uniform land use. Dry-weather samples were collected approximately monthly on days for which there was less than 0.1 in. of precipitation in the preceding 72 hr. Stormwater samples were collected during nine storms by automated samplers at the eight gaging stations.

Streamflow in the lower Charles River Watershed can be characterized as being highly variable, or “flashy,” and unpredictable. These characteristics result from flood-control practices, the highly impervious character of land throughout the watershed, and extensive wetlands in the headwaters of the upstream watershed. The Charles River upstream of the Watertown Dam is the largest source of water to the lower Charles River (about 92 percent by volume annually). The largest tributaries to the lower Charles River are the Muddy River and Stony Brook. These gaged tributaries together discharge about 5 percent of the total annual flow to the lower Charles River. The remaining gaged and ungaged tributaries contribute the remaining 3 percent of the annual flow.

The water quality of the lower Charles River can be considered good—generally meeting water-quality standards and guidelines—during dry weather. However, water quality at some of the subbasin sampling stations frequently exceeded standards for fecal coliform densities during dry weather; these exceedences indicated the persistence of illicit sanitary cross-connections in some of the subbasins. After rainstorms, the water quality of the river becomes impaired, despite the fact that stormwater quality in the study area is generally equal to or better than that found in other studies. The poor water quality of the river after rainstorms may result from the river’s non-capacity to assimilate large contaminant loads than from the unusually high concentrations of constituents in the stormwater.

Most of the dry-weather and stormwater loads of the selected constituents and water-quality properties can be attributed to upstream sources, with the exception of fecal coliform bacteria. Stony Brook, a large tributary affected by combined sewer overflows, contributed more than one-half of the annual fecal coliform load to the lower Charles River for WY 2000, most of it during rainstorms. Sewer separation in the Stony Brook Subbasin would likely reduce annual and design-storm loads of constituents associated with sewage; increases of constituents associated with street runoff are projected.

The unique environment of the lower Charles River compounds the environmental implications of high constituent loads. The lower Charles River is characterized by low hydraulic gradients, a lack of flushing, and a lack of natural uncontaminated sediment from erosion of upstream solids. The lower Charles River also contains an anoxic, sulfide-rich zone within a non-tidal salt wedge. Individually and in combination, these characteristics increase the likelihood of adverse effects by contaminants on the water, biota, and sediment of the lower Charles River. Achievement of water-quality standards in this environment depend critically upon continuing efforts to address the remaining illicit sewer connections, separate combined-sewer areas, improve the quality of non-CSO stormwater, and reduce upstream sources of contamination.

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TABLES 22–27

Table 22. Dry-weather constituent concentrations and physical properties measured between July 1999 and July 2000, Lower

[**Date:** Is in month, day, and year. **Time:** All times are eastern standard and are in hours and minutes. CFU/100 mL, colony-forming units per 100 milliliters; S, split samples; e, estimated; <,less than value shown; --, not measured]

Date	Time	Specific conductance (µS/cm)	Turbidity (NTU)	Biochemical oxygen demand (mg/L)	Coliform, fecal, membrane filter (CFU/100 mL)	Entero-coccus, membrane filter (CFU/100 mL)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Nitrate, total (mg/L as N)
Charles River at Watertown (01104615)									
6-29-99	0930	420	4.0	--	230	<10	461	4	--
7-19-99	1300	390	2.0	<2	270	40	232	5	0.20
7-30-99	1225	380	2.0	<2	--	--	185	<4	.10
8-26-99	1100	94	2.3	<2	90	40	257	<2.5	.10
8-26-99S	--	--	--	<2	--	--	245	<2.5	.10
9-27-99	1245	260	4.0	3.1	330	100	207	6	.30
10-26-99	1152	310	3.9	<2	60	60	208	6	.50
11-19-99	1245	--	--	<2	5,000	3,000	219	3	.60
12-29-99	0950	59	2.0	<2	40	60	282	3	.90
12-29-99S	--	--	--	<2	60	50	252	3	.90
1-24-00	1350	370	2.6	4.3	260	20	202	<4	.80
2-24-00	0900	77	3.0	<2	60	90	258	3	1.00
3-23-00	0920	280	1.9	<2	30	10	128	4	.50
5-01-00	1050	250	8.5	<2	70	20	136	6	.40
6-27-00	0930	320	3.7	<2	390	90	148	4	.50
6-27-00S	--	--	--	<2	560	70	143	4	.50
7-25-00	0530	260	9.6	3.6	510	180	190	8	.20
Single-family land use (01104630)									
6-29-99	--	--	--	--	--	--	614	23	--
7-19-99	1130	930	22.0	15.0	120,000	61,000	427	20	0.80
7-30-99	1045	--	--	--	200	60	--	--	--
8-26-99	0930	46	2.8	<2	58,000	5,400	153	<2.5	2.80
9-27-99	1041	540	2.7	<2	4,900	10,000	313	3	4.10
10-26-99	0950	460	1.3	<2	2,900	1,500	246	<2.5	2.60
11-19-99	1145	--	--	<2	<10	<10	198	4	1.20
12-29-99	1200	730	10.0	<2	<10	<10	1,910	12	.20
1-24-00	1245	350	3.7	2.0	<10	<10	264	7	.80
2-24-00	1030	360	9.3	<2	<10	<10	987	6	1.40
3-24-00	1100	520	1.3	<2	<10	<10	265	e2.5	1.80
5-01-00	1145	700	7.2	<2	<10	<10	345	<2.5	2.10
6-27-00	1030	610	2.8	<2	21,000	850	301	<2.5	2.40
7-25-00	0645	44	22.0	4.9	670	1,700	250	5	3.30
Laundry Brook (01104640)									
6-29-99	--	--	--	--	--	--	--	--	--
7-19-99	1207	430	10.0	<2	790	2,600	247	<4	2.30
7-30-99	1025	--	--	--	1,900	1,400	--	--	--
8-26-99	1000	91	2.3	<2	1,200	310	265	<2.5	2.90
8-26-99S	--	--	--	--	1,800	180	--	--	--

µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; µg/L, micrograms per liter; mg/L, milligrams per liter;

Date	Time	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, total Kjeldahl (mg/L as N)	Phos-phorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Lead, total (µg/L)	Zinc, total (µg/L)
Charles River at Watertown (01104615)									
6-29-99	0930	--	--	--	<0.05	e1.1	2.7	3.4	10.0
7-19-99	1300	0.10	0.80	<0.05	<.05	e1	2.8	3.8	10.0
7-30-99	1225	<.075	.50	<.05	<.5	e.8	2.2	1.3	<10
8-26-99	1100	.10	.80	.10	<.2	2.0	2.2	1.0	e4
8-26-99S	--	.10	.70	.10	<.2	<2	2.0	.9	2.7
9-27-99	1245	.10	1.00	.10	<.2	e4	e5	4.9	15.0
10-26-99	1152	.10	.90	e.05	<.2	e3	e4	3.4	12.0
11-19-99	1245	.10	.90	.10	<.2	2.0	e3	2.2	9.0
12-29-99	0950	.20	.80	.10	<.2	2.0	e2	2.2	19.0
12-29-99S	--	.20	.80	<.1	<.2	<2	8.0	2.3	18.0
1-24-00	1350	.20	.70	.10	<.2	2.0	e3	2.4	15.0
2-24-00	0900	.20	.70	.10	<.2	5.0	e3	1.6	17.0
3-23-00	0920	.20	.60	<.1	<.5	<2	e3	2.6	9.8
5-01-00	1050	<.075	.70	.10	<.2	2.0	e3	3.8	99.0
6-27-00	0930	.10	.70	.10	<.2	e2	e4	5.2	14.0
6-27-00S	--	.10	.80	.10	<.2	2.0	4.0	5.2	14.0
7-25-00	0530	<.075	.80	.10	<.2	<2	3.6	3.4	9.7
Single-family land use (01104630)									
6-29-99	--	--	--	--	0.1	e1.8	27.0	9.7	24.0
7-19-99	1130	15.00	19.00	1.20	.6	e1	13.0	23.0	88.0
7-30-99	1045	--	--	--	--	--	--	--	--
8-26-99	0930	<.075	.90	.50	<.2	<2	15.0	5.5	39.0
9-27-99	1041	1.60	2.00	.40	<.2	<2	19.0	2.1	17.0
10-26-99	0950	.90	2.10	.20	<.2	<2	e8	1.2	14.0
11-19-99	1145	.70	1.70	.30	<.2	<2	e5	1.1	7.7
12-29-99	1200	.60	1.00	.10	<.2	e2	e12	7.6	14.0
1-24-00	1245	.50	.90	.10	<.2	<2	e7	2.4	8.7
2-24-00	1030	.50	1.60	.10	<.2	<5	14.0	8.9	32.0
3-24-00	1100	.50	2.00	.10	<.5	<2	7.7	.8	15.0
5-01-00	1145	.50	1.40	.10	<.2	<2	9.6	.8	15.0
6-27-00	1030	.40	1.20	.30	<.2	e1	e9	1.0	12.0
7-25-00	0645	1.10	1.80	.40	<.2	<2	12.0	4.5	17.0
Laundry Brook (01104640)									
6-29-99	--	--	--	--	0.1	e1	3.0	0.5	11.0
7-19-99	1207	0.10	0.50	0.10	<.05	e.71	4.6	1.5	11.0
7-30-99	1025	--	--	--	--	--	--	--	--
8-26-99	1000	<.075	.40	.10	<.2	<2	6.3	e.6	19.0
8-26-99S	--	--	--	--	--	--	--	--	--

Table 22. Dry-weather constituent concentrations and physical properties measured between July 1999 and July 2000, Lower

Date	Time	Specific conductance (µS/cm)	Turbidity (NTU)	Biochemical oxygen demand (mg/L)	Coliform, fecal, membrane filter (CFU/100 mL)	Entero-coccus, membrane filter (CFU/100 mL)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Nitrate, total (mg/L as N)
Laundry Brook (01104640)—*Continued*									
9-27-99	1126	300	0.7	2.2	4,600	290	201	<2.5	1.20
10-26-99	1042	300	3.3	3.1	2,000	520	178	4	.90
11-19-99	1215	--	--	<2	50	40	232	e2.5	1.00
12-29-99	1045	71	2.5	2.4	760	140	322	<2.5	1.30
1-24-00	1320	570	1.9	<2	4,500	380	295	<4	1.50
2-24-00	1000	180	4.2	<2	5,500	1,300	503	3	1.50
3-24-00	1030	610	2.4	<2	830	220	332	e4	1.50
5-01-00	1110	500	2.6	<2	480	440	268	4	1.80
6-27-00	1000	460	2.2	2.7	1,000	570	227	<2.5	.70
7-25-00	0645	150	11.0	<2	150	290	180	<5	.80
7-25-00S	--	--	--	<2	210	240	190	<5	.80
Faneuil Brook (01104660)									
6-29-99	--	--	--	--	--	--	--	--	--
7-19-99	1340	740	--	22.0	230,000	49,000	497	109	2.90
7-30-99	0745	850	52.0	8.8	270,000	24,000	349	10	3.50
8-26-99	1115	180	100.0	6.4	78,000	2,500	466	35	2.10
9-27-99	1120	690	97.0	3.2	27,000	4,200	407	117	1.80
10-26-99	1100	1,100	1.6	<2	14,000	1,400	562	<2.5	3.00
11-19-99	1300	--	--	4.8	67,000	22,000	592	e2.5	3.10
12-29-99	1230	160	2.0	2.7	22,000	3,200	478	<2.5	2.20
12-29-99S	--	--	--	3.2	31,000	3,100	506	<2.5	2.40
1-24-00	1415	950	4.2	<2	13,000	3,000	492	<5	3.30
2-24-00	1330	500	37.0	3.6	5,400	1,700	783	11	1.90
3-24-00	0930	870	2.2	4.6	11,000	88,000	469	3	2.50
5-01-00	1045	--	--	<2	22,000	450	478	<2.5	2.40
6-27-00	1230	980	2.5	<2	64,000	1,900	532	<2.5	2.60
7-25-00	0800	360	15.0	2.5	39,000	6,400	530	<5	e2
Multifamily land use (01104673)									
6-29-99	--	--	--	--	--	--	--	--	--
7-19-99	--	--	--	--	--	--	--	--	--
7-30-99	0900	--	--	2.6	<10	<10	1,010	15	3.40
8-26-99	0930	220	5.8	<2	320	320	1,050	7	3.70
9-27-99	1040	1,100	1.6	<2	1,800	170	954	<2.5	3.50
10-26-99	1100	1,100	.8	<2	180	30	675	<2.5	2.40
10-26-99S	--	--	--	<2	57	21	635	<2.5	2.40
11-19-99	1225	--	--	2.4	3,500	130	656	e2.5	5.00
12-29-99	1135	200	1.7	3.3	350	40	742	<2.5	3.80
1-24-00	1200	920	1.7	4.8	5,800	3,500	1,010	<4	2.10

Date	Time	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, total Kjeldahl (mg/L as N)	Phos-phorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Lead, total (µg/L)	Zinc, total (µg/L)
Laundry Brook (01104640)—*Continued*									
9-27-99	1126	<0.075	0.60	0.10	<0.2	e2	9.0	2.8	11.0
10-26-99	1042	<.075	1.10	.10	<.2	<2	e5	2.4	11.0
11-19-99	1215	.10	.80	.10	<.2	<2	e6	3.2	9.9
12-29-99	1045	<.075	.60	.10	<.2	<2	e9	3.6	12.0
1-24-00	1320	.10	.60	.10	<.2	<2	e4	2.0	13.0
2-24-00	1000	.30	.90	.10	<.2	<5	e8	3.4	27.0
3-24-00	1030	.10	.60	.10	<.5	<2	6.2	2.5	18.0
5-01-00	1110	.10	.70	.10	<.2	<2	e5	1.7	40.0
6-27-00	1000	<.075	.70	.10	<.2	e1	e5	2.0	9.2
7-25-00	0645	<.075	.80	<.05	<.2	<2	5.3	2.3	7.3
7-25-00S	--	<.075	.60	.10	<.2	<2	5.4	2.3	7.2
Faneuil Brook (01104660)									
6-29-99	--	--	--	--	--	--	--	--	--
7-19-99	1340	2.20	6.40	0.90	0.3	3.0	25.0	38.0	100.0
7-30-99	0745	1.20	2.50	.20	<.5	e.7	4.6	3.8	15.0
8-26-99	1115	.80	1.60	.20	<.2	<2	4.2	4.3	11.0
9-27-99	1120	.50	1.20	.20	<.2	e6	e13	16.0	80.0
10-26-99	1100	.60	1.10	.10	<.2	<2	e4	.5	13.0
11-19-99	1300	.70	1.60	.10	<.5	<2	e4	.7	200.0
12-29-99	1230	.60	1.20	.10	<.2	<2	e4	.7	77.0
12-29-99S	--	.50	1.10	<.1	<.2	<2	3.2	.7	78.0
1-24-00	1415	.40	.90	.10	<.2	<2	e4	8.8	63.0
2-24-00	1330	.30	1.20	.10	<.2	<5	e10	5.9	50.0
3-24-00	930	.20	.80	<.1	<.5	<2	4.0	.8	29.0
5-01-00	1045	.20	1.00	.10	<.2	<2	e6	1.1	21.0
6-27-00	1230	.30	.90	.10	<.2	e1	e5	.6	9.7
7-25-00	0800	.50	1.60	.20	<.2	<2	4.8	1.0	9.9
Multifamily land use (01104673)									
6-29-99	--	--	--	--	--	--	--	--	--
7-19-99	--	--	--	--	--	--	--	--	--
7-30-99	0900	<.075	0.80	0.30	<0.5	7.6	25.0	180.0	180.0
8-26-99	0930	<.075	1.50	.20	.6	<2	19.0	21.0	160.0
9-27-99	1040	.10	.40	.30	.2	e.9	[1]9	10.0	350.0
10-26-99	1100	.20	.80	.30	<.2	<2	e7	1.9	24.0
10-26-99S	--	.20	.80	.30	<.2	<2	6.3	1.7	25.0
11-19-99	1225	.70	1.50	.70	<.2	<2	13.0	3.6	44.0
12-29-99	1135	.30	1.20	.40	<.2	<2	e10	3.3	27.0
1-24-00	1200	2.60	3.20	1.00	<.2	<2	16.0	8.6	45.0

Table 22. Dry-weather constituent concentrations and physical properties measured between July 1999 and July 2000, Lower

Date	Time	Specific conductance (µS/cm)	Turbidity (NTU)	Biochemical oxygen demand (mg/L)	Coliform, fecal, membrane filter (CFU/100 mL)	Entero-coccus, membrane filter (CFU/100 mL)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Nitrate, total (mg/L as N)
Multifamily land use (01104673)—*Continued*									
2-24-00	1220	350	35.0	5.6	22,000	10,000	1,380	18	1.80
3-24-00	1030	1,200	.5	<2	1,400	2,300	1,180	e2.5	3.10
5-01-00	1145	--	--	4.6	27,000	1,800	287	3	2.00
6-27-00	1045	960	2.9	17.0	19,000	1,200	564	<2.5	2.50
7-26-00	0742	25	7.6	7.8	21,000	1,300	930	9	5.20
Commercial land use (01104677)									
6-29-99	--	--	--	--	--	--	--	--	--
7-19-99	--	--	--	--	--	--	--	--	--
7-30-99	1045	--	--	45.0	--	--	490	21	0.30
8-26-99	1015	400	110.0	10.0	170	150	631	6	.20
9-27-99	1015	1,600	.7	<2	<10	<10	648	3	.30
10-26-99	0945	1,200	1.0	<2	10	10	616	52	.60
11-19-99	1145	--	--	<2	<10	30	699	e2.5	.40
12-29-99	1055	250	3.1	<2	1,100	1,000	671	3	2.60
1-24-00	1100	1,800	6.2	<2	<10	20	484	<4	1.50
2-24-00	1055	510	32.0	3.3	120	360	926	13	1.50
3-24-00	1120	2,100	1.3	<2	10	20	691	e2.5	2.30
5-01-00	1215	4,100	3.7	<2	<10	<10	632	<2.5	1.90
6-27-00	1000	1,100	2.6	2.9	54,000	780	950	<2.5	.40
7-25-00	0825	110	9.3	<2	250	90	560	19	.50
Muddy River (01104683)									
6-29-99	--	--	--	--	--	--	547	11	--
7-19-99	1450	360	--	2.2	<10	<10	196	5	0.30
7-30-99	--	--	--	--	--	--	--	--	--
8-26-99	0840	59	5.3	<2	<10	<10	176	5	.30
9-27-99	0957	350	5.1	<2	10	<10	224	8	.50
10-26-99	0930	400	5.3	<2	20	<10	218	7	.70
11-19-99	1025	--	--	<2	<10	20	204	5	.50
12-29-99	1230	75	2.6	<2	10	<10	324	3	1.10
1-24-00	1210	860	13.0	4.6	660	610	525	5	1.00
2-24-00	1100	220	10.0	<2	260	300	626	6	1.30
3-24-00	1325	590	3.4	<2	10	<10	307	3	1.50
3-24-00S	--	--	--	<2	--	--	302	3	1.50
5-01-00	1230	670	8.0	4.4	250	160	366	7	1.60
6-27-00	1100	700	5.8	2.9	4,200	1,100	350	11	.90
7-25-00	1000	120	23.0	4.6	1,200	160	200	11	.50

Date	Time	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, total Kjeldahl (mg/L as N)	Phos-phorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Lead, total (µg/L)	Zinc, total (µg/L)
Multifamily land use (01104673)—*Continued*									
2-24-00	1220	1.30	2.50	0.40	<0.2	<5	26.0	15.0	61.0
3-24-00	1030	1.70	2.70	.40	<.5	<2	14.0	2.1	49.0
5-01-00	1145	.30	.80	.20	<.2	2.2	18.0	14.0	65.0
6-27-00	1045	3.70	5.70	.60	<.2	e2	36.0	15.0	91.0
7-25-00	0742	.40	1.00	.60	<.2	2.0	19.0	41.0	60.0
Commercial land use (01104677)									
6-29-99	--	--	--	--	--	--	--	--	--
7-19-99	--	--	--	--	--	--	--	--	--
7-30-99	1045	0.60	1.60	0.70	<0.5	e1	40.0	23.0	110.0
8-26-99	1015	.30	1.60	2.70	<.2	<2	25.0	4.6	60.0
9-27-99	1015	.10	.20	.20	<.2	e.9	e11	3.0	42.0
10-26-99	1045	<.075	.30	.40	<.2	<2	17.0	34.0	38.0
11-19-99	1145	<.075	.30	.20	<.2	<2	e6	1.4	28.0
12-29-99	1055	.10	.60	.30	<.2	<2	e8	6.8	64.0
1-24-00	1100	<.075	.30	.20	<.2	<2	e3	.8	15.0
2-24-00	1055	.30	1.00	.20	<.2	<5	23.0	24.0	100.0
3-24-00	1120	<.075	.50	.10	<.5	<2	6.1	1.2	14.0
5-01-00	1215	.10	.50	.10	<.2	<2	e7	1.5	25.0
6-27-00	1000	.70	.70	.30	<.2	e1	61.0	20.0	120.0
7-25-00	0825	.20	.50	.20	<.2	<2	21.0	9.4	38.0
Muddy River (01104683)									
6-29-99	--	--	--	--	0.1	e0.96	4.7	2.6	10.0
7-19-99	1450	0.50	1.20	0.10	<.05	e.73	5.6	4.7	12.0
7-30-99	--	--	--	--	--	--	--	--	--
8-26-99	0840	.40	1.00	.10	<.2	<2	5.2	4.5	e10
9-27-99	0957	.60	1.10	.10	<.2	<2	e8	e4.3	29.0
10-26-99	0930	.50	1.10	.10	<.2	2.0	e7	6.3	15.0
11-19-99	1025	.60	1.10	.10	<.2	<2	e6	3.9	9.7
12-29-99	1230	.50	.90	<.1	<.2	<2	e6	3.3	14.0
1-24-00	1210	.60	1.30	.20	<.2	<2	e5	3.6	20.0
2-24-00	1100	.40	1.10	.10	<.2	<5	e9	4.8	30.0
3-24-00	1325	.30	1.40	<.1	<.5	<2	6.2	3.4	15.0
3-24-00S	--	.30	1.00	<.1	<.5	<2	4.9	2.9	15.0
5-01-00	1230	.30	1.10	.10	<.2	<2	e5	4.9	97.0
6-27-00	1100	.80	1.30	.20	<.2	e1	e7	5.6	18.0
7-25-00	1000	.40	9.00	.10	<.2	<2	6.8	4.4	9.1

Table 22. Dry-weather constituent concentrations and physical properties measured between July 1999 and July 2000, Lower

Date	Time	Specific conductance (µS/cm)	Turbidity (NTU)	Biochemical oxygen demand (mg/L)	Coliform, fecal, membrane filter (CFU/100 mL)	Entero-coccus, membrane filter (CFU/100 mL)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Nitrate, total (mg/L as N)
Stony Brook (01104687)									
6-29-99	--	--	--	--	--	--	--	--	--
7-19-99	--	--	--	--	--	--	--	--	--
7-30-99	0900	470	2.0	<2	310	90	230	<4	1.30
8-26-99	0815	100	3.5	<2	20	<10	172	<2.5	1.40
9-27-99	0855	600	3.1	<2	10	<10	351	<2.5	1.50
9-27-99S	--	--	--	<2	--	--	342	<2.5	1.50
10-26-99	0835	560	1.6	<2	<10	<10	295	<2.5	1.20
11-19-99	1000	--	--	<2	20	<10	224	e2.5	1.30
12-29-99	0945	110	1.9	<2	<10	<10	318	<2.5	1.40
1-24-00	1310	670	4.3	3.1	40	30	844	4	1.50
2-24-00	0930	220	6.8	<2	40	<10	633	3	1.30
2-24-00S	--	--	--	--	30	<10	--	--	--
3-24-00	1330	680	2.5	<2	50	60	367	e2.5	1.90
3-24-00S	--	--	--	--	50	20	--	--	--
5-01-00	1325	660	7.2	<2	20	<10	365	3	1.90
5-01-00S	--	--	--	<2	50	<10	374	3	1.90
6-27-00	1145	720	5.0	<2	40	<10	369	<2.5	2.00
7-25-00	0910	250	23.0	<2	<10	10	370	<5	1.90
Charles River at Boston Science Museum (01104710)									
6-29-99	1310	--	--	--	<10	<10	876	6	--
7-19-99	1300	--	--	5.5	10	<10	889	<5	0.10
7-30-99	--	--	--	--	--	--	--	--	--
8-26-99	0740	350	4.2	<2	20	<10	885	<2.5	.20
9-27-99	0850	490	3.1	<2	20	<10	875	5	.40
10-26-99	0811	500	3.0	<2	30	10	635	e4	.50
11-19-99	0950	--	--	2.3	80	10	266	e4	.50
12-29-99	1400	71	2.3	2.1	30	10	295	<4	.80
1-24-00	1130	470	3.3	2.7	<10	20	188	<4	.80
2-24-00	1135	120	6.0	<2	100	20	328	3	1.00
3-24-00	1230	450	2.9	<2	30	10	430	5	e.7
5-01-00	1310	290	4.2	<2	10	10	143	3	.50
5-01-00S	--	--	--	<2	10	10	134	3	.50
6-27-00	1130	460	5.2	<2	30	10	233	4	.50
7-25-00	0910	970	2.4	<2	60	10	520	<5	.50

Date	Time	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, total Kjeldahl (mg/L as N)	Phos-phorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Lead, total (µg/L)	Zinc, total (µg/L)
Stony Brook (01104687)									
6-29-99	--	--	--	--	--	--	--	--	--
7-19-99	--	--	--	--	--	--	--	--	--
7-30-99	0900	0.50	1.20	1.30	<0.5	e0.5	3.2	1.8	<10
8-26-99	0815	.40	1.20	<.1	<.2	<2	3.4	.9	e8
9-27-99	0855	.40	1.00	.10	<.2	e.9	e4	1.1	20.0
9-27-99S	--	.40	.80	.10	<.2	<.2	3.8	1.0	19.0
10-26-99	0835	.30	1.00	.10	<.2	<2	e4	1.0	20.0
11-19-99	1000	.40	.90	.10	<.2	<2	e4	1.0	11.0
12-29-99	0945	.40	1.00	<.1	<.2	<2	e3	9.5	23.0
1-24-00	1310	.50	1.30	.10	<.2	<2	e4	2.1	16.0
2-24-00	0930	.30	.90	.10	<.2	<5	7.0	e4.2	35.0
2-24-00S	--	--	--	--	--	--	--	--	--
3-24-00	1330	.30	.90	<.1	<.5	<2	4.7	1.3	23.0
3-24-00S	--	--	--	--	--	--	--	--	--
5-01-00	1325	.20	.80	.10	<.2	<2	e7	1.8	25.0
5-01-00S	--	.20	.80	--	<.2	<2	e4	1.8	24.0
6-27-00	1145	.40	.80	.10	<.2	e1	e7	1.7	36.0
7-25-00	0910	.50	1.10	.10	<.2	<2	5.2	1.1	17.0
Charles River at Boston Science Museum (01104710)									
6-29-99	1310	--	--	--	0.1	e1.4	5.9	2.8	10.0
7-19-99	1300	<0.075	0.80	<0.05	<.05	e.82	6.6	2.2	<10
7-30-99	--	--	--	--	--	--	--	--	--
8-26-99	0740	<.075	.60	<.1	<.2	<2	6.1	1.6	23.0
9-27-99	0850	.30	.70	.10	<.2	e2	e6	5.5	12.0
10-26-99	0811	.10	.70	.10	<.2	e3	e6	5.0	19.0
11-19-99	0950	.20	.80	.10	<.2	<2	e4	3.7	11.0
12-29-99	1400	.20	.70	<.01	<.2	<2	e5	2.6	22.0
1-24-00	1130	.20	.70	.10	<.2	e2	e8	1.8	16.0
2-24-00	1135	.20	.70	.20	<.2	<5	e4	2.4	20.0
3-24-00	1230	.40	.50	<.01	<.5	<2	5.3	2.8	19.0
5-01-00	1310	<.075	.80	<.05	<.2	<2	e6	3.9	12.0
5-01-00S	--	.10	.70	--	<.2	<2	e4	3.8	11.0
6-27-00	1130	.30	1.00	.10	<.2	e2	e7	8.9	21.0
7-25-00	0910	.20	.70	<.05	<.2	<2	6.9	6.4	31.0

Table 23. Event mean concentrations of stormwater constituents and water-quality properties measured between January 2000

[**Date:** Is in month, day, and year. **Time:** All times are eastern standard and are in hours and minutes. CFU/100 mL, colony-forming units per 100 milliliters; S, split samples; e, estimated; <, less than value shown; --, not measured]

Start date and time		End date and time		Specific conductance (µS/cm)	Turbidity (NTU)	Biochemical oxygen demand, 5-day (mg/L)	Coliform, fecal, membrane filter (CFU/100 mL)	Enterococcus, membrane filter (CFU/100 mL)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Nitrate, total (mg/L as N)
Charles River at Watertown (01104615)											
1-10-00	1430	1-11-00	1845	--	--	2.1	650	1,700	214	7	0.70
4-09-00	0015	4-10-00	0000	--	--	--	220	180	156	10	.50
5-18-00	1600	5-20-00	0000	280	6.2	<2	510	810	175	10	.50
6-02-00	1630	6-03-00	0730	280	7.4	3.4	3,900	2,600	e180	12	.60
6-06-00	0800	6-07-00	1900	240	7.4	--	1,900	1,600	137	14	.50
7-09-00	1915	7-10-00	2330	340	5.0	--	4,500	2,700	220	<10	.50
7-16-00	0000	7-16-00	1800	330	3.7	<2	5,200	3,800	190	6	.40
7-27-00	0545	7-28-00	0000	270	9.6	<2	4,700	8,300	160	16	.20
7-27-00S	--	--	--	--	--	3.0	--	--	140	18	.20
9-15-00	0730	9-16-00	0000	270	14.0	--	17,000	--	130	20	.30
Single-family land use (01104630)											
1-10-00	1515	1-10-00	2200	130	57.0	4.0	16,000	5,500	118	91	0.60
4-09-00	0015	4-09-00	0930	120	76.0	--	2,800	9,400	43	103	.30
5-18-00	1845	5-18-00	1645	94	50.0	13.0	28,000	87,000	65	55	.60
6-02-00	1745	6-02-00	2100	150	100.0	24.0	14,000	39,000	e130	269	1.30
6-02-00S	--	--	--	--	--	20.0	--	--	e120	240	1.40
6-06-00	0800	6-07-00	1030	49	17.0	--	34,000	30,000	20	61	.20
7-09-00	1915	7-09-00	2345	130	44.0	20.0	94,000	38,000	120	82	2.00
7-16-00	0000	7-16-00	0615	130	28.0	15.0	21,000	7,600	32	27	1.20
7-27-00	0400	7-27-00	1515	44	22.0	3.1	32,000	54,000	38	48	.30
9-15-00	0630	9-15-00	1445	--	--	--	--	--	--	--	--
Laundry Brook (01104640)											
1-10-00	1445	1-11-00	1215	240	12.0	5.2	3,500	1,700	172	16	1.00
4-09-00	0015	4-09-00	2115	--	--	--	1,200	3,600	124	51	.60
5-18-00	1600	5-19-00	2330	240	16.0	7.2	9,100	13,000	154	20	.70
6-02-00	1730	6-03-00	1145	250	86.0	20.0	36,000	10,000	e170	142	1.10
6-06-00	0815	6-08-00	0000	160	12.0	--	25,000	29,000	89	23	.30
7-09-00	1915	7-10-00	2000	310	27.0	12.0	9,400	4,600	200	62	1.00
7-16-00	0000	7-16-00	2045	240	18.0	9.3	44,000	29,000	110	33	.60
7-27-00	0445	7-27-00	2115	150	11.0	3.4	34,000	46,000	83	18	.30
9-15-00	0615	9-15-00	1700	250	23.0	--	32,000	--	120	36	.40
Faneuil Brook (01104660)											
1-10-00	1500	1-10-00	0245	120	12.0	8.4	27,000	13,000	152	49	1.10
4-09-00	0015	4-09-00	0915	320	32.0	--	24,000	4,400	155	34	.70
5-18-00	1900	5-19-00	0818	340	44.0	8.6	43,000	63,000	212	45	1.10
6-02-00	1730	6-02-00	2115	230	160.0	20.0	41,000	34,000	--	318	e.8
6-06-00	0815	6-07-00	1115	190	24.0	--	21,000	19,000	102	43	.30

µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units;

Start date and time		End date and time		Nitrogen, ammonia, total (mg/L as N)	Nitrogen, total Kjeldahl (mg/L as N)	Phos-phorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Lead, total (µg/L)	Zinc, total (µg/L)
Charles River (01104615)											
1-10-00	1430	1-11-00	1845	0.10	0.80	0.10	<0.2	2.0	4.1	4.8	16.0
4-09-00	0015	4-10-00	0000	<.075	.80	.10	<.5	e2	5.0	e5.2	17.0
5-18-00	1600	5-20-00	0000	.10	.80	.20	<.2	e2	e5	5.2	15.0
6-02-00	1630	6-03-00	0730	.20	1.00	.10	.2	e2	e9	8.4	30.0
6-06-00	0800	6-07-00	1900	.10	.70	.10	<.2	2.2	5.7	8.3	25.0
7-09-00	1915	7-10-00	2330	.20	1.10	.10	<.2	e2	e10	6.4	20.0
7-16-00	0000	7-16-00	1800	.20	.90	.10	<.2	e2	4.8	4.4	14.0
7-27-00	0545	7-28-00	0000	.30	.80	.10	<.2	2.5	7.9	10.0	18.0
7-27-00S	--	--	--	.30	.90	.10	.2	2.4	7.5	9.8	32.0
9-15-00	0730	9-16-00	0000	.20	1.60	.20	<.2	e3	8.0	12.9	92.0
Single-family land use (01104630)											
1-10-00	1515	1-10-00	2200	0.34	1.40	0.20	0.2	e9	31.2	57.9	79.0
4-09-00	0015	4-09-00	0930	<.075	1.30	.20	<.5	9.6	31.3	54.5	86.0
5-18-00	1845	5-18-00	1645	.20	2.60	.50	<.2	e7	35.5	32.0	90.0
6-02-00	1745	6-02-00	2100	1.20	5.20	e.91	.5	17.0	72.8	135.0	230.0
6-02-00S	--	--	--	1.20	5.60	e.96	.5	16.0	72.0	129.0	230.0
6-06-00	0800	6-07-00	1030	.10	.90	.30	<.2	4.3	13.7	22.4	45.0
7-09-00	1915	7-09-00	2345	1.30	3.80	.50	.3	8.2	63.6	53.3	160.0
7-16-00	0000	7-16-00	0615	.70	2.40	.40	<.5	5.0	35.3	23.2	92.0
7-27-00	0400	7-27-00	1515	.20	.90	.10	.2	5.4	19.4	35.3	64.0
9-15-00	0630	9-15-00	1445	--	--	--	--	--	--	--	--
Laundry Brook (01104640)											
1-10-00	1445	1-11-00	1215	0.10	0.90	0.10	<0.2	e3	e16	16.0	40.0
4-09-00	0015	4-09-00	2115	<.075	1.20	.20	<.5	e5	20.0	39.0	120.0
5-18-00	1600	5-19-00	2330	.10	1.40	.20	<.2	e3	26.0	18.0	63.0
6-02-00	1730	6-03-00	1145	.80	3.40	.60	.9	15.0	82.0	110.0	270.0
6-06-00	0815	6-08-00	0000	.10	.80	.10	<.2	2.9	13.0	17.0	38.0
7-09-00	1915	7-10-00	2000	.50	2.60	.30	.3	e5	36.0	39.0	120.0
7-16-00	0000	7-16-00	2045	.50	1.80	.20	<.5	3.0	20.0	24.0	100.0
7-27-00	0445	7-27-00	2115	.10	1.40	.10	<.2	3.0	10.0	12.0	24.0
9-15-00	0615	9-15-00	1700	.20	3.40	.30	<.2	e3	15.0	18.0	43.0
Faneuil Brook (01104660)											
1-10-00	1500	1-10-00	0245	0.10	1.10	0.10	0.2	e4	e15	34.0	85.0
4-09-00	0015	4-09-00	0915	<.075	.90	.10	<.5	e4	15.0	23.0	69.0
5-18-00	1900	5-19-00	0818	<.075	1.70	.30	<.2	e4	28.0	21.0	70.0
6-02-00	1730	6-02-00	2115	.80	3.40	e.17	.8	16.0	73.0	140.0	230.0
6-06-00	0815	6-07-00	1115	<.075	.80	.10	<.2	3.6	13.0	20.0	50.0

Table 23. Event mean concentrations of stormwater constituents and water-quality properties measured between January 2000

Start date and time		End date and time		Specific conductance (µS/cm)	Turbidity (NTU)	Biochemical oxygen demand, 5-day (mg/L)	Coliform, fecal, membrane filter (CFU/100 mL)	Enterococcus, membrane filter (CFU/100 mL)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Nitrate, total (mg/L as N)
Faneuil Brook (01104660)—*Continued*											
7-09-00	1930	7-10-00	0230	530	50.0	16.0	26,000	30,000	340	94	2.20
7-16-00	0000	7-16-00	0445	500	76.0	13.0	86,000	50,000	160	100	1.80
7-27-00	0345	7-27-00	1500	360	15.0	2.8	41,000	56,000	210	29	.70
9-15-00	0615	9-15-00	1500	340	65.0	--	300,000	--	170	160	1.00
Multifamily land use (01104673)											
1-10-00	1445	1-10-00	2200	62	9.0	2.9	5,500	22,000	99	26	0.40
4-09-00	0145	4-09-00	0815	110	24.0	--	2,200	3,200	32	15	<.023
5-18-00	1845	5-18-00	2030	170	28.0	14.0	20,000	32,000	121	36	.70
6-02-00	1730	6-03-00	0245	89	18.0	8.3	26,000	9,300	e120	21	.80
6-06-00	0800	6-07-00	1430	110	17.0	--	4,500	14,000	212	46	1.20
7-09-00	1845	7-10-00	0200	160	26.0	9.6	17,000	13,000	180	41	1.70
7-16-00	0000	7-16-00	0745	130	23.0	15.0	31,000	34,000	480	72	.50
7-27-00	0215	7-27-00	1830	25	7.6	5.0	25,000	49,000	79	17	.40
9-15-00	0615	9-15-00	1800	--	--	--	--	--	--	--	--
Commercial land use (01104677)											
1-10-00	1445	1-10-00	2200	220	16.0	3.0	2,200	9,400	38	23	0.50
4-09-00	0145	4-09-00	0815	--	--	--	680	2,100	34	34	.40
5-18-00	1845	5-19-00	2145	200	29.0	18.0	10,000	15,000	116	54	.80
6-02-00	1730	6-03-00	0245	200	18.0	7.1	12,000	8,600	e60	22	.90
6-06-00	0730	6-07-00	1430	200	7.5	--	6,500	8,300	42	18	.20
7-09-00	1915	7-10-00	0100	300	20.0	15.0	3,300	7,200	130	62	1.40
7-16-00	0000	7-16-00	0945	920	29.0	15.0	28,000	24,000	43	78	.80
7-16-00S	--	--	--	--	--	--	--	--	<10	58	.80
7-27-00	0215	7-27-00	1800	110	9.3	<2	17,000	35,000	26	110	.10
9-15-00	0630	9-15-00	1430	--	--	--	--	--	--	--	--
Muddy River (01104683)											
1-10-00	1445	1-11-00	1500	--	--	4.5	3,100	4,000	150	27	0.90
4-09-00	0015	4-09-00	2330	--	--	--	3,100	3,500	113	43	.50
5-18-00	1745	5-19-00	2330	330	23.0	6.3	19,000	7,600	212	25	.90
6-02-00	1530	6-03-00	0830	370	34.0	13.0	28,000	11,000	e229	49	1.10
6-06-00	0945	6-07-00	1445	150	27.0	--	26,000	21,000	86	50	.50
7-09-00	1915	7-10-00	0900	250	16.0	8.9	7,700	1,300	160	24	1.00
7-09-00S	--	--	--	--	--	8.1	--	--	160	24	1.20
7-16-00	0000	7-16-00	1645	160	24.0	8.9	38,000	19,000	10	36	.50
7-27-00	0245	7-28-00	0000	120	23.0	<2	25,000	20,000	70	32	.30
9-15-00	0815	9-15-00	2115	180	39.0	--	7,200	--	75	65	.60

Start date and time		End date and time		Nitrogen, ammonia, total (mg/L as N)	Nitrogen, total Kjeldahl (mg/L as N)	Phos-phorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Lead, total (µg/L)	Zinc, total (µg/L)
Faneuil Brook (01104660)—*Continued*											
7-09-00	1930	7-10-00	0230	0.60	2.60	0.30	0.2	e6	39.0	37.0	100.0
7-16-00	0000	7-16-00	0445	.40	2.00	.40	<.5	5.0	28.0	35.0	79.0
7-27-00	0345	7-27-00	1500	.20	.90	.10	<.2	3.3	12.0	16.0	30.0
9-15-00	0615	9-15-00	1500	.30	2.00	.50	.3	e8	28.0	70.0	100.0
Multifamily land use (01104673)											
1-10-00	1445	1-10-00	2200	0.20	0.90	0.10	0.4	e4	41.0	46.0	110.0
4-09-00	0145	4-09-00	0815	<.075	.70	.10	<.5	4.0	34.0	28.0	110.0
5-18-00	1845	5-18-00	2030	<.075	2.20	.30	.4	e7	84.0	75.0	200.0
6-02-00	1730	6-03-00	0245	.70	1.70	.40	.4	e7	85.0	73.0	190.0
6-06-00	0800	6-07-00	1430	.20	1.30	.20	.5	7.0	46.0	61.0	140.0
7-09-00	1845	7-10-00	0200	.60	2.40	.30	.4	e6	120.0	130.0	240.0
7-16-00	0000	7-16-00	0745	.60	1.30	.40	<.5	6.0	58.0	96.0	140.0
7-27-00	0215	7-27-00	1830	.20	1.30	.10	<.2	4.0	39.0	32.0	73.0
9-15-00	0615	9-15-00	1800	--	--	--	--	--	--	--	--
Commercial land use (01104677)											
1-10-00	1445	1-10-00	2200	0.30	0.90	0.20	0.3	e3	50.0	120.0	150.0
4-09-00	0145	4-09-00	0815	.20	.90	.10	<.5	e5	75.0	110.0	150.0
5-18-00	1845	5-19-00	2145	.10	2.60	.30	.4	e7	130.0	110.0	210.0
6-02-00	1730	6-03-00	0245	.70	2.00	.30	.3	e4	150.0	130.0	190.0
6-06-00	0730	6-07-00	1430	.10	.50	.10	.2	2.8	32.0	57.0	74.0
7-09-00	1915	7-10-00	0100	.50	2.80	.30	1.0	7.5	250.0	200.0	310.0
7-16-00	0000	7-16-00	0945	.40	2.50	.30	<.5	7.1	81.0	110.0	190.0
7-16-00S	--	--	--	.30	2.70	.30	<.5	7.7	83.0	110.0	190.0
7-27-00	0215	7-27-00	1800	.10	.80	.10	.4	5.3	49.0	260.0	150.0
9-15-00	0630	9-15-00	1430	--	--	--	--	--	--	--	--
Muddy River (01104683)											
1-10-00	1445	1-11-00	1500	0.40	1.10	0.20	0.2	3.3	21.0	25.0	77.0
4-09-00	0015	4-09-00	2330	.10	1.60	.20	<.5	4.0	28.0	34.0	92.0
5-18-00	1745	5-19-00	2330	.30	1.80	.20	e.2	12.0	33.0	18.0	100.0
6-02-00	1530	6-03-00	0830	.60	2.40	.40	.3	e6	52.0	42.0	120.0
6-06-00	0945	6-07-00	1445	.10	.90	.10	.2	4.2	22.0	27.0	66.0
7-09-00	1915	7-10-00	0900	.50	1.90	.20	<.2	e3	52.0	26.0	78.0
7-09-00S	--	--	--	.50	1.90	.20	<.2	e3	50.0	25.0	76.0
7-16-00	0000	7-16-00	1645	.40	1.60	.20	<.5	3.0	32.0	25.0	60.0
7-27-00	0245	7-28-00	0000	.20	.90	.10	.5	4.4	22.0	24.0	52.0
9-15-00	0815	9-15-00	2115	.40	1.60	.30	<.2	5.0	34.0	45.0	80.0

Table 23. Event mean concentrations of stormwater constituents and water-quality properties measured between January 2000

Start date and time		End date and time		Specific conductance (µS/cm)	Turbidity (NTU)	Biochemical oxygen demand, 5-day (mg/L)	Coliform, fecal, membrane filter (CFU/100 mL)	Enterococcus, membrane filter (CFU/100 mL)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Nitrate, total (mg/L as N)
Stony Brook (01104687)											
1-10-00	1445	1-10-00	1145	--	--	5.7	24,000	11,000	150	39	1.50
4-09-00	0015	4-09-00	2045	--	--	--	15,000	6,600	144	104	.60
5-18-00	1600	5-19-00	2330	430	17.0	5.7	15,000	5,700	261	23	1.30
5-18-00S	--	--	--	--	--	4.3	--	--	265	22	1.40
6-02-00	1530	6-03-00	0730	220	220.0	25.0	60,000	23,000	130	260	1.10
6-06-00	0800	6-07-00	1715	130	18.0	--	24,000	23,000	91	36	.50
7-09-00	2000	7-10-00	0930	450	84.0	28.0	210,000	30,000	280	180	1.60
7-16-00	0000	7-16-00	1200	260	55.0	16.0	180,000	29,000	98	120	.90
7-27-00	0345	7-27-00	2330	250	23.0	10.0	29,000	24,000	140	110	.80
9-15-00	0815	9-16-00	0000	200	39.0	--	31,000	--	100	89	.90

and September 2000, Lower Charles River Watershed, Massachusetts —*Continued*

Start date and time		End date and time		Nitrogen, ammonia, total (mg/L as N)	Nitrogen, total Kjeldahl (mg/L as N)	Phos-phorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Lead, total (µg/L)	Zinc, total (µg/L)
Stony Brook (01104687)											
1-10-00	1445	1-10-00	1145	0.30	1.20	0.20	0.2	3.5	15.0	34.0	67.0
4-09-00	0015	4-09-00	2045	.10	1.20	.40	<.5	e7	28.0	86.0	140.0
5-18-00	1600	5-19-00	2330	.20	1.50	.20	<.2	e2	e16	19.0	57.0
5-18-00S	--	--	--	.30	1.40	.20	<.20	e2	e15	20.0	58.0
6-02-00	1530	6-03-00	0730	.70	4.40	e.83	1.2	20.0	75.0	260.0	290.0
6-06-00	0800	6-07-00	1715	.10	.80	.20	.2	3.5	11.0	28.0	49.0
7-09-00	2000	7-10-00	0930	.80	4.60	.70	.9	10.0	73.0	160.0	220.0
7-16-00	0000	7-16-00	1200	.50	2.90	.50	<.5	6.0	38.0	84.0	120.0
7-27-00	0345	7-27-00	2330	.20	1.70	.40	.4	7.2	36.0	120.0	120.0
9-15-00	0815	9-16-00	0000	.30	2.10	.40	e.33	6.0	34.0	79.0	180.0

Table 24. Bacterial densities in discrete stormwater samples collected between January 2000 and September 2000, Lower Charles River Watershed, Massachusetts

[**Date** Is in month, day, and year. **Time:** All times are eastern standard time and are in hours and minutes. R, concurrent replicates; S, split; CFU/100mL, colony-forming units per 100 milliliters; <, actual value is less than value shown; --, not sampled]

Date	Time	Coliform, fecal, membrane filter (CFU/100 mL)	Entero-coccus, membrane filter (CFU/100 mL)
Charles River (01104615)			
12-15-99	1010	1,100	2,000
12-18-99	1400	300	100
12-18-99R	1400	250	90
1-10-00	1945	1,700	7,800
1-10-00	2330	690	1,000
1-11-00	0647	280	410
4-09-00	0100	110	70
4-09-00	0300	300	270
4-09-00	1300	180	210
5-18-00	2100	690	560
5-19-00	0740	620	430
5-19-00	1225	420	920
5-19-00	1645	440	2,400
6-02-00	1750	130	160
6-02-00	2010	8,100	5,400
6-06-00	1330–1445	630	590
6-07-00	1155	3,500	2,900
7-09-00	1955	420	100
7-09-00	2340	10,000	8,900
7-10-00	0255	6,700	3,200
7-16-00	0100	560	360
7-16-00	0430	5,100	2,800
7-16-00	0630	11,000	8,300
7-27-00	0900	8,600	14,000
7-27-00	1205	15,000	16,000
7-27-00	1345	1,700	9,000
9-15-00	0930	19,000	--
9-15-00	1305	28,000	--
Single-family land use (01104630)			
1-10-00	1600	34,000	10,000
1-10-00	1900	2,500	2,000
4-09-00	0900	2,800	7,200
4-09-00	1030	1,600	3,600
4-09-00	0016– 228	2,900	11,000
Single-family land use (01104630)—*Continued*			
4-09-00	1200	30	280
4-09-00	1333	<10	<10
5-18-00	1740	6,000	11,000
5-19-00	0950	40,000	31,000
5-19-00	1345	39,000	180,000
5-19-00	1521	13,000	120,000
6-02-00	1738	2,000	13,000
6-02-00	1822	17,000	40,000
6-02-00	1920	16,000	49,000
6-02-00R	1921	19,000	33,000
6-06-00	1238–1326	48,000	42,000
6-07-00	1109	160	480
7-09-00	1946	210,000	37,000
7-09-00	2030	47,000	39,000
7-10-00	0200	19,000	43,000
7-16-00	0500	90,000	33,000
7-27-00	0512	35,000	60,000
7-27-00	1020	33,000	53,000
7-27-00	1400	8,000	26,000
Laundry Brook (01104640)			
12-06-99	1910	9,000	8,300
12-06-99	2100	20,000	4,500
12-07-99	1025	18,000	21,000
12-07-99	1210	26,000	22,000
12-07-99	1420	28,000	25,000
12-10-99	1935	2,700	2,600
12-10-99R	1936	2,900	3,000
12-10-99	2035	3,700	2,400
12-10-99	2135	16,000	460,000
12-15-99	1020	3,100	5,400
1-10-00	1900	6,000	1,800
1-10-00	2030	1,700	2,400
4-08-00	2328– 248	620	5,400
4-09-00	0638	1,700	6,400
4-09-00	0722	700	3,100

Table 24. Bacterial densities of discrete stormwater samples collected between January 2000 and September 2000, Lower Charles River Watershed, Massachusetts—*Continued*

Date	Time	Coliform, fecal, membrane filter (CFU/100 mL)	Entero-coccus, membrane filter (CFU/100 mL)
Laundry Brook (01104640)—*Continued*			
4-09-00	0849	740	2,200
4-09-00	1249	2,200	1,500
5-18-00	1908	8,200	2,800
5-19-00	0756	21,000	20,000
5-19-00	1230	8,100	20,000
5-19-00	1504	5,700	16,000
6-02-00	1726	2,800	2,300
6-02-00	1818	110,000	18,000
6-02-00	2032	9,100	9,800
6-06-00	1300–1432	26,000	29,000
6-07-00	1138	28,000	33,000
7-09-00	1922	23,000	9,700
7-09-00	2332	4,000	2,900
7-10-00	0230	1,600	1,300
7-16-00	0022	7,000	18,000
7-16-00	0200	100,000	64,000
7-16-00	0524	2,600	1,600
7-27-00	0552	20,000	53,000
7-27-00	1032	48,000	65,000
7-27-00	1340	47,000	24,000
9-15-00	0810	38,000	--
9-15-00	1045	35,000	--
Faneuil Brook (01104660)			
12-10-99	1906	8,500	710
12-10-99R	1907	6,800	660
12-10-99	2006	82,000	3,600
12-10-99	2106	11,000	2,600
12-15-99	1035	22,000	6,600
1-10-00	1600	37,000	17,000
1-10-00	2130	11,000	7,600
4-09-00	0448	33,000	3,300
4-09-00	1035	2,900	7,400
4-09-00	1135	3,500	2,800
4-09-00	1235	12,000	2,900
4-09-00	1335	5,700	1,000
5-18-00	1854	27,000	6,200
5-18-00	2056	6,000	7,100
5-19-00	0740	76,000	100,000

Date	Time	Coliform, fecal, membrane filter (CFU/100 mL)	Entero-coccus, membrane filter (CFU/100 mL)
Faneuil Brook (01104660)—*Continued*			
5-19-00	1404	16,000	41,000
5-19-00	1624	11,000	33,000
6-02-00	1730	90,000	61,000
6-02-00	1846	17,000	24,000
6-02-00	2030	9,400	9,000
6-06-00	1248–1530	20,000	24,000
6-06-00 S	1248–1530	15,000	27,000
6-07-00	0754	24,000	5,400
7-09-00	1922	46,000	59,000
7-09-00	2206	4,600	3,800
7-10-00	0138	23,000	9,500
7-16-00	0004	73,000	86,000
7-16-00	0136	100,000	50,000
7-16-00	0430	18,000	4,400
7-27-00	0530	28,000	45,000
7-27-00R	0531	24,000	53,000
7-27-00	0940	62,000	91,000
7-27-00	1213	22,000	11,000
9-15-00	0854	100,000	--
9-15-00	1116	2,000,000	--
Multifamily land use (01104673)			
1-10-00	1600	8,800	32,000
1-10-00	2000	1,300	11,000
4-09-00	0800	1,900	4,200
4-09-00	0900	2,500	6,300
4-09-00	1000	920	4,100
5-18-00	1740	4,100	4,800
5-19-00	0736	26,000	29,000
5-19-00	1358	26,000	53,000
5-19-00	1733	8,700	19,000
6-02-00	1816	53,000	13,000
6-02-00	1850	15,000	12,000
6-02-00	1936	17,000	12,000
6-06-00	1258–1424	6,000	20,000
6-07-00	0536	1,500	2,400
7-09-00	1906	25,000	5,700

Table 24. Bacterial densities of discrete stormwater samples collected between January 2000 and September 2000, Lower Charles River Watershed, Massachusetts—*Continued*

Date	Time	Coliform, fecal, membrane filter (CFU/100 mL)	Entero-coccus, membrane filter (CFU/100 mL)
Multifamily land use (01104673)—*Continued*			
7-09-00	2014	19,000	15,000
7-09-00	2245	530	11,000
7-16-00	0054	34,000	42,000
7-16-00	0250	29,000	26,000
7-27-00	0504	37,000	56,000
7-27-00	0930	16,000	38,000
7-27-00	1048	25,000	74,000
Commercial land use (01104677)			
1-10-00	1700	1,100	9,500
1-10-00	2100	6,600	13,000
4-09-00	0100	20	2,000
4-09-00	0300	550	2,900
4-09-00	0500	1,400	3,400
5-18-00	1815	5,800	3,900
5-19-00	0814	19,000	17,000
5-19-00	1416	7,900	23,000
5-19-00	1815	3,600	9,000
6-02-00	1804	11,000	4,000
6-02-00	1843	13,000	10,000
6-02-00	1943	18,000	17,000
6-06-00	1224–1336	6,900	8,000
6-07-00	1308	6,200	11,000
7-09-00	1910	1,400	8,500
7-09-00	2014	4,600	8,100
7-10-00	2300	140	3,300
7-16-00	0056	37,000	30,000
7-16-00	0212	28,000	26,000
7-27-00	0730	19,000	27,000
7-27-00	0948	21,000	61,000
7-27-00	1130	20,000	74,000
Muddy River (01104683)			
12-10-99	1720	<10.0	<10.0
12-15-99	1108	30	<10.0
12-15-99R	1110	<10.0	20
4-09-00	1301	2,100	1,100
4-09-00R	1301	2,000	1,000

Date	Time	Coliform, fecal, membrane filter (CFU/100 mL)	Entero-coccus, membrane filter (CFU/100 mL)
Muddy River (01104683)—*Continued*			
1-10-00	1745	2,300	2,100
1-10-00	2300	4,400	6,500
1-11-00	0835	<10.0	<10.0
4-09-00	0200	2,400	540
4-09-00	0400	5,900	6,500
4-09-00	0800	2,400	4,400
4-09-00	1000	2,200	3,200
4-09-00	1201	4,700	1,900
5-19-00	0908	17,000	9,300
5-19-00	1443	31,000	11,000
6-02-00	1828	13,000	25,000
6-02-00	1938	45,000	17,000
6-02-00	2028	33,000	7,600
6-06-00	1328–1518	32,000	28,000
6-07-00	0954	20,000	13,000
7-09-00	2146	670	930
7-09-00	2343	19,000	2,200
7-10-00	0128	8,000	1,200
7-16-00	0210	62,000	29,000
7-16-00	0338	64,000	40,000
7-16-00	0508	16,000	3,600
7-27-00	0553	3,900	1,700
7-27-00	1118	52,000	44,000
7-27-00	1333	8,800	4,300
9-15-00	0903	19,000	--
9-15-00	1225	1,400	--
Stony Brook (01104687)			
12-10-99	2115	20	360
12-18-99	1142	2,800	2,600
1-10-00	1815	33,000	15,000
1-11-00	0915	120	30
4-09-00	0203	6,800	1,000
4-09-00	0242	12,000	7,200
4-09-00	0312	19,000	2,000
4-09-00	0352	900	7,000
4-09-00	0422	14,000	16,000
4-09-00	0447	28,000	9,500

Table 24. Bacterial densities of discrete stormwater samples collected between January 2000 and September 2000, Lower Charles River Watershed, Massachusetts—*Continued*

Date	Time	Coliform, fecal, membrane filter (CFU/100 mL)	Entero-coccus, membrane filter (CFU/100 mL)
Stony Brook (01104687)—*Continued*			
4-09-00	1400	3,200	3,400
5-19-00	0832	16,000	6,300
5-19-00	1353	29,000	4,500
5-19-00	1607	34,000	17,000
6-02-00	1903	31,000	30,000
6-02-00	1942	43,000	14,000
6-02-00	2032	120,000	34,000
6-06-00	1523	22,000	18,000
6-07-00	1018	30,000	35,000
6-07-00R	1018	29,000	19,000
7-09-00	2013	62,000	19,000
7-09-00	2347	430,000	59,000
7-10-00	0400	33,000	1,700
7-16-00	0058	49,000	15,000
7-16-00	0243	260,000	43,000

Date	Time	Coliform, fecal, membrane filter (CFU/100 mL)	Entero-coccus, membrane filter (CFU/100 mL)
Stony Brook (01104687)—*Continued*			
7-16-00	0452	240,000	32,000
7-27-00	0537	29,000	3,900
7-27-00	0952	39,000	38,000
7-27-00	1322	21,000	20,000
9-15-00	0900	18,000	--
9-15-00	1027	49,000	--
Charles River at Boston Science Museum (01104710)			
12-18-99	1347	200	<10.0
1-10-00	2030	180	630
1-10-00R	2032	130	720
1-11-00	1115	80	70
5-19-00	1800	20	20
5-19-00R	1801	20	20
7-16-00	0445	<10	110
7-27-00	1245	120	170
7-27-00	1813	90	20

Table 25. Statistical summary for constituents and water-quality properties of dry-weather and stormwater flow-composite

[Statistics were calculated on unrounded values. Bold, statistics determined by setting censored data equal to one-half the detection limit. e, estimated; mg/L, milligrams per liter; NTU, nephelometric turbidity units; <, less than minimum reporting level; --, not determined]

Constituent or property	Dry weather									
	Number of samples		Mean	Standard deviation	Coeffi-cient of variation	Lower quartile	Median	Upper quartile	Inter-quartile range	Flow-weighted mean
	Total	Less than detec-tion								
Charles River at Watertown (01104615)										
Specific conductance, laboratory (µS/cm)	13	0	270	120	45	250	280	370	0.424	**220**
Turbidity, laboratory (NTU)	13	0	3.8	2.5	65	2.0	3.0	4.0	.667	**4.1**
Biochemical oxygen demand, 5-day (mg/L)	13	10	2.1	1.0	47	1.3	1.9	2.8	.769	**1.1**
Coliform, fecal, membrane filter (CFU/100 mL)	13	0	560	1300	240	60	230	330	1.174	**490**
Enterococcus, membrane filter (CFU/100 mL)	13	1	290	820	290	20	60	95	1.250	**270**
Dissolved solids (mg/L)	14	0	222	82	37.1	186	208	251	.311	**185**
Suspended solids (mg/L)	14	3	4.20	1.73	41.3	2.80	3.75	6.00	.853	**4.3**
Nitrate plus nitrite (mg/L as N)	13	0	.50	.30	64	.20	.50	.60	.870	**.6**
Nitrogen, ammonia, total (mg/L as N)	13	3	.10	.10	40	.10	.10	.20	.738	**.1**
Nitrogen, total Kjeldahl (mg/L as N)	13	0	.80	.10	16	.70	.80	.80	.133	**.70**
Phosphorus, total (mg/L)	13	3	.10	.02	32	.10	.10	.10	.643	**.10**
Cadmium, total (µg/L)	14	14	<	<	--	<	<	<	--	**.10**
Chromium, total (µg/L)	14	2	2.0	1.3	64	1.0	2.0	2.3	.650	**2.3**
Copper, total (µg/L)	14	0	3.1	.8	26	2.7	3.0	3.5	.242	**3.1**
Lead, total (µg/L)	14	0	2.9	1.3	43	2.2	3.0	3.7	.500	**3.0**
Zinc, total (µg/L)	14	1	18	24	140	9.5	11	15	.534	**33**
Single-family land use (01104630)										
Specific conductance, laboratory (µS/cm)	11	0	480	270	57	360	520	650	0.571	**450**
Turbidity, laboratory (NTU)	11	0	7.8	7.7	99	2.7	3.7	9.8	1.910	**6.2**
Biochemical oxygen demand, 5-day (mg/L)	12	9	1.9	4.4	230	.02	.1	1.6	12.954	**1.50**
Coliform, fecal, membrane filter (CFU/100 mL)	**13**	**6**	**16,000**	**35,000**	**220**	**5.0**	**440**	**8,900**	**20.506**	**3,300**
Enterococcus, membrane filter (CFU/100 mL)	**13**	**6**	**6,200**	**17,000**	**270**	**5.0**	**460**	**2,600**	**5.758**	**430**

samples measured between July 1999 and September 2000, Lower Charles River Watershed, Massachusetts

CFU/100 mL, colony-forming units per 100 milliliters; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;

Constituent or property	Stormwater									
	Number of samples									
	Total	Less than detection	Mean	Standard deviation	Coefficient of variation	Lower quartile	Median	Upper quartile	Inter-quartile range	Flow-weighted mean
Charles River (01104615)										
Specific conductance, laboratory (µS/cm)	7	0	290	35	12	270	280	310	0.128	**190**
Turbidity, laboratory (NTU)	7	0	7.6	3.4	45	5.6	7.4	8.5	.395	**5.3**
Biochemical oxygen demand, 5-day (mg/L)	**5**	**3**	**2.1**	**1.1**	**53**	**1.0**	**2.1**	**3.0**	**.952**	**.80**
Coliform, fecal, membrane filter (CFU/100 mL)	9	0	4,300	5,100	120	650	3,900	4,700	1.042	**2,600**
Enterococcus, membrane filter (CFU/100 mL)	8	0	2,700	2,500	93	1,400	2,100	3,000	.736	**1,900**
Dissolved solids (mg/L)	9	0	174	31.4	18.1	156	175	190	.194	**168**
Suspended solids (mg/L)	9	1	11.0	5.12	46.6	6.50	10.3	15.2	.840	**11**
Nitrate plus nitrite (mg/L as N)	9	0	.50	.20	33	.40	.50	.50	.348	**.50**
Nitrogen, ammonia, total (mg/L as N)	9	1	.20	.10	36	.10	.20	.20	.444	**.10**
Nitrogen, total Kjeldahl (mg/L as N)	9	0	.90	.30	29	.80	.80	1.00	.271	**.90**
Phosphorus, total (mg/L)	9	0	.10	.05	45	.10	.10	.10	.777	**.10**
Cadmium, total (µg/L)	**9**	**8**	**.10**	**.10**	**45**	**.10**	**.10**	**.10**	**0**	**.10**
Chromium, total (µg/L)	9	0	2.2	.30	16	2.0	2.0	2.2	.122	**2.1**
Copper, total (µg/L)	9	0	6.6	2.1	32	5.0	5.7	8.0	.524	**6.0**
Lead, total (µg/L)	9	0	7.3	2.9	39	5.2	6.4	8.4	.500	**7.0**
Zinc, total (µg/L)	9	0	27	25	90	15	18	25	.522	**23**
Single-family land use (01104630)										
Specific conductance, laboratory (µS/cm)	8	0	100	39	37	83	120	130	0.368	**61**
Turbidity, laboratory (NTU)	8	0	50	29	59	26	47	62	.756	**28**
Biochemical oxygen demand, 5-day (mg/L)	6	0	13	8.4	64	6.3	14	19	.893	**3.3**
Coliform, fecal, membrane filter (CFU/100 mL)	8	0	30,000	28,000	91	16,000	24,000	33,000	.701	**26,000**
Enterococcus, membrane filter (CFU/100 mL)	8	0	34,000	28,000	82	8,900	34,000	43,000	.988	**27,000**

Table 25. Statistical summary for constituents and water-quality properties of dry-weather and stormwater flow-composite

Constituent or property	Dry weather									
	Number of samples									
	Total	Less than detection	Mean	Standard deviation	Coefficient of variation	Lower quartile	Median	Upper quartile	Inter-quartile range	Flow-weighted mean
Single-family land use[1] (01104630)—*Continued*										
Dissolved solids (mg/L)	13	0	483	482	100	250	301	427	0.588	**494**
Suspended solids (mg/L)	**13**	**4**	**6.85**	**7.31**	**107**	**2.19**	**4.80**	**8.45**	**1.305**	**4.19**
Nitrate plus nitrite (mg/L as N)	12	0	1.9	1.2	59	1.1	2.0	2.6	.786	**1.8**
Nitrogen, ammonia, total (mg/L as N)	12	1	1.9	4.2	220	.50	.60	1.0	.966	**.6**
Nitrogen, total Kjeldahl (mg/L as N)	12	0	3.0	5.1	170	1.2	1.7	2.0	.515	**1.5**
Phosphorus, total (mg/L)	12	0	.30	.30	98	.10	.20	.40	1.351	**.2**
Cadmium, total (µg/L)	13	11	.10	.10	91	.10	.10	.10	.025	**.1**
Chromium, total (µg/L)	13	9	1.3	.50	40	1.0	1.0	1.2	.200	**1.2**
Copper, total (µg/L)	13	0	12	5.9	48	8.0	12	14	.475	**9.3**
Lead, total (µg/L)	13	0	5.3	6.2	120	1.1	2.4	7.6	2.708	**2.8**
Zinc, total (µg/L)	13	0	23	21	92	14.1	15	24	.730	**15**
Laundry Brook (01104640)										
Specific conductance, laboratory (µS/cm)	11	0	330	190	58	160	300	480	1.065	**350**
Turbidity, laboratory (NTU)	11	0	3.9	3.3	84	2.3	2.5	3.7	.591	**3.2**
Biochemical oxygen demand, 5-day (mg/L)	12	8	1.8	.7	35	1.3	1.7	2.4	.612	**1.6**
Coliform, fecal, membrane filter (CFU/100 mL)	13	0	1,800	1,800	100	760	1,000	2,000	1.192	**1,600**
Enterococcus, membrane filter (CFU/100 mL)	13	0	650	710	110	290	380	570	.737	**440**
Dissolved solids (mg/L)	12	0	271	88.7	32.8	221	256	302	.317	**281**
Suspended solids (mg/L)	12	7	2.72	.80	29.3	2.14	2.55	3.55	.553	**2.84**
Nitrate plus nitrite (mg/L as N)	12	0	1.5	.60	43	1.00	1.4	1.60	.436	**1.3**
Nitrogen, ammonia, total (mg/L as N)	12	6	.10	.10	76	.04	.10	.10	1.063	**.10**
Nitrogen, total Kjeldahl (mg/L as N)	12	0	.70	.20	26	.60	.70	.80	.364	**.7**
Phosphorus, total (mg/L)	12	1	.10	.03	30	.10	.10	.10	.438	**.10**
Cadmium, total (µg/L)	**13**	**12**	**.10**	**.10**	**50**	**.10**	**.10**	**.10**	**.000**	**.10**
Chromium, total (µg/L)	**13**	**9**	**1.2**	**.5**	**42**	**1.0**	**1.0**	**1.0**	**.000**	**1.1**
Copper, total (µg/L)	13	0	5.9	1.8	31	5.0	5.3	6.3	.245	**5.8**
Lead, total (µg/L)	13	0	2.2	1.0	44	1.7	2.3	2.8	.478	**2.5**
Zinc, total (µg/L)	13	0	15	9.0	59	11	11	18	.632	**18**

samples measured between July 1999 and September 2000, Lower Charles River Watershed, Massachusetts—*Continued*

Constituent or property	Stormwater: Number of samples: Total	Number of samples: Less than detection	Mean	Standard deviation	Coefficient of variation	Lower quartile	Median	Upper quartile	Inter-quartile range	Flow-weighted mean
Single-family land use (01104630)—*Continued*										
Dissolved solids (mg/L)	8	0	71	45	64	37	54	119	1.526	**42**
Suspended solids (mg/L)	8	0	92	76	82	53	72	94	.570	**65**
Nitrate plus nitrite (mg/L as N)	8	0	.80	.60	77	.30	.60	1.20	1.576	**0**
Nitrogen, ammonia, total (mg/L as N)	**8**	**1**	**.50**	**.50**	**99**	**.10**	**.30**	**.90**	**2.616**	**.2**
Nitrogen, total Kjeldahl (mg/L as N)	8	0	2.3	1.5	66	1.2	1.9	2.9	.891	**1.2**
Phosphorus, total (mg/L)	8	0	.40	.30	65	.20	.30	.50	.880	**.2**
Cadmium, total (µg/L)	**8**	**4**	**.2**	**.2**	**73**	**.10**	**.20**	**.30**	**.984**	**.1**
Chromium, total (µg/L)	8	0	8.2	4.1	50	5.3	7.6	9.2	.507	**5.2**
Copper, total (µg/L)	8	0	38	20	54	28	33	43	.429	**20**
Lead, total (µg/L)	8	0	52	36	71	30	44	55	.577	**31**
Zinc, total (µg/L)	8	0	110	61	58	75	88	110	.380	**59**
Laundry Brook (01104640)										
Specific conductance, laboratory (µS/cm)	8	0	230	52	23	220	240	250	0.142	**180**
Turbidity, laboratory (NTU)	8	0	25	25	99	12	17	24	.677	**17**
Biochemical oxygen demand, 5-day (mg/L)	6	0	9.5	6.0	63	5.7	8.3	11	.682	**3**
Coliform, fecal, membrane filter (CFU/100 mL)	9	0	22,000	16,000	74	9,100	25,000	34,000	.963	**22,000**
Enterococcus, membrane filter (CFU/100 mL)	8	0	17,000	16,000	92	4,400	12,000	29,000	2.066	**20,000**
Dissolved solids (mg/L)	9	0	136	40.2	29.6	110	124	170	.484	**115**
Suspended solids (mg/L)	9	0	44.6	39.7	88.9	20.2	33.0	51.2	.939	**33.0**
Nitrate plus nitrite (mg/L as N)	9	0	.70	.30	45	.40	.60	1.0	.839	**.50**
Nitrogen, ammonia, total (mg/L as N)	9	1	.30	.30	92	.10	.10	.50	3.287	**.20**
Nitrogen, total Kjeldahl (mg/L as N)	9	0	1.9	1.0	54	1.2	1.4	2.6	1.000	**1.5**
Phosphorus, total (mg/L)	9	0	.20	.20	74	.10	.20	.30	.713	**.20**
Cadmium, total (µg/L)	**9**	**7**	**.10**	**.10**	**45**	**.10**	**.10**	**.10**	**.000**	**.20**
Chromium, total (µg/L)	9	0	4.8	4.0	84	3	3.0	5.0	.667	**3.8**
Copper, total (µg/L)	9	0	26	22	84	15	20	26	.531	**19**
Lead, total (µg/L)	9	0	32	29	91	17	18	39	1.183	**24**
Zinc, total (µg/L)	9	0	90	75	83	40	63	120	1.214	**61**

Table 25. Statistical summary for constituents and water-quality properties of dry-weather and stormwater flow-composite

Constituent or property	Dry weather									
	Number of samples									
	Total	Less than detection	Mean	Standard deviation	Coefficient of variation	Lower quartile	Median	Upper quartile	Interquartile range	Flow-weighted mean
Faneuil Brook (01104660)										
Specific conductance, laboratory (µS/cm)	11	0	670	321	48	431	740	910	0.654	**500**
Turbidity, laboratory (NTU)	10	0	31	39	130	2.3	9.6	48	4.794	**5.9**
Biochemical oxygen demand, 5-day (mg/L)	13	4	4.8	5.7	120	1.2	3.2	5.6	1.364	**2.3**
Coliform, fecal, membrane filter (CFU/100 mL)	13	0	66,000	84,000	130	14,000	27,000	67,000	1.963	**28,000**
Enterococcus, membrane filter (CFU/100 mL)	13	0	16,000	26,000	160	1,900	3,200	22,000	6.281	**14,000**
Dissolved solids (mg/L)	13	0	510	103	20.2	469	492	532	.128	**536**
Suspended solids (mg/L)	13	6	22.3	41.4	185	.33	2.5	22.7	8.946	**2.78**
Nitrate plus nitrite (mg/L as N)	13	0	2.6	.60	22	2.1	2.5	3.0	.372	**2.5**
Nitrogen, ammonia, total (mg/L as N)	13	0	.60	.50	83	.30	.50	.7	.745	**.4**
Nitrogen, total Kjeldahl (mg/L as N)	13	0	1.7	1.5	88	1.0	1.2	1.6	.500	**1.1**
Phosphorus, total (mg/L)	13	1	.2	.2	110	.10	.10	.20	.660	**.1**
Cadmium, total (µg/L)	**13**	**12**	**.20**	**.10**	**54**	**.10**	**.10**	**.30**	**1.500**	**.1**
Chromium, total (µg/L)	13	9	1.5	1.5	100	.65	1.0	1.7	1.107	1.1
Copper, total (µg/L)	13	0	7.1	6.0	84	4.0	4.6	6.0	.435	**5.2**
Lead, total (µg/L)	13	0	6.2	10	170	.70	1.1	5.9	4.727	**2.0**
Zinc, total (µg/L)	13	0	52.	54	100	13	29.	77	2.170	**45**
Multifamily land use (01104673)										
Specific conductance, laboratory (µS/cm)	9	0	680	470	69	220	920	1,100	0.995	**510**
Turbidity, laboratory (NTU)	9	0	6.3	11	170	1.6	1.7	5.8	2.448	**5.3**
Biochemical oxygen demand, 5-day (mg/L)	12	4	4.3	4.5	100	1.2	3.0	5.4	1.424	**5.8**
Coliform, fecal, membrane filter (CFU/100 mL)	**12**	**1**	**8,500**	**10,000**	**120**	**340**	**2,700**	**20,000**	**7.229**	**13,000**
Enterococcus, membrane filter (CFU/100 mL)	**12**	**1**	**1,700**	**2,800**	**160**	**110**	**760**	**1,900**	**2.391**	**2,200**
Dissolved solids (mg/L)	12	0	869	297	34.2	670	942	1,020	.371	**802**
Suspended solids (mg/L)	12	5	5.13	5.93	116	1.01	2.50	8.28	2.91	**4.53**
Nitrate plus nitrite (mg/L as N)	12	0	3.2	1.1	35	2.3	3.2	3.7	.448	**3.1**
Nitrogen, ammonia, total (mg/L as N)	12	2	1.0	1.2	120	.20	.40	1.6	3.806	**1.3**
Nitrogen, total Kjeldahl (mg/L as N)	12	0	1.8	1.5	81	.80	1.4	2.6	1.283	**2.2**

samples measured between July 1999 and September 2000, Lower Charles River Watershed, Massachusetts—*Continued*

Constituent or property	Stormwater									
	Number of samples		Mean	Standard deviation	Coeffi-cient of variation	Lower quartile	Median	Upper quartile	Inter-quartile range	Flow-weighted mean
	Total	Less than detec-tion								
Faneuil Brook (01104660)										
Specific conductance, laboratory (µS/cm)	9	0	330	130	41	230	340	360	0.374	**260**
Turbidity, laboratory (NTU)	9	0	53	46	87	24	44	65	.942	**35**
Biochemical oxygen demand, 5-day (mg/L)	6	0	11	6.1	54	8.5	11	15	.630	**3**
Coliform, fecal, membrane filter (CFU/100 mL)	9	0	68,000	90,000	130	26,000	41,000	43,000	.410	**72,000**
Enterococcus, membrane filter (CFU/100 mL)	8	0	34,000	21,000	63	18,000	32,000	51,000	1.047	**24,000**
Dissolved solids (mg/L)	8	0	188	70.7	37.2	154	165	211	.341	**146**
Suspended solids (mg/L)	9	0	96.8	93.2	96.3	42.6	48.8	100	1.177	**69.8**
Nitrate plus nitrite (mg/L as N)	9	0	1.1	.60	54	.70	1.0	1.1	.381	**.70**
Nitrogen, ammonia, total (mg/L as N)	9	3	.30	.30	93	.10	.20	.50	2.579	**.20**
Nitrogen, total Kjeldahl (mg/L as N)	9	0	1.7	.90	52	.90	1.7	2.0	.624	**1.20**
Phosphorus, total (mg/L)	9	0	.20	.10	59	.10	.20	.30	1.353	**.20**
Cadmium, total (µg/L)	9	5	.20	.20	100	.10	.20	.30	.944	**.20**
Chromium, total (µg/L)	9	0	6.0	3.9	66	4.0	4.0	6.0	.500	**4.8**
Copper, total (µg/L)	9	0	28	19	69	15	28	28	.482	**19**
Lead, total (µg/L)	9	0	44	40	91	21	34	37	.461	**33**
Zinc, total (µg/L)	9	0	92	58	64	69	79	100	.427	**68**
Multifamily land use (01104673)										
Specific conductance, laboratory (µS/cm)	8	0	130	87	66	82	120	160	0.651	**86**
Turbidity, laboratory (NTU)	8	0	19	7.8	41	15	20	25	.498	**14**
Biochemical oxygen demand, 5-day (mg/L)	6	0	9.1	4.8	52	5.8	9.0	13	.791	**2.7**
Coliform, fecal, membrane filter (CFU/100 mL)	8	0	16,000	11,000	67	5,200	19,000	25,000	1.086	**9,600**
Enterococcus, membrane filter (CFU/100 mL)	8	0	22,000	15,000	70	12,000	18,000	33,000	1.168	**18,000**
Dissolved solids (mg/L)	8	0	165	139	84.0	94.0	121	188	.779	**154**
Suspended solids (mg/L)	8	0	34.20	19.0	55.7	19.6	30.9	42.3	.733	**32.7**
Nitrate plus nitrite (mg/L as N)	**8**	**1**	**.70**	**.50**	**75**	**.40**	**.60**	**.90**	**.867**	**.7**
Nitrogen, ammonia, total (mg/L as N)	**8**	**3**	**.30**	**.30**	**81**	**.20**	**.20**	**.60**	**2.088**	**.2**
Nitrogen, total Kjeldahl (mg/L as N)	8	0	1.5	.60	40	1.2	1.3	1.8	.490	**1.1**

Table 25. Statistical summary for constituents and water-quality properties of dry-weather and stormwater flow-composite

Constituent or property	Dry weather									
	Number of samples									
	Total	Less than detection	Mean	Standard deviation	Coefficient of variation	Lower quartile	Median	Upper quartile	Inter-quartile range	Flow-weighted mean
Multifamily land use (01104673)—*Continued*										
Phosphorus, total (mg/L)	12	0	0.40	0.20	50	0.30	0.40	0.60	0.625	**0.50**
Cadmium, total (µg/L)	**12**	**10**	**.20**	**.20**	**84**	**.10**	**.10**	**.20**	**1.425**	**.10**
Chromium, total (µg/L)	12	7	1.9	1.9	97	1.0	1.0	2.1	1.050	**1.6**
Copper, total (µg/L)	12	0	18	8.2	47	12	17	21	.497	**19**
Lead, total (µg/L)	12	0	27	51	190	3.5	12	17	1.118	**13**
Zinc, total (µg/L)	12	0	96	93	97	45	60	110	1.067	**55**
Commercial land use (01104677)										
Specific conductance, laboratory (µS/cm)	10	0	1,300	1,200	90	430	1,200	1,700	1.110	**1,200**
Turbidity, laboratory (NTU)	10	0	16	32	200	1.7	3.4	8.5	2.013	**6.6**
Biochemical oxygen demand, 5-day (mg/L)	12	8	5.2	13	250	.03	.30	3.2	12.424	**1.5**
Coliform, fecal, membrane filter (CFU/100 mL)	**11**	**4**	**5,100**	**16,000**	**320**	**5.0**	**10**	**210**	**20.500**	**6,200**
Enterococcus, membrane filter (CFU/100 mL)	**11**	**2**	**220**	**350**	**160**	**15**	**30**	**260**	**8.000**	**260**
Dissolved solids (mg/L)	12	0	667	145	21.7	602	640	693	0.142	**692**
Suspended solids (mg/L)	12	3	10.3	15.0	145	1.95	2.65	17.00	5.886	**10.8**
Nitrate plus nitrite (mg/L as N)	12	0	1.0	.90	85	.30	.60	1.6	2.246	**1.3**
Nitrogen, ammonia, total (mg/L as N)	12	4	.20	.20	110	.04	.10	.30	2.075	**.20**
Nitrogen, total Kjeldahl (mg/L as N)	12	0	.70	.50	71	.30	.50	.70	.793	**.50**
Phosphorus, total (mg/L)	12	0	.50	.70	160	.20	.20	.30	.686	**.20**
Cadmium, total (µg/L)	12	12	<	<	--	<	<	<	--	**.10**
Chromium, total (µg/L)	**12**	**9**	**1.1**	**.4**	**39**	**1.0**	**1.0**	**1.0**	**.000**	**1.2**
Copper, total (µg/L)	12	0	19	17	90	6.8	14	23	1.207	**17**
Lead, total (µg/L)	12	0	11	11	110	1.5	5.7	20	3.333	**11**
Zinc, total (µg/L)	12	0	55	37	68	27	40	73	1.147	**50**
Muddy River (01104683)										
Specific conductance, laboratory (µS/cm)	11	0	400	270	68	170	360	630	1.295	**420**
Turbidity, laboratory (NTU)	10	0	8.1	6.0	74	5.1	5.5	9.7	.826	**7.9**
Biochemical oxygen demand, 5-day (mg/L)	12	7	2.4	1.4	60	1.2	1.9	4.0	1.447	**2.5**
Coliform, fecal, membrane filter (CFU/100 mL)	**12**	**3**	**550**	**1,200**	**220**	**9**	**15**	**360**	**23.417**	**690**
Enterococcus, membrane filter (CFU/100 mL)	**12**	**6**	**190**	**330**	**170**	**5**	**13**	**200**	**15.200**	**240**

samples measured between July 1999 and September 2000, Lower Charles River Watershed, Massachusetts—*Continued*

Constituent or property	Stormwater									
	Number of samples		Mean	Standard deviation	Coeffi-cient of variation	Lower quartile	Median	Upper quartile	Inter-quartile range	Flow-weighted mean
	Total	Less than detec-tion								
Multifamily land use (01104673)—*Continued*										
Phosphorus, total (mg/L)	8	0	0.20	0.10	43	0.10	0.30	0.30	0.717	**0.2**
Cadmium, total (µg/L)	8	3	.30	.10	54	.10	.40	.40	.757	**.3**
Chromium, total (µg/L)	8	0	5.6	1.4	25	4.0	6.0	7.0	.498	**5.2**
Copper, total (µg/L)	8	0	64	31	49	41	52	84	.846	**44**
Lead, total (µg/L)	8	0	67	34	50	42	67	81	.570	**51**
Zinc, total (µg/L)	8	0	150	55	37	110	140	190	.594	**120**
Commercial land use (01104677)										
Specific conductance, laboratory (µS/cm)	7	0	310	280	90	200	200	260	0.317	**200**
Turbidity, laboratory (NTU)	7	0	18	8.4	46	13	18	24	.655	**12**
Biochemical oxygen demand, 5-day (mg/L)	**6**	**1**	**9.9**	**7.1**	**72.0**	**4.0**	**11**	**15**	**.993**	**4.5**
Coliform, fecal, membrane filter (CFU/100 mL)	8	0	9,900	9,000	91	3,100	8,400	13,000	1.198	**8,500**
Enterococcus, membrane filter (CFU/100 mL)	8	0	14,000	11,000	79	8,000	9,000	17,000	1.001	**13,000**
Dissolved solids (mg/L)	8	0	61.2	39.5	64.5	37	42.9	74.0	0.862	**47.7**
Suspended solids (mg/L)	8	0	50.1	32.4	64.6	22.9	43.8	66.0	.984	**42.7**
Nitrate plus nitrite (mg/L as N)	8	0	.70	.40	64	.40	.60	.80	.727	**.40**
Nitrogen, ammonia, total (mg/L as N)	8	0	.30	.20	73	.10	.20	.40	1.230	**.20**
Nitrogen, total Kjeldahl (mg/L as N)	8	0	1.6	.90	58	.90	1.5	2.5	1.135	**1.1**
Phosphorus, total (mg/L)	8	0	.20	.10	45	.10	.20	.30	.612	**.10**
Cadmium, total (µg/L)	**8**	**2**	**.40**	**.30**	**80**	**.20**	**.3**	**.40**	**.654**	**.30**
Chromium, total (µg/L)	8	0	5.2	1.9	36	3.8	5.2	7.0	.636	**4.1**
Copper, total (µg/L)	8	0	100	71	70	50	78	130	1.064	**69**
Lead, total (µg/L)	8	0	140	64	47	110	110	150	.309	**110**
Zinc, total (µg/L)	8	0	180	66	37	150	170	200	.263	**130**
Muddy River (01104683)										
Specific conductance, laboratory (µS/cm)	7	0	220	97	43	160	180	290	0.732	**150**
Turbidity, laboratory (NTU)	7	0	26	7.7	29	23	24	30	.313	**25**
Biochemical oxygen demand, 5-day (mg/L)	**6**	**1**	**7.1**	**4.2**	**59**	**4.9**	**7.6**	**8.9**	**.524**	**1.7**
Coliform, fecal, membrane filter (CFU/100 mL)	9	0	17,000	13,000	73	7,200	19,000	26,000	.968	**20,000**
Enterococcus, membrane filter (CFU/100 mL)	8	0	11,000	8,000	74	3,900	9,200	19,000	1.682	**14,000**

Table 25. Statistical summary for constituents and water-quality properties of dry-weather and stormwater flow-composite

Constituent or property	Dry weather: Number of samples: Total	Dry weather: Number of samples: Less than detection	Mean	Standard deviation	Coefficient of variation	Lower quartile	Median	Upper quartile	Interquartile range	Flow-weighted mean
Muddy River (01104683)—*Continued*										
Dissolved solids (mg/L)	13	0	328	151	46.0	204	307	366	0.528	**342**
Suspended solids (mg/L)	13	0	6.62	2.75	41.6	4.80	5.80	7.80	.517	**6.53**
Nitrate plus nitrite (mg/L as N)	12	0	.90	.50	54	.50	.80	1.2	.807	**1.0**
Nitrogen, ammonia, total (mg/L as N)	12	0	.50	.20	33	.40	.50	.60	.437	**.50**
Nitrogen, total Kjeldahl (mg/L as N)	12	0	1.8	2.3	130	1.1	1.1	1.3	.182	**2.0**
Phosphorus, total (mg/L)	12	2	.10	.02	20	.10	.10	.10	.292	**.10**
Cadmium, total (µg/L)	**13**	**12**	**.10**	**.10**	**50**	**.10**	**.10**	**.10**	**.000**	**.10**
Chromium, total (µg/L)	**13**	**9**	**1.2**	**.5**	**42**	**1.0**	**1.0**	**1.0**	**.000**	**1.3**
Copper, total (µg/L)	13	0	6.3	1.3	20	5.2	6.0	7.0	.300	**6.4**
Lead, total (µg/L)	13	0	4.3	1.0	23	3.6	4.4	4.8	.273	**4.5**
Zinc, total (µg/L)	13	0	22	23	110	10	15	20	.644	**29**
Stony Brook (011046887)										
Specific conductance, laboratory (µS/cm)	11	0	460	240	53	240	560	670	0.774	**430**
Turbidity, laboratory (NTU)	11	0	5.5	6.1	110	2.2	3.5	5.9	1.064	**5.8**
Biochemical oxygen demand, 5-day (mg/L)	12	11	**1.2**	**.60**	**52**	**1.0**	**1.0**	**1.0**	**.000**	**1.2**
Coliform, fecal, membrane filter (CFU/100 mL)	12	3	47	84	180	6.8	20	40	1.661	**25**
Enterococcus, membrane filter (CFU/100 mL)	12	8	17	29	170	.60	2.9	25	8.562	**14**
Dissolved solids (mg/L)	12	0	378	186	49.3	279	358	369	.253	**421**
Suspended solids (mg/L)	12	7	2.41	.73	30.1	1.88	2.26	2.88	.442	**2.48**
Nitrate plus nitrite (mg/L as N)	12	0	1.6	.30	18	1.3	1.4	1.9	.400	**1.60**
Nitrogen, ammonia, total (mg/L as N)	12	0	.40	.10	25	.30	.40	.40	.296	**.40**
Nitrogen, total Kjeldahl (mg/L as N)	12	0	1.0	.20	17	.90	1.0	1.1	.262	**.90**
Phosphorus, total (mg/L)	**12**	**3**	**.20**	**.40**	**200**	**.10**	**.10**	**.10**	**.391**	**.10**
Cadmium, total (µg/L)	12	12	<	<	--	<	<	<	--	**.10**
Chromium, total (µg/L)	**12**	**9**	**1.2**	**.60**	**52**	**1.0**	**1.0**	**1.0**	**.000**	**1.2**
Copper, total (µg/L)	12	0	4.7	1.5	32	3.9	4.0	5.7	.450	**5.1**
Lead, total (µg/L)	12	0	2.3	2.4	110	1.1	1.5	1.9	.533	**2.6**
Zinc, total (µg/L)	**12**	**1**	**20**	**9.5**	**48**	**15**	**20**	**23**	**.440**	**23**

samples measured between July 1999 and September 2000, Lower Charles River Watershed, Massachusetts—*Continued*

Constituent or property	Stormwater									
	Number of samples		Mean	Standard deviation	Coeffi-cient of variation	Lower quartile	Median	Upper quartile	Inter-quartile range	Flow-weighted mean
	Total	Less than detec-tion								
Muddy River (01104683)—*Continued*										
Dissolved solids (mg/L)	9	0	123	71.3	58.0	75.0	113	160	0.752	**98.9**
Suspended solids (mg/L)	9	0	39.0	13.8	35.5	26.7	36.0	49.4	.632	**45.3**
Nitrate plus nitrite (mg/L as N)	9	0	.70	.30	41	.50	.60	.90	.742	**.50**
Nitrogen, ammonia, total (mg/L as N)	9	0	.30	.20	52	.20	.40	.40	.519	**.20**
Nitrogen, total Kjeldahl (mg/L as N)	9	0	1.5	.50	32	1.1	1.6	1.8	.409	**1.2**
Phosphorus, total (mg/L)	9	0	.20	.10	42	.20	.20	.20	.415	**.20**
Cadmium, total (µg/L)	9	4	.20	.10	57	.10	.20	.20	.505	**.20**
Chromium, total (µg/L)	9	0	4.9	2.7	54	3.3	4.2	5.0	.400	**4.5**
Copper, total (µg/L)	9	0	33.0	12.0	36	22	32	34	.380	**27**
Lead, total (µg/L)	9	0	29.0	8.9	30	25	26	34	.347	**29**
Zinc, total (µg/L)	9	0	81.0	21.0	26	66	78	92	.339	**72**
Stony Brook (011046887)										
Specific conductance, laboratory (µS/cm)	7	0	280	120	43	210	250	350	0.558	**150**
Turbidity, laboratory (NTU)	7	0	64	71	110	21	39	70	1.250	**28**
Biochemical oxygen demand, 5-day (mg/L)	6	0	15	9.7	64	6.8	13	23	1.227	**3.2**
Coliform, fecal, membrane filter (CFU/100 mL)	9	0	65,000	74,000	110	24,000	29,000	60,000	1.205	**34,000**
Enterococcus, membrane filter (CFU/100 mL)	8	0	19,000	9,800	52	9,900	23,000	25,000	.655	**20,000**
Dissolved solids (mg/L)	9	0	155	69	45	100	140	150	.360	**113**
Suspended solids (mg/L)	9	0	107	76	71	39	104	120	.782	**62.6**
Nitrate plus nitrite (mg/L as N)	9	0	1.0	.40	39	.80	.90	1.3	.596	**.70**
Nitrogen, ammonia, total (mg/L as N)	9	0	.40	.20	69	.20	.30	.50	1.319	**.20**
Nitrogen, total Kjeldahl (mg/L as N)	9	0	2.3	1.4	62	1.2	1.7	2.9	1.000	**1.3**
Phosphorus, total (mg/L)	9	0	.40	.20	53	.20	.40	.50	.515	**.30**
Cadmium, total (µg/L)	9	3	.40	.40	85	.20	.30	.70	1.455	**.30**
Chromium, total (µg/L)	9	0	7.2	5.3	73	3.5	6.0	7.2	.617	**4.9**
Copper, total (µg/L)	9	0	36	23	64	16	34	38	.645	**21**
Lead, total (µg/L)	9	0	96	74	78	34	84	120	1.029	**55**
Zinc, total (µg/L)	9	0	140	81	59	67	120	180	.957	**85**

Table 25. Statistical summary for constituents and water-quality properties of dry-weather and stormwater flow-composite

Constituent or property	Dry weather									
	Number of samples									
	Total	Less than detection	Mean	Standard deviation	Coefficient of variation	Lower quartile	Median	Upper quartile	Interquartile range	Flow-weighted mean
Charles River at Boston Science Museum (01104710)										
Specific conductance, laboratory (µS/cm)	10	0	420	250	60	300	460	480	0.393	--
Turbidity, laboratory (NTU)	10	0	3.6	1.2	33	2.9	3.2	4.2	.417	--
Biochemical oxygen demand, 5-day (mg/L)	12	8.0	1.5	1.5	100.0	.4	.9	2.3	1.989	--
Coliform, fecal, membrane filter (CFU/100 mL)	13	2	33	29	89	10	30	45	1.167	--
Enterococcus, membrane filter (CFU/100 mL)	13	4	10	5.0	50	8.8	10	10	.125	--
Dissolved solids (mg/L)	13	0	505	293	58.0	266	430	875	1.416	--
Suspended solids (mg/L)	13	5	3.71	1.01	27.2	2.83	3.89	4.55	.443	--
Nitrate plus nitrite (mg/L as N)	12	0	.50	.30	48	.40	.50	.70	.545	--
Nitrogen, ammonia, total (mg/L as N)	12	3	.20	.10	45	.10	.20	.20	.798	--
Nitrogen, total Kjeldahl (mg/L as N)	12	0	.70	.10	16	.70	.70	.80	.110	--
Phosphorus, total (mg/L)	12	6	.10	.10	100	.02	.04	.10	1.078	--
Cadmium, total (µg/L)	**13**	**12**	**.10**	**.10**	**50**	**.10**	**.10**	**.10**	**.000**	--
Chromium, total (µg/L)	**13**	**7**	**1.5**	**.70**	**46**	**1.0**	**1.2**	**2.0**	**.833**	--
Copper, total (µg/L)	13	0	5.9	1.1	19	5.3	6.0	6.6	.217	--
Lead, total (µg/L)	13	0	3.8	2.1	56	2.4	2.8	5.0	.929	--
Zinc, total (µg/L)	13	1	17	6.9	41	12	19	21	.517	--
Total watershed										
Specific conductance, laboratory (µS/cm)	97	0	540	530	97	250	430	690	1.040	--
Turbidity, laboratory (NTU)	95	0	9.4	19.1	200	2.3	3.4	7.2	1.463	--
Biochemical oxygen demand, 5-day (mg/L)	110	69	2.7	5.2	200	.5	1.2	3.0	2.140	--
Coliform, fecal, membrane filter (CFU/100 mL)	**112**	**19**	**11,000**	**37,000**	**330**	**20**	**220**	**3,700**	**17.000**	--
Enterococcus, membrane filter (CFU/100 mL)	**112**	**28**	**2,900**	**11,000**	**390**	**8.8**	**75**	**1,000**	**13.383**	--
Dissolved solids (mg/L)	114	0	465	299	64.2	236	366	624	1.060	--
Suspended solids (mg/L)	114	40	7.05	16	225	1.4	3.09	6.0	1.491	--
Nitrate plus nitrite (mg/L as N)	110	0	1.5	1.1	74	.50	1.3	2.1	1.192	--
Nitrogen, ammonia, total (mg/L as N)	110	19	.50	1.5	270	.10	.30	.50	1.375	--
Nitrogen, total Kjeldahl (mg/L as N)	110	0	1.3	2.0	150	.70	.90	1.2	.547	--

samples measured between July 1999 and September 2000, Lower Charles River Watershed, Massachusetts—*Continued*

Constituent or property	Stormwater: Number of samples: Total	Number of samples: Less than detection	Mean	Standard deviation	Coefficient of variation	Lower quartile	Median	Upper quartile	Interquartile range	Flow-weighted mean
Charles River at Boston Science Museum (01104710)										
Specific conductance, laboratory (µS/cm)	--	--	--	--	--	--	--	--	--	--
Turbidity, laboratory (NTU)	--	--	--	--	--	--	--	--	--	--
Biochemical oxygen demand, 5-day (mg/L)	--	--	--	--	--	--	--	--	--	--
Coliform, fecal, membrane filter (CFU/100 mL)	--	--	--	--	--	--	--	--	--	--
Enterococcus, membrane filter (CFU/100 mL)	--	--	--	--	--	--	--	--	--	--
Dissolved solids (mg/L)	--	--	--	--	--	--	--	--	--	--
Suspended solids (mg/L)	--	--	--	--	--	--	--	--	--	--
Nitrate plus nitrite (mg/L as N)	--	--	--	--	--	--	--	--	--	--
Nitrogen, ammonia, total (mg/L as N)	--	--	--	--	--	--	--	--	--	--
Nitrogen, total Kjeldahl (mg/L as N)	--	--	--	--	--	--	--	--	--	--
Phosphorus, total (mg/L)	--	--	--	--	--	--	--	--	--	--
Cadmium, total (µg/L)	--	--	--	--	--	--	--	--	--	--
Chromium, total (µg/L)	--	--	--	--	--	--	--	--	--	--
Copper, total (µg/L)	--	--	--	--	--	--	--	--	--	--
Lead, total (µg/L)	--	--	--	--	--	--	--	--	--	--
Zinc, total (µg/L)	--	--	--	--	--	--	--	--	--	--
Total watershed										
Specific conductance, laboratory (µS/cm)	61	0	230	140	60	130	220	300	0.755	--
Turbidity, laboratory (NTU)	61	0	34	36.0	110.0	15.0	23.0	39	1.048	--
Biochemical oxygen demand, 5-day (mg/L)	47	5	9.9	6.9	70.0	3.4	8.6	15	1.349	--
Coliform, fecal, membrane filter (CFU/100 mL)	69	0	30,000	48,000	160	5,200	20,000	31,000	1.268	--
Enterococcus, membrane filter (CFU/100 mL)	64	0	19,000	18,000	94	5,300	13,000	29,000	1.915	--
Dissolved solids (mg/L)	68	0	135	79.1	58.7	85.1	130	171	0.657	--
Suspended solids (mg/L)	69	1	59.3	61.1	103	22.0	38.6	75.0	1.356	--
Nitrate plus nitrite (mg/L as N)	69	1	.80	.50	59	.40	.70	1.0	.824	--
Nitrogen, ammonia, total (mg/L as N)	69	8	.30	.30	87	.10	.20	.50	1.775	--
Nitrogen, total Kjeldahl (mg/L as N)	69	0	1.7	1.0	59	.90	1.4	2.2	.907	--

Table 25. Statistical summary for constituents and water-quality properties of dry-weather and stormwater flow-composite

Constituent or property	Dry weather									
	Number of samples		Mean	Standard deviation	Coefficient of variation	Lower quartile	Median	Upper quartile	Interquartile range	Flow-weighted mean
	Total	Less than detection								
Total watershed—*Continued*										
Phosphorus, total (mg/L)	110	16	0.20	0.30	150	0.10	0.10	0.20	1.169	--
Cadmium, total (µg/L)	**115**	**107**	**.10**	**.10**	**68**	**.10**	**.10**	**.10**	**.000**	--
Chromium, total (µg/L)	**115**	**70**	**1.4**	**1.0**	**70**	**1.0**	**1.0**	**2.0**	**1.000**	--
Copper, total (µg/L)	115	0	8.9	8.5	95	4.0	6.0	9.0	.833	--
Lead, total (µg/L)	115	0	7.0	18	260	1.7	3.3	5.4	1.121	--
Zinc, total (µg/L)	**115**	**3**	**35**	**46**	**130**	**11**	**18**	**37**	**1.385**	--

samples measured between July 1999 and September 2000, Lower Charles River Watershed, Massachusetts—*Continued*

Constituent or property	Stormwater									
	Number of samples		Mean	Standard deviation	Coeffi-cient of variation	Lower quartile	Median	Upper quartile	Inter-quartile range	Flow-weighted mean
	Total	Less than detec-tion								
Total watershed—*Continued*										
Phosphorus, total (mg/L)	69	0	0.30	0.20	70	0.10	0.20	0.30	0.950	--
Cadmium, total (µg/L)	69	36	.30	.20	84	.10	.20	.30	1.038	--
Chromium, total (µg/L)	69	0	5.5	3.6	66	3.0	4.3	7.0	.932	--
Copper, total (µg/L)	69	0	40	39	97	15	31	50	1.115	--
Lead, total (µg/L)	69	0	57	56	98	20	34	79	1.733	--
Zinc, total (µg/L)	69	0	110	71	67	57	90	140	.948	--

Table 26. Regression coefficients of models used to estimate event-mean concentrations from storm-rainfall characteristics

[CFU/100 mL, colony-forming units per 100 milliliters; in., inches; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter;

Explanatory variable	Specific conductance (µS/cm)	Turbidity (NTU)	Biochemical oxygen demand, 5-day (mg/L)	Coliform, fecal, membrane filter (CFU/100 mL)	Enterococcus, membrane filter (CFU/100 mL)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Nitrate, total (mg/L as N)
Charles River at Watertown (01104615)								
Intercept	316.75	8.528	0.697	2.488	nm	158.665	-2.813	0.670
Duration (hours)	--	--	--	-.019	nm	--	0.254	--
Total rainfall (in.)	24.041	--	--	--	nm	--	0.786	--
Intensity, maximum in inches per hour	--	--	--	--	nm	--	10.484	--
Antecedent dry period (>0.1 in.), in hours	--	--	.013	--	nm	.358	0.043	--
Antecedent dry period (>0.5 in.), in hours	--	-.006	-.001	--	nm	--	-0.003	--
Antecedent dry period (>1 in.), in hours	--	--	.0002	.001	nm	-.037	--	.000
Antecedent rainfall (48 hours), in inches	--	--	--	--	nm	--	--	--
Antecedent rainfall (72 hours), in inches	--	92.506	--	--	nm	--	117.912	--
Antecedent rainfall (168 hours), in inches	--	--	--	--	nm	--	--	--
Single-family land use (01104630)								
Intercept	155.258	nm	20.875	nm	nm	25.274	nm	-0.357
Duration (hours)	-1.881	nm	--	nm	nm	--	nm	--
Total rainfall (in.)	-16.213	nm	--	nm	nm	--	nm	.060
Intensity, maximum in inches per hour	--	nm	--	nm	nm	--	nm	-.949
Antecedent dry period (>0.1 in.), in hours	--	nm	--	nm	nm	.798	nm	.009
Antecedent dry period (>0.5 in.), in hours	--	nm	--	nm	nm	-.090	nm	.0005
Antecedent dry period (>1 in.), in hours	--	nm	--	nm	nm	-.050	nm	--
Antecedent rainfall (48 hours), in inches	--	nm	--	nm	nm	--	nm	--
Antecedent rainfall (72 hours), in inches	--	nm	--	nm	nm	--	nm	-6.967
Antecedent rainfall (168 hours), in inches	--	nm	-17.349	nm	nm	--	nm	--
Laundry Brook (01104640)								
Intercept	294.11	nm	11.621	3.138	3.651	79.806	-4.076	0.513
Duration (hours)	-2.11	nm	--	--	--	--	--	--
Total rainfall (in.)	-23.349	nm	-7.908	--	--	--	--	--
Intensity, maximum in inches per hour	--	nm	51.391	--	-1.156	--	--	--
Antecedent dry period (>0.1 in.), in hours	--	nm	-.035	--	-.003	.442	0.385	.003
Antecedent dry period (>0.5 in.), in hours	--	nm	--	--	--	--	--	--
Antecedent dry period (>1 in.), in hours	--	nm	--	.001	.001	--	--	.0004
Antecedent rainfall (48 hours), in inches	--	nm	--	--	--	--	--	--
Antecedent rainfall (72 hours), in inches	--	nm	--	--	--	--	--	--
Antecedent rainfall (168 hours), in inches	--	nm	-7.565	--	--	--	--	--
Faneuil Brook (01104660)								
Intercept	243.411	nm	-1.511	4.588	4.122	136.256	nm	0.636
Duration (hours)	--	nm	--	--	--	--	nm	--
Total rainfall (in.)	--	nm	--	--	--	--	nm	--
Intensity, maximum in inches per hour	--	nm	--	--	--	--	nm	-1.555
Antecedent dry period (>0.1 in.), in hours	--	nm	.084	-.002	--	.805	nm	.004

and antecedent conditions, lower Charles River Watershed, Massachusetts

NTU, nephelometric turbidity units; nm, no model; >,greater than value shown; --, explanatory variable not used in the model]

Explanatory variable	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, total, Kjeldahl (mg/L as N)	Phosphorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Lead, total (µg/L)	Zinc, total (µg/L)
Charles River at Watertown (01104615)								
Intercept	nm	0.517	0.138	nm	1.609	nm	2.226	12.209
Duration (hours)	nm	--	--	nm	--	nm	--	--
Total rainfall (in.)	nm	--	--	nm	--	nm	--	--
Intensity, maximum in inches per hour	nm	.734	--	nm	--	nm	18.011	40.076
Antecedent dry period (>0.1 in.), in hours	nm	--	--	nm	--	nm	--	--
Antecedent dry period (>0.5 in.), in hours	nm	.001	--	nm	--	nm	--	--
Antecedent dry period (>1 in.), in hours	nm	--	--	nm	.0004	nm	--	--
Antecedent rainfall (48 hours), in inches	nm	--	--	nm	--	nm	--	--
Antecedent rainfall (72 hours), in inches	nm	--	--	nm	6.467	nm	--	--
Antecedent rainfall (168 hours), in inches	nm	--	-.084	nm	.326	nm	--	-6.592
Single-family land use (01104630)								
Intercept	-0.563	-0.589	0.672	0.468	nm	-2.981	nm	-6.592
Duration (hours)	--	--	--	-.007	nm	--	nm	--
Total rainfall (in.)	--	--	--	--	nm	--	nm	--
Intensity, maximum in inches per hour	--	--	--	--	nm	--	nm	--
Antecedent dry period (>0.1 in.), in hours	.008	.021	--	--	nm	.299	nm	.821
Antecedent dry period (>0.5 in.), in hours	--	--	--	--	nm	--	nm	--
Antecedent dry period (>1 in.), in hours	--	--	--	--	nm	--	nm	--
Antecedent rainfall (48 hours), in inches	--	--	--	--	nm	--	nm	--
Antecedent rainfall (72 hours), in inches	--	--	-9.726	--	nm	--	nm	--
Antecedent rainfall (168 hours), in inches	--	--	-.541	--	nm	--	nm	--
Laundry Brook (01104640)								
Intercept	-0.124	1.120	0.365	nm	nm	19.321	nm	-8.857
Duration (hours)	-.008	--	--	nm	nm	.119	nm	--
Total rainfall (in.)	--	-.691	--	nm	nm	--	nm	--
Intensity, maximum in inches per hour	--	5.393	--	nm	nm	--	nm	--
Antecedent dry period (>0.1 in.), in hours	.002	--	--	nm	nm	.083	nm	.779
Antecedent dry period (>0.5 in.), in hours	--	--	--	nm	nm	--	nm	--
Antecedent dry period (>1 in.), in hours	.0003	.001	--	nm	nm	-.007	nm	--
Antecedent rainfall (48 hours), in inches	--	--	--	nm	nm	--	nm	--
Antecedent rainfall (72 hours), in inches	--	--	--	nm	nm	--	nm	--
Antecedent rainfall (168 hours), in inches	--	-.959	-.346	nm	nm	-13.869	nm	--
Faneuil Brook (01104660)								
Intercept	-0.285	0.454	0.109	nm	nm	5.596	nm	100.991
Duration (hours)	--	--	--	nm	nm	--	nm	-1.733
Total rainfall (in.)	-.062	--	--	nm	nm	--	nm	--
Intensity, maximum in inches per hour	.671	--	--	nm	nm	--	nm	--
Antecedent dry period (>0.1 in.), in hours	.003	.010	--	nm	nm	.090	nm	--

Table 26. Regression coefficients of models used to estimate event-mean concentrations from storm-rainfall characteristics

Explanatory variable	Specific conductance (µS/cm)	Turbidity (NTU)	Biochemical oxygen demand, 5-day (mg/L)	Coliform, fecal, membrane filter (CFU/100 mL)	Enterococcus, membrane filter (CFU/100 mL)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Nitrate, total (mg/L as N)
Faneuil Brook (01104660)—*Continued*								
Antecedent dry period (>0.5 in.), in hours	0.216	nm	--	0.001	--	--	nm	0.001
Antecedent dry period (>1 in.), in hours	--	nm	--	--	0.001	--	nm	--
Antecedent rainfall (48 hours), in inches	--	nm	--	--	--	--	nm	--
Antecedent rainfall (72 hours), in inches	--	nm	--	--	-12.235	--	nm	--
Antecedent rainfall (168 hours), in inches	--	nm	--	--	--	-103.766	nm	--
Multifamily lland use (01104673)								
Intercept	--	nm	nm	3.660	nm	nm	nm	nm
Duration (hours)	--	nm	nm	--	nm	nm	nm	nm
Total rainfall (in.)	--	nm	nm	-.372	nm	nm	nm	nm
Intensity, maximum in inches per hour	--	nm	nm	-.869	nm	nm	nm	nm
Antecedent dry period (>0.1 in.), in hours	--	nm	nm	--	nm	nm	nm	nm
Antecedent dry period (>0.5 in.), in hours	--	nm	nm	--	nm	nm	nm	nm
Antecedent dry period (>1 in.), in hours	--	nm	nm	.001	nm	nm	nm	nm
Antecedent rainfall (48 hours), in inches	--	nm	nm	--	nm	nm	nm	nm
Antecedent rainfall (72 hours), in inches	--	nm	nm	--	nm	nm	nm	nm
Antecedent rainfall (168 hours), in inches	--	nm	nm	.398	nm	nm	nm	nm
Commercial land use (01104677)								
Intercept	--	25.051	nm	nm	3.596	28.739	nm	-0.159
Duration (hours)	--	--	nm	nm	--	--	nm	--
Total rainfall (in.)	--	-5.537	nm	nm	--	--	nm	--
Intensity, maximum in inches per hour	--	--	nm	nm	--	--	nm	--
Antecedent dry period (>0.1 in.), in hours	--	--	nm	nm	--	--	nm	.006
Antecedent dry period (>0.5 in.), in hours	--	--	nm	nm	.001	.150	nm	--
Antecedent dry period (>1 in.), in hours	--	--	nm	nm	--	--	nm	--
Antecedent rainfall (48 hours), in inches	--	--	nm	nm	--	--	nm	--
Antecedent rainfall (72 hours), in inches	--	--	nm	nm	--	--	nm	--
Antecedent rainfall (168 hours), in inches	--	--	nm	nm	--	--	nm	--
Muddy River (01104683)								
Intercept	329.732	nm	8.287	3.569	nm	nm	nm	0.336
Duration (hours)	--	nm	--	--	nm	nm	nm	--
Total rainfall (in.)	--	nm	-6.665	--	nm	nm	nm	--
Intensity, maximum in inches per hour	-356.082	nm	--	--	nm	nm	nm	--
Antecedent dry period (>0.1 in.), in hours	--	nm	--	--	nm	nm	nm	.003
Antecedent dry period (>0.5 in.), in hours	--	nm	--	--	nm	nm	nm	--
Antecedent dry period (>1 in.), in hours	--	nm	.005	.001	nm	nm	nm	--
Antecedent rainfall (48 hours), in inches	--	nm	--	--	nm	nm	nm	--
Antecedent rainfall (72 hours), in inches	--	nm	--	-5.981	nm	nm	nm	--
Antecedent rainfall (168 hours), in inches	--	nm	--	--	nm	nm	nm	--

and antecedent conditionslower Charles River Watershed, Massachusetts—*Continued*

Explanatory variable	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, total, Kjeldahl (mg/L as N)	Phosphorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Lead, total (µg/L)	Zinc, total (µg/L)
Faneuil Brook (01104660)—*Continued*								
Antecedent dry period (>0.5 in.), in hours	--	--	0.0003	nm	nm	0.015	nm	--
Antecedent dry period (>1 in.), in hours	--	--	--	nm	nm	--	nm	--
Antecedent rainfall (48 hours), in inches	--	--	--	nm	nm	--	nm	--
Antecedent rainfall (72 hours), in inches	--	--	--	nm	nm	--	nm	--
Antecedent rainfall (168 hours), in inches	--	--	--	nm	nm	--	nm	--
Multifamily land use (01104673)								
Intercept	-0.207	0.980	nm	nm	nm	-43.356	10.229	62.34
Duration (hours)	--	--	nm	nm	nm	1.426	--	--
Total rainfall (in.)	-.206	--	nm	nm	nm	--	--	--
Intensity, maximum in inches per hour	1.882	--	nm	nm	nm	--	--	--
Antecedent dry period (>0.1 in.), in hours	.001	--	nm	nm	nm	.613	.415	.639
Antecedent dry period (>0.5 in.), in hours	--	.002	nm	nm	nm	--	--	--
Antecedent dry period (>1 in.), in hours	.0002	--	nm	nm	nm	--	--	--
Antecedent rainfall (48 hours), in inches	33.817	--	nm	nm	nm	--	--	--
Antecedent rainfall (72 hours), in inches	--	--	nm	nm	nm	--	--	--
Antecedent rainfall (168 hours), in inches	-.037	--	nm	nm	nm	--	--	--
Commercial land use (01104677)								
Intercept	-0.226	0.178	0.365	0.215	nm	16.337	nm	163.929
Duration (hours)	--	--	--	--	nm	--	nm	--
Total rainfall (in.)	--	--	-.243	--	nm	--	nm	-32.285
Intensity, maximum in inches per hour	--	--	--	--	nm	-247.945	nm	--
Antecedent dry period (>0.1 in.), in hours	.005	.010	-.001	--	nm	1.143	nm	--
Antecedent dry period (>0.5 in.), in hours	-.001	--	--	.001	nm	--	nm	.242
Antecedent dry period (>1 in.), in hours	--	--	.0002	--	nm	--	nm	--
Antecedent rainfall (48 hours), in inches	--	--	40.684	--	nm	--	nm	--
Antecedent rainfall (72 hours), in inches	--	--	.699	--	nm	--	nm	--
Antecedent rainfall (168 hours), in inches	--	--	.071	--	nm	--	nm	--
Muddy River (01104683)								
Intercept	0.514	2.068	nm	nm	nm	4.724	26.709	nm
Duration (hours)	-.012	--	nm	nm	nm	--	--	nm
Total rainfall (in.)	--	-.283	nm	nm	nm	--	--	nm
Intensity, maximum in inches per hour	--	--	nm	nm	nm	--	--	nm
Antecedent dry period (>0.1 in.), in hours	--	--	nm	nm	nm	.199	--	nm
Antecedent dry period (>0.5 in.), in hours	--	--	nm	nm	nm	--	--	nm
Antecedent dry period (>1 in.), in hours	--	--	nm	nm	nm	--	--	nm
Antecedent rainfall (48 hours), in inches	--	--	nm	nm	nm	--	--	nm
Antecedent rainfall (72 hours), in inches	--	--	nm	nm	nm	176.699	163.774	nm
Antecedent rainfall (168 hours), in inches	--	-.668	nm	nm	nm	--	--	nm

Table 26. Regression coefficients of models used to estimate event-mean concentrations from storm-rainfall characteristics

Explanatory variable	Specific conductance (µS/cm)	Turbidity (NTU)	Biochemical oxygen demand, 5-day (mg/L)	Coliform, fecal, membrane filter (CFU/100 mL)	Enterococcus, membrane filter (CFU/100 mL)	Dissolved solids (mg/L)	Suspended solids (mg/L)	Nitrate, total (mg/L as N)
Stony Brook (01104687)								
Intercept	319.125	39.725	-1.460	3.271	nm	nm	162.427	1.268
Duration (hours)	--	--	--	--	nm	nm	--	--
Total rainfall (in.)	--	-26.202	--	.113	nm	nm	--	-.187
Intensity, maximum in inches per hour	-410.857	277.066	--	--	nm	nm	155.274	--
Antecedent dry period (>0.1 in.), in hours	.924	--	.125	.005	nm	nm	--	--
Antecedent dry period (>0.5 in.), in hours	--	--	--	.003	nm	nm	--	--
Antecedent dry period (>1 in.), in hours	--	-.089	--	--	nm	nm	-.118	--
Antecedent rainfall (48 hours), in inches	--	--	--	--	nm	nm	--	--
Antecedent rainfall (72 hours), in inches	--	--	--	--	nm	nm	--	--
Antecedent rainfall (168 hours), in inches	--	--	-6.084	--	nm	nm	-137.780	--

Explanatory variable	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, total, Kjeldahl (mg/L as N)	Phosphorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Lead, total (µg/L)	Zinc, total (µg/L)
Stony Brook (01104687)								
Intercept	-0.206	-0.828	0.296	0.424	-4.920	7.396	nm	270.951
Duration (hours)	--	--	--	--	--	--	nm	-3.270
Total rainfall (in.)	--	--	--	-.041	--	--	nm	--
Intensity, maximum in inches per hour	--	1.573	--	.756	18.162	30.944	nm	106.654
Antecedent dry period (>0.1 in.), in hours	.004	.018	.002	.002	.045	.226	nm	--
Antecedent dry period (>0.5 in.), in hours	--	.002	--	--	--	--	nm	-.241
Antecedent dry period (>1 in.), in hours	--	--	--	.0004	--	--	nm	--
Antecedent rainfall (48 hours), in inches	--	--	--	--	--	--	nm	--
Antecedent rainfall (72 hours), in inches	1.934	5.503	--	--	--	--	nm	--
Antecedent rainfall (168 hours), in inches	--	-.588	-.281	-.388	--	-24.238	nm	-150.016

Table 27. Constituent loads for Water Year 2000 stormwater, Water Year 2000 dry-weather conditions, and 3-month and

[g, gram; kg, kilogram; TCFU, trillion colony-forming units; --, no model]

Annual loads	Biochemical oxygen demand, 5-day (kg)	Coliform, fecal, filter membrane (TCFU)	Entero-coccus, filter membrane (TCFU)	Dissolved solids (kg)	Suspended solids (kg)	Nitrate, total (kg as N)	Nitrogen, ammonia, total (kg as N)
Charles River at Watertown (01104615)							
Average							
Dry weather	640,000	1,700	860	67,000,000	1,270,000	140,000	38,000
Stormwater	280,000	5,600	3,600	22,800,000	1,440,000	61,000	20,000
Weighted average							
Dry weather	410,000	1,500	820	55,700,000	1,290,000	170,000	39,000
Stormwater	100,000	3,500	2,500	22,100,000	1,490,000	63,000	16,000
Regression analysis							
Stormwater	270,000	860	--	23,900,000	4,900,000	73,000	--
Single-family land use (01104630)							
Average							
Dry weather	190	16	6.0	46,900	666	190	180
Stormwater	2,300	52	58	12,200	15,800	140	89
Weighted average							
Dry weather	130	3.0	1.0	44,700	380	160	55
Stormwater	590	46	48	6,940	11,000	69	40
Regression analysis							
Stormwater	2,000	--	--	14,300	--	110	88
Laundry Brook (01104640)							
Average							
Dry weather	1,400	13	4.8	199,000	2,000	1,100	65
Stormwater	15,000	340	270	216,000	71,100	1,100	450
Weighted average							
Dry weather	1,100	12	3.3	207,000	2,090	930	68
Stormwater	4,800	350	320	184,000	52,700	820	290
Regression analysis							
Stormwater	10,000	140	83	213,000	68,300	1,100	290
Faneuil Brook Subbasin							
Average							
Dry weather	2,300	310	75	240,000	10,500	1,200	300
Stormwater	11,000	630	310	173,000	89,100	990	270
Weighted average							
Dry weather	1,100	130	64	252,000	1,310	1,200	180
Stormwater	2,800	660	220	135,000	64,300	670	140
Regression analysis							
Stormwater	7,200	500	360	146,000	--	800	240

1-year design storms, Lower Charles River Watershed, Massachusetts

Annual loads	Nitrogen, total Kjeldahl (kg as N)	Phos-phorus, total (kg)	Cadmium, total (g)	Chromium, total (g)	Copper, total (g)	Lead, total (g)	Zinc, total (g)
Charles River at Watertown (01104620)							
Average							
Dry weather	230,000	23,000	30,000	600,000	940,000	890,000	5,300,000
Stormwater	120,000	14,000	16,000	290,000	870,000	960,000	3,600,000
Weighted average							
Dry weather	220,000	23,000	38,000	690,000	940,000	900,000	10,000,000
Stormwater	110,000	13,000	17,000	280,000	780,000	910,000	3,100,000
Regression analysis							
Stormwater	110,000	9,900	--	490,000	--	690,000	2,100,000
Single-family land use (01104630)							
Average							
Dry weather	290	31	14	120	1,200	510	2,300
Stormwater	400	67	37	1,400	6,500	8,900	18,000
Weighted average							
Dry weather	140	17	11	110	840	250	1,300
Stormwater	210	45	27	930	3,600	5,600	11,000
Regression analysis							
Stormwater	360	40	54	--	6,000	--	17,000
Laundry Brook (01104640)							
Average							
Dry weather	520	64	75	860	4,300	1,600	11,000
Stormwater	3,000	350	190	7,600	42,000	51,000	140,000
Weighted average							
Dry weather	550	61	87	850	4,300	1,800	14,000
Stormwater	2,300	250	260	6,000	30,000	38,000	97,000
Regression analysis							
Stormwater	2,600	280	--	--	30,000	--	140,000
Faneuil Brook Subbasin							
Average							
Dry weather	790	88	71	700	3,300	2,900	25,000
Stormwater	1,600	220	210	5,500	26,000	41,000	84,000
Weighted average							
Dry weather	520	49	61	530	2,400	930	21,000
Stormwater	1,100	170	160	4,400	17,000	30,000	62,000
Regression analysis							
Stormwater	1,400	170	--	--	18,000	--	58,000

Table 27. Constituent loads for Water Year 2000 stormwater, Water Year 2000 dry-weather conditions, and 3-month and

Annual loads	Biochemical oxygen demand, 5-day (kg)	Coliform, fecal, filter membrane (TCFU)	Entero-coccus, filter membrane (TCFU)	Dissolved solids (kg)	Suspended solids (kg)	Nitrate, total (kg as N)	Nitrogen, ammonia, total (kg as N)
Multifamily land-use[2] (01104673)							
Average							
Dry weather	25	0.50	0.10	4,920	29	18	5.4
Stormwater	730	13	18	13,300	2,750	57	26
Weighted average							
Dry weather	29	.6	.1	4,040	22.9	16	6.6
Stormwater	210	7.8	14	12,400	2,630	59	17
Regression analysis							
Stormwater	--	7.4	--	--	--	--	12
Commercial land use (01104677)							
Average							
Dry weather	880	8.6	0.40	113,000	1,750	170	35
Stormwater	600	6.0	8.3	3,700	3,030	39	17
Weighted average							
Dry weather	250	10	.40	117,000	1,860	220	29
Stormwater	270	5.2	7.8	2,870	2,580	26	11
Regression analysis							
Stormwater	--	--	5.4	3,890	--	--	--
Muddy River							
Average							
Dry weather	2,200	5.0	1.8	298,000	6,010	770	440
Stormwater	22,000	550	340	385,000	122,000	2,200	1,000
Weighted average							
Dry weather	2,300	6.3	2.2	311,000	5,920	950	420
Stormwater	5,300	620	440	310,000	142,000	1,700	680
Regression analysis							
Stormwater	11,000	680	--	--	--	2,200	810
Muddy River conduit							
Average							
Dry weather	4,100	9.5	3.3	562,000	11,400	1,500	830
Stormwater	28,000	680	420	476,000	151,000	2,700	1,300
Weighted average							
Dry weather	4,300	12	4.1	588,000	11,200	1,800	790
Stormwater	6,600	770	550	383,000	176,000	2,100	840
Regression analysis							
Stormwater	17,600	680	--	--	--	2,800	1,000

1-year design storms, Lower Charles River Watershed, Massachusetts

Annual loads	Nitrogen, total Kjeldahl (kg as N)	Phos-phorus, total (kg)	Cadmium, total (g)	Chromium, total (g)	Copper, total (g)	Lead, total (g)	Zinc, total (g)
Multifamily land use (01104673)							
Average							
Dry weather	10	2.5	1.0	11	100	150	540
Stormwater	120	20	22	450	5,100	5,400	12,000
Weighted average							
Dry weather	11	2.5	.60	8.0	93	64	270
Stormwater	92	15	25	420	3,500	4,100	9,400
Regression analysis							
Stormwater	120	20	22	450	300	5,200	12,000
Commercial land use (01104677)							
Average							
Dry weather	110	78	17	190	3,200	1,800	9,200
Stormwater	98	12	22	310	6,100	8,200	11,000
Weighted average							
Dry weather	88	38	20	200	2,900	1,900	8,400
Stormwater	67	8.3	18	250	4,200	6,800	7,900
Regression analysis							
Stormwater	90	21	27	--	6,500	--	11,000
Muddy River							
Average							
Dry weather	1,600	110	92	1,100	5,700	3,900	20,000
Stormwater	4,800	670	710	15,000	100,000	92,000	250,000
Weighted average							
Dry weather	1,800	99	110	1,200	5,800	4,100	27,000
Stormwater	3,700	570	780	14,000	84,000	92,000	220,000
Regression analysis							
Stormwater	3,700	--	--	--	160,000	150,000	--
Muddy River conduit							
Average							
Dry weather	3,100	200	170	2,000	11,000	7,400	38,000
Stormwater	6,000	830	870	19,000	130,000	110,000	310,000
Weighted average							
Dry weather	3,500	190	200	2,200	11,000	7,800	50,000
Stormwater	4,600	710	960	18,000	100,000	110,000	280,000
Regression analysis							
Stormwater	5,000	--	--	--	220,000	200,000	--

Table 27. Constituent loads for Water Year 2000 stormwater, Water Year 2000 dry-weather conditions, and 3-month and

Annual loads	Biochemical oxygen demand, 5-day (kg)	Coliform, fecal, filter membrane (TCFU)	Entero-coccus, filter membrane (TCFU)	Dissolved solids (kg)	Suspended solids (kg)	Nitrate, total (kg as N)	Nitrogen, ammonia, total (kg as N)
Stony Brook Subbasin							
Average							
Dry weather	7,200	3.4	1.2	2,740,000	17,500	11,000	2,800
Stormwater	100,000	4,300	1,300	1,030,000	707,000	6,700	2,400
Weighted average							
Dry weather	10,000	2.0	1.2	3,440,000	20,200	13,000	3,000
Stormwater	21,000	2,300	1,300	746,000	415,000	4,500	1,300
Regression analysis							
Stormwater	68,000	4,200	--	--	568,000	6,300	4,100
Stony Brook overflow							
Average							
Dry weather	0	0	0	0	0	0	0
Stormwater	4,800	210	61	49,600	34,200	320	110
Weighted average							
Dry weather	0	0	0	0	0	0	0
Stormwater	1,000	110	63	35,100	20,100	220	61
Regression analysis							
Stormwater	830	90	--	--	21,900	120	35
Ungaged area							
Average							
Dry weather	4,300	25	8.7	615,000	9,610	2,400	590
Stormwater	50,000	1,200	840	774,000	250,000	4,100	1,800
Weighted average							
Dry weather	4,200	23	7.0	641,000	9,630	2,400	570
Stormwater	14,000	1,300	1,000	641,000	234,000	3,200	1,200
Regression analysis							
Stormwater	34,000	780	510	775,000	252,000	4,200	1,400

Design storm loads	Biochemical oxygen demand, 5-day (kg)	Coliform, fecal, filter membrane (TCFU)	Entero-coccus, filter membrane (TCFU)	Dissolved solids (kg)	Suspended solids (kg)	Nitrate, total (kg as N)	Nitrogen, ammonia, total (kg as N)
Charles River at Watertown (01104620)							
Average							
3-month	4,800	97	61	394,000	24,900	1,000	340
1-year	12,000	250	160	1,000,000	63,300	2,700	870
Weighted average							
3-month	1,800	67	44	382,000	25,800	1,100	280
1-year	4,500	150	110	970,000	65,500	2,800	710

1-year design storms, Lower Charles River Watershed, Massachusetts

Annual loads	Nitrogen, total Kjeldahl (kg as N)	Phos-phorus, total (kg)	Cadmium, total (g)	Chromium, total (g)	Copper, total (g)	Lead, total (g)	Zinc, total (g)
Stony Brook Subbasin							
Average							
Dry weather	7,200	1,300	720	8,700	34,000	17,000	140,000
Stormwater	15,000	2,900	2,900	48,000	240,000	630,000	910,000
Weighted average							
Dry weather	7,800	670	950	9,500	42,000	22,000	190,000
Stormwater	8,800	1,700	1,900	33,000	140,000	360,000	560,000
Regression analysis							
Stormwater	19,000	2,300	3,000	45,000	200,000	--	650,000
Stony Brook overflow							
Average							
Dry weather	0	0	0	0	0	0	0
Stormwater	730	140	140	2,300	12,000	31,000	44,000
Weighted average							
Dry weather	0	0	0	0	0	0	0
Stormwater	430	83	94	1,600	6,600	18,000	27,000
Regression analysis							
Stormwater	290	59	81	2,200	5,200	--	22,000
Ungaged area							
Average							
Dry weather	2,600	210	210	2,400	12,000	6,700	39,000
Stormwater	10,000	1,300	1,000	29,000	180,000	180,000	510,000
Weighted average							
Dry weather	2,800	200	240	2,500	13,000	7,200	49,000
Stormwater	7,900	1,000	1,200	25,000	140,000	160,000	400,000
Regression analysis							
Stormwater	9,000	1,200	--	--	230,000	250,000	510,000

Design storm loads	Nitrogen, total Kjeldahl (kg as N)	Phos-phorus, total (kg)	Cadmium, total (g)	Chromium, total (g)	Copper, total (g)	Lead, total (g)	Zinc, total (g)
Charles River at Watertown (01104615)							
Average							
3-month	2,200	240	270	5,000	15,000	17,000	62,000
1-year	5,500	600	680	13,000	38,000	42,000	160,000
Weighted average							
3-month	1,900	230	290	4,900	14,000	16,000	53,000
1-year	4,900	570	740	12	34,000	40,000	140,000

Table 27. Constituent loads for Water Year 2000 stormwater, Water Year 2000 dry-weather conditions, and 3-month and

Design storm loads	Biochemical oxygen demand, 5-day (kg)	Coliform, fecal, filter membrane (TCFU)	Entero-coccus, filter membrane (TCFU)	Dissolved solids (kg)	Suspended solids (kg)	Nitrate, total (kg as N)	Nitrogen, ammonia, total (kg as N)
Charles River at Watertown (01104620)—*Continued*							
Regression analysis							
3-month	4,200	9.9	--	396,000	29,100	1,200	--
1-year	11,000	24	--	1,010,000	94,900	3,100	--
Single-family land use (01104630)							
Average							
3-month	100	2.4	2.7	557	726	6.4	4.1
1-year	170	3.8	4.3	887	1,150	10	6.5
Weighted average							
3-month	26	2.0	2.1	306	484	3.0	1.8
1-year	41	3.2	3.4	487	771	4.8	2.8
Regression analysis							
3-month	110	--	--	456	--	2.1	1.6
1-year	180	--	--	727	--	1.1	2.6
Laundry Brook (01104640)							
Average							
3-month	580	13	10	8,260	2,710	41	17
1-year	950	22	17	13,600	4,470	67	28
Weighted average							
3-month	180	14	12	7,010	2,010	31	11
1-year	300	22	20	11,500	3,310	52	18
Regression analysis							
3-month	690	3.0	1.6	7,430	2,000	38	3.5
1-year	1,700	4.9	1.3	12,200	3,290	63	4.9
Faneuil Brook Subbasin							
Average							
3-month	310	19	9.3	5,150	2,650	30	7.9
1-year	530	31	16	8,690	4,480	50	13
Weighted average							
3-month	82	20	6.6	4,010	1,910	20	2.5
1-year	140	33	11	6,780	3,230	34	4.4
Regression analysis							
3-month	180	12	9.2	4,750	--	17	4.3
1-year	300	20	16	8,010	--	10	12
Multifamily land use (01104673)							
Average							
3-month	31	0.60	0.80	561	116	2.4	1.1
1-year	54	1.0	1.3	972	201	4.2	1.9
Weighted average							
3-month	9	.30	.60	523	111	2.5	.70
1-year	16	.60	1.0	907	192	4.3	1.3

Design storm loads	Nitrogen, total Kjeldahl (kg as N)	Phos-phorus, total (kg)	Cadmium, total (g)	Chromium, total (g)	Copper, total (g)	Lead, total (g)	Zinc, total (g)
Charles River at Watertown (01104615)—*Continued*							
Regression analysis							
3-month	2,300	240	--	4,600	--	21,000	58,000
1-year	6,900	610	--	12,000	--	80,000	210,000
Single-family land use (01104630)							
Average							
3-month	18	3.1	1.7	65	300	410	830
1-year	29	4.9	2.7	100	480	650	1,300
Weighted average							
3-month	9.3	2.0	1.2	41	160	240	470
1-year	15	3.1	1.9	65	250	390	740
Regression analysis							
3-month	11	2.9	2.5	--	200	--	570
1-year	18	4.6	3.9	--	320	--	910
Laundry Brook (01104640)							
Average							
3-month	110	13	7.2	290	1,600	1,900	5,500
1-year	190	22	12	480	2,600	3,200	9,000
Weighted average							
3-month	89	9.7	10	230	1,100	1,400	3,700
1-year	150	16	16	380	1,900	2,400	6,100
Regression analysis							
3-month	130	14	--	--	1,300	--	4,000
1-year	280	23	--	--	2,100	--	6,600
Faneuil Brook Subbasin							
Average							
3-month	47	6.5	6.2	160	760	1,200	2,500
1-year	79	11	10	280	1,300	2,000	4,200
Weighted average							
3-month	20	3.1	2.9	78	310	540	1,100
1-year	35	5.4	5.0	140	240	950	2,000
Regression analysis							
3-month	39	5.0	--	--	480	--	1,800
1-year	65	8.4	--	--	810	--	2,900
Multifamily land use (01104673)							
Average							
3-month	5.0	0.80	0.90	19	220	230	510
1-year	8.7	1.4	1.6	33	380	400	880
Weighted average							
3-month	3.9	.60	1.0	18	150	170	400
1-year	6.7	1.1	1.8	31	260	300	690

Table 27. Constituent loads for Water Year 2000 stormwater, Water Year 2000 dry-weather conditions, and 3-month and

Design storm loads	Biochemical oxygen demand, 5-day (kg)	Coliform, fecal, filter membrane (TCFU)	Entero-coccus, filter membrane (TCFU)	Dissolved solids (kg)	Suspended solids (kg)	Nitrate, total (kg as N)	Nitrogen, ammonia, total (kg as N)
Multifamily land use (01104673)—*Continued*							
Regression analysis							
3-month	--	.10	--	--	--	--	1.1
1-year	--	--	--	--	--	--	1.9
Commercial land use (01104677)							
Average							
3-month	29	0.30	0.40	180	148	1.9	0.80
1-year	45	.40	.60	278	227	3.0	1.3
Weighted average							
3-month	13	0.30	0.40	140	126	1.9	0.50
1-year	21	.40	.60	216	194	3.0	.80
Regression analysis							
3-month	--	--	.20	177	--	--	--
1-year	--	--	.30	273	--	--	--
Muddy River							
Average							
3-month	990	24	15	17,100	5,420	96	45
1-year	1,900	47	29	33,200	10,500	190	88
Weighted average							
3-month	240	28	20	13,800	6,300	76	42
1-year	460	58	42	26,700	12,200	150	79
Regression analysis							
3-month	--	15	--	--	--	87	36
1-year	--	30	--	--	--	170	68
Muddy River conduit							
Average							
3-month	1,000	26	16	17,900	5,700	100	47
1-year	1,800	43	27	30,500	9,670	170	81
Weighted average							
3-month	250	29	21	14,500	6,620	80	32
1-year	420	49	35	24,500	11,200	140	54
Regression analysis							
3-month	--	16	--	--	--	91	38
1-year	--	28	--	--	--	150	62
Stony Brook Subbasin[1]							
3-month	2,500	97	32	31,000	21,700	200	62
1-year	52,000	220	77	58,000	41,100	400	140

Design storm loads	Nitrogen, total Kjeldahl (kg as N)	Phos-phorus, total (kg)	Cadmium, total (g)	Chromium, total (g)	Copper, total (g)	Lead, total (g)	Zinc, total (g)
Multifamily land use (01104673)—*Continued*							
Regression analysis							
3-month	4.8	--	--	--	11	170	420
1-year	8.2	--	--	--	16	290	730
Commercial land use (01104677)							
Average							
3-month	4.8	0.60	1.1	15	300	400	520
1-year	7.4	.90	1.6	24	460	620	810
Weighted average							
3-month	3.3	0.40	0.90	12	200	330	390
1-year	5.1	.60	1.4	19	310	510	590
Regression analysis							
3-month	3.4	--	1.3	--	79	--	460
1-year	5.2	--	1.9	--	--	--	570
Muddy River							
Average							
3-month	210	30	31	690	4,600	4,100	11,000
1-year	420	58	61	1,300	8,800	7,900	22,000
Weighted average							
3-month	230	36	49	880	5,200	5,800	14,000
1-year	430	66	90	1,600	9,700	11,000	26,000
Regression analysis							
3-month	180	--	--	--	3,600	3,900	--
1-year	270	--	--	--	6,900	7,700	--
Muddy River conduit							
Average							
3-month	230	31	33	720	4,800	4,300	12,000
1-year	380	53	56	1,200	8,100	7,300	20,000
Weighted average							
3-month	170	27	36	660	3,900	4,300	10,000
1-year	300	45	62	1,100	6,600	7,300	18,000
Regression analysis							
3-month	190	--	--	--	3,700	4,100	--
1-year	250	--	--	--	6,400	7,000	--
Stony Brook Subbasin[1]							
3-month	430	81	0.10	1.5	7.0	20	28
1-year	840	170	.19	2.9	13	37	53

Table 27. Constituent loads for Water Year 2000 stormwater, Water Year 2000 dry-weather conditions, and 3-month and

Design storm loads	Biochemical oxygen demand, 5-day (kg)	Coliform, fecal, filter membrane (TCFU)	Entero-coccus, filter membrane (TCFU)	Dissolved solids (kg)	Suspended solids (kg)	Nitrate, total (kg as N)	Nitrogen, ammonia, total (kg as N)
Ungaged area							
Average							
3-month	950	25	16	16,200	5,160	91	43
1-year	1,500	40	25	25,900	8,220	140	68
Weighted average							
3-month	600	59	46	27,300	9,970	130	50
1-year	960	95	73	43,400	15,900	220	80
Regression analysis							
3-month	950	14	15	16,200	5,110	82	34
1-year	1,600	23	24	25,800	8,140	130	51

[1]Calculated by means of equation 6.

1-year design storms, Lower Charles River Watershed, Massachusetts—*Continued*

Design storm loads	Nitrogen, total Kjeldahl (kg as N)	Phos-phorus, total (kg)	Cadmium, total (g)	Chromium, total (g)	Copper, total (g)	Lead, total (g)	Zinc, total (g)
Ungaged area							
Average							
3-month	200	28	29	650	4,300	3,900	11,000
1-year	330	45	47	1,000	6,800	6,200	17,000
Weighted average							
3-month	340	43	53	1,100	5,800	6,800	17,000
1-year	540	69	84	1,700	9,200	11,000	27,000
Regression analysis							
3-month	170	28	--	--	3,400	3,800	11,000
1-year	230	45	--	--	5,300	6,000	17,000