Rhode Island Streams—1978-88, An Update on Water-Quality Conditions

By John C. Briggs

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DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., *Secretary*

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, *Director*

For additional information
write to:

Chief, New England District
U.S. Geological Survey
10 Causeway Street, Suite 926
Boston, Massachusetts 02222-1040

Copies of this report may be
purchased from:

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Box 25425
Denver, Colorado 80225

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Conversion Factors

The following factors can be used to convert inch-pound units to International System of Units (SI).

Multiply	*By*	*To obtain*
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	Kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	453.6	gram (g)
tons (short)	.9072	megagrams (Mg) or metric ton

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ABSTRACT

Water-quality data, collected from November 1978 through March 1988 at six stream sites, show that concentrations of common constituents are low compared to other parts of the United States. At several sites, concentrations of major plant nutrients, nitrogen and phosphorus, were in the range that may cause undesirable eutrophication if the waters were impounded. Lowest concentrations of nitrogen and phosphorus species were at the Branch River at Forestdale and the Pawcatuck River at Westerly.

Concentrations of the trace elements cadmium, chromium, and lead, which are at or exceed U.S. Environmental Protection Agency drinking-water criteria, were found at several sites, including the Blackstone River at Millville, Mass. Trace element concentrations that potentially exceed acute aquatic-life protection criteria at all sites were cadmium, chromium, copper, lead, and silver. Median concentrations of zinc at three sites potentially exceed the criterion for acute aquatic-life protection.

Several organic compounds were found in the water column, polychlorinated biphenyls (PCBs) were found at four of the six sites, dieldrin at three sites, lindane at two sites, and heptachlor at one site. In the bottom material, chlordane, DDD, DDE, DDT, dieldrin, and PCBs were found at all sites and aldrin, endosulfan, endrin, heptachlor, heptachlor epoxide, lindane, methoxychlor, and mirex at one or more sites.

Trend analysis of total phosphorus and nitrogen concentrations, specific conductance, and streamflow show no overall pattern of upward or downward trends for the sites. Most trends were flow dependent. However, an increase shown by the flow-adjusted specific conductance at the Pawcatuck River at Westerly, R.I., may indicate an increase in the dissolved solids entering the stream independent of the volume of flow.

INTRODUCTION

Rhode Island requires water-quality data to preserve, protect, and enhance the quality of its ground and surface waters. Additionally, the State must monitor and control the water quality of its streams to meet the requirements of Federal law. Water-quality data are required to (1) prepare comprehensive water-pollution control plans, including the establishment of effluent limitations for point-source discharges; (2) develop information on the causes and effects of reduction in (or increase in) pollution; (3) determine water quality of major rivers on a regular basis and appraise long-term quality changes; (4) promulgate, revise, and modify State water-quality standards for surface water to protect the public health and welfare, promote the economic development of the State, and enhance the quality of the State's water for present and future uses; and (5) evaluate the success of management strategies for surface-water quality.

The U.S. Geological Survey requires information on water quality to accomplish the Bureau's mission to appraise the quantity, quality, and use of the Nation's water. Two sites, Blackstone River at Millville, Mass., and Pawcatuck River at Westerly, are NASQAN (National Stream Quality Accounting Network) sites. NASQAN is a set of 438 stations on rivers nationwide where many water-quality characteristics are measured regularly. The major objectives of the NASQAN program are to (1) account for the quantity and quality of water moving within and from the United States; (2) depict the areal variability of stream quality; (3) depict the temporal variability of stream quality; and (4) detect long-term trends in stream quality.

Samples from additional sites were needed to improve spatial coverage of the State and to supplement the information collected at the NASQAN sites. To address these problems, a program to collect water-quality data from four additional Rhode Island streams, plus additional data to supplement the two NASQAN stations, was initiated in October 1978 in cooperation with the Rhode Island Department of Environmental Management.

Purpose and Scope

Specific objectives of this report are to (1) determine temporal trends in concentrations and/or loads for selected water-quality constituents and (2) provide information of the spatial variations of water-quality constituents within Rhode Island streams. An earlier report, Water Quality of Rhode Island Streams (Briggs and Feiffer, 1986) summarized the water-quality data available through September 1983. This report provides an update on water-quality samples collected and analyzed since the previous report and at the same time summarizes all available water-quality data for the stations in the study. Data from the stations have been published annually each water year (October through September), in the series of publications, "Water Resources Data for Massachusetts and Rhode Island" (U.S. Geological Survey, 1979-89). Additional data collected prior to 1978 are included in the summary.

Description of the Stream Stations

Six water-quality stations were chosen for the study. Five of the sites are located within Rhode Island, whereas the sixth, Blackstone River at Millville, Mass. is located upstream from the Massachusetts-Rhode Island border (figure 1). This latter site provides information on the water quality of the Blackstone River as it enters Rhode Island. Table 1 lists the Survey's station number, name, period of record, location, and any remarks about each site. The period of record indicates the years in which water-quality samples were collected and indicates that the analytical results are included in the summaries of data later in this report. All six sites are located downstream from regulated stream reaches. The Pawtuxet River is heavily regulated by the Scituate Reservoir, the Flat River Reservoir, and power plants. The Branch River at Forestdale is not actively regulated but there are old mill dams upstream from the sampling site.

The Rhode Island Department of Environmental Management (1988) established a water-use classification system that allows all of the freshwaters of the State to be assigned to one of the classes listed below. The stream classification system serves a dual purpose of setting desirable goals for achieving improved water quality and of reporting present water-quality conditions in the stream segment. The freshwater classes are:

Class A:	Drinking-water supply.
Class B:	Public water supply with appropriate treatment, agricultural uses, bathing or other primary contact recreational activities, and fish and wildlife habitat.
Class C:	Boating or other secondary contact recreational activities, fish and wildlife habitat, and industrial processes and cooling.
Class D:	Migration of fish and good aesthetic value.
Class E:	Nuisance conditions limiting use to certain industrial processes and cooling, to power production, and to navigation.

Class D and E are used only to describe an existing condition. Neither class is considered as an acceptable goal for any waters of the State.

The Rhode Island Department of Environmental Management (1988) rates the present water-quality conditions at all of the sites as class C, except for the two Pawtuxet River sites which are classified C/D. Desirable goals for all of the sites are class C, except for the Branch River at Forestdale which has a goal of class B.

METHODS OF STUDY

Characteristics and constituents currently measured as part of the Rhode Island water-quality program are listed in table 2. Water samples are collected monthly for analysis of major nitrogen and phosphorus species, bacteria, and selected physical constituents and twice-yearly for analyses of common chemical constituents, trace elements, and organic compounds. The twice-yearly samples are collected during periods of high and low streamflow. Once yearly during periods of low streamflow, bottom materials are collected for analysis of organic compounds. Additional chemical constituents are included in analyses for the NASQAN program and as part of various hydrologic studies. These additional constituents are included in the summary of

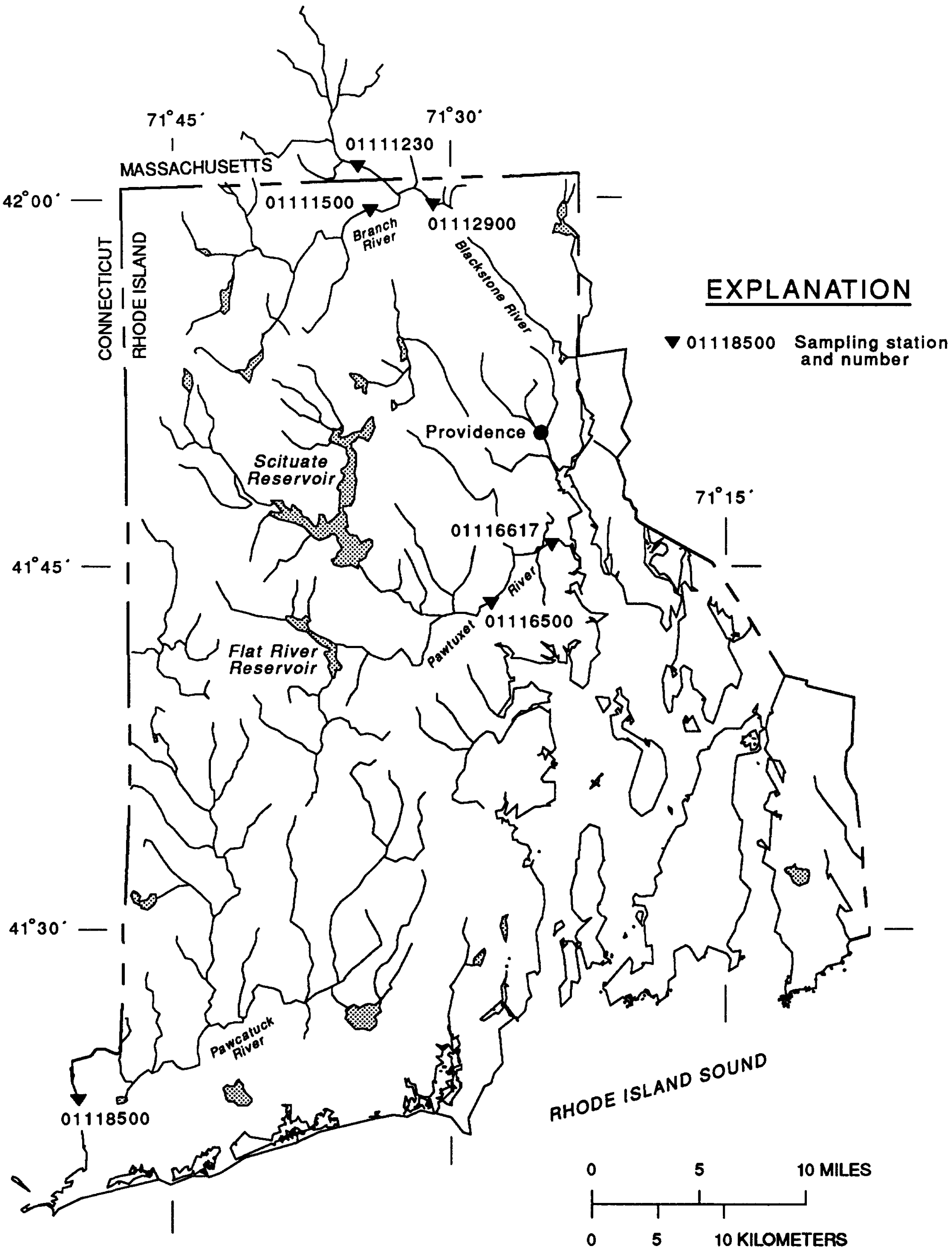

Figure 1.--Location of study area and sampling stations.

Table 1.—*Water-quality-sampling stations within the study area*

Station number, station name, and period of record	Station location and remarks
01111230 **Blackstone River at Millville, Mass.** 1971, 1973, 1978-March 1988	Latitude 42°01'16", longitude 71°34'04", Worcester County, 400 feet above railroad bridge, 0.8 mile southeast of Millville, 1 mile upstream from the Rhode Island-Massachusetts border, and 1.4 miles upstream from the Branch River, drainage area 277 mi^2. Flow regulated by powerplants, by West Hill Reservoir, and by other upstream reservoirs.
01111500 **Branch River at Forestdale, R.I.** 1953-58, 1965-69, 1971-72, 1975-March 1988	Latitude 41°59'47", longitude 71°33'47", Providence County, 400 feet downstream from the milldam at Forestdale, 1 mile east of Slatersville, and 1.6 mi upstream from the mouth, drainage area 91.2 mi^2. No active regulation by milldams upstream.
01112900 **Blackstone River at Manville, R.I.** 1970, 1978-March 1988	Latitude 41°58'18", longitude 71°28'14", Providence County, at Manville Road Bridge, 400 feet downstream from milldam at Manville, and 2.5 miles downstream from the Woonsocket Sewage Treatment Plant. Flow regulated by powerplants, by West Hill Reservoir, and by other upstream reservoirs.
01116500 **Pawtuxet River at Cranston, R.I.** 1953-58, 1961-73, 1975-March 1988	Latitude 41°45'03", longitude 71°26'44", Providence County, at Cranston, 0.7 mile upstream from Pocasset River, 1.4 miles upstream from the I-95 bridge, 1 mile downstream from the Warwick Sewage Treatment Plant, 4.5 miles downstream from the West Warwick Sewage Treatment Plant, drainage area 200 mi^2. Flow regulated by powerplants and the Scituate, Flat River, and other reservoirs.
01116617 **Pawtuxet River at Pawtuxet, R.I.** 1978-March 1988	Latitude 41°46'03", longitude 71°24'21", Providence County, at Warwick Avenue Road bridge, 3.2 miles downstream from the Cranston Sewage Treatment Plant, drainage area 232 mi^2. Flow regulated by powerplants and the Scituate, Flat River, and other reservoirs.
01118500 **Pawcatuck River at Westerly, R.I.** 1976-March 1988	Latitude 41°23'01", longitude 71°50'01", Washington County, at Westerly, 2.1 miles downstream from the Shunock River, drainage area 295 mi^2. No active regulation by mill dams.

data later in this report. All major classes of compounds have been included in analyses since 1978.

Samples for bacterial analysis are collected at one point in the stream and dissolved oxygen and temperature measured at one point. Other water samples are collected using fluvial-sediment sampling techniques described by Guy and Norman (1970). Briefly, depth-integrating samplers are lowered and raised at a uniform rate throughout the depth of the stream using sampling procedures called depth integration. The water-sediment mixture accumulates from all points in the sampled depth so that at every point an incremental volume of the mixture is collected that is proportional to the flow velocity at that point. Samplers are designed so that the water-sediment mixture moves with no acceleration as it leaves the ambient streamflow and enters the sampler intake. Depth-integrated samples

Table 2.—*Characteristics and constituents currently measured at all Rhode Island stations*

Measured monthly

Field determinations
- Streamflow
- Water temperature
- Specific conductance
- pH
- Dissolved oxygen

Biological characteristics
- Fecal coliform bacteria
- Fecal streptococci bacteria

Other (measured bimonthly)
- 5-day biochemical oxygen demand (BOD)

Major nutrients
- Nitrogen
  - Total nitrogen
  - Total organic nitrogen
  - Total ammonia nitrogen
  - Total nitrite nitrogen
  - Total nitrate nitrogen
- Phosphorus
  - Total phosphorus
  - Total orthophosphate

Measured twice yearly during periods of low and high streamflow

Common constituents
- Dissolved calcium
- Dissolved magnesium
- Dissolved sodium
- Dissolved potassium
- Dissolved chloride
- Dissolved sulfate
- Alkalinity

Other
- Color
- Chemical oxygen demand
- Total ROE (residue on evaporation) at 105°C
- Suspended ROE at 105°C
- Phenols
- Total oil and grease

Trace elements
- Total aluminum
- Total arsenic
- Total boron
- Total cadmium
- Total chromium
- Total copper
- Total iron
- Total lead
- Total manganese
- Total mercury
- Total molybdenum
- Total nickel
- Total selenium
- Total silver
- Total zinc

Organic compounds
- Total aldrin
- Total chlordane
- Total DDD
- Total DDE
- Total DDT
- Total Diazinon[1]
- Total dieldrin
- Total endosulfan
- Total endrin
- Total ethion[1]
- Total heptachlor epoxide
- Total heptachlor
- Total lindane
- Total malathion[1]

Organic compounds
- Total methoxychlor
- Total methyl parathion[1]
- Total Methyl Trithion[1]
- Total mirex
- Total parathion[1]
- Total Perthane
- Total PCB
- Total PCN
- Total silvex[1]
- Total Trithion[1]
- Total toxaphene
- Total 2,4–D[1]
- Total 2,4–DP[1]
- Total 2,4,5–T[1]

Measured yearly during periods of low streamflow

Organic compounds in stream bottom material
- Total aldrin
- Total chlordane
- Total DDD
- Total DDE
- Total DDT
- Total Diazinon[1]
- Total dieldrin
- Total endosulfan
- Total endrin
- Total ethion[1]
- Total heptachlor epoxide
- Total heptachlor
- Total lindane
- Total malathion[1]
- Total methoxychlor
- Total methyl parathion[1]
- Total Methyl Trithion[1]
- Total mirex
- Total parathion[1]
- Total Perthane
- Total PCB
- Total PCN
- Total Trithion[1]
- Total toxaphene

[1] Added in 1988 water year.

are collected across the cross section of the stream and combined into one sample for analysis.

Use of these techniques ensures that samples collected for analysis of chemical constituents contain representative subsamples of both the dissolved and suspended material passing through the stream cross section at the time of sampling. The term "total" used with a constituent means that the sample consists of a water-sediment mixture and that the analytical method determines all of the constituent in the sample. The term "total, recoverable" is the amount of a given constituent in solution after a representative water-suspended sediment sample has been digested by a method (usually using a dilute acid solution) that results in dissolution of readily soluble substances only. Complete dissolution of all particulate matter is not achieved by the digestion treatment and thus the determination represents less than the "total" amount. A "dissolved" constituent refers to that material in a representative water sample which passes through a 0.45-micrometer membrane filter. This is a convenient operational definition of a dissolved constituent used by Federal agencies and many State agencies that collect water samples.

Bottom material samples are collected using techniques described by Guy and Norman (1970). Streamflow values are either from measurements made at the time of sample collection or from a stage-discharge rating (Rantz and others, 1982). Specific conductance and pH were measured using methods described by Wood (1976), and dissolved oxygen concentration was measured using a dissolved-oxygen meter and techniques described in Fishman and Friedman (1985). Samples collected for laboratory analyses were preserved in the field and immediately shipped to the Survey laboratory in Atlanta, Georgia, until early 1985. Since then, the samples have been analyzed by the Survey laboratory in Arvada, Colorado. Sample preservation and analytical methods are described in Fishman and Friedman (1985), Britton and Greeson (1989), and Wershaw and others (1987).

Certain constituents often are not found in a sample of water from a stream. For example, the concentration of trace elements, organic compounds, or bacteria may be below the reporting level of the analytical procedure. The reporting level, which may be higher than the detection limit, is the lowest measured concentration of a constituent that may be reliably reported using a given analytical method (Feltz and others, 1985). Normally these results are reported and published as < (less than) the reporting level of the analytical procedure used for the determination. Reporting levels (Feltz and others, 1985) for any particular constituent in this study are listed in the summary tables shown later in this report. Reporting levels may have varied during the study; however, the listing is typical for each constituent. The actual values are available for each analysis in "Water resources data for Massachusetts and Rhode Island" (U.S. Geological Survey, 1979-89).

When summarizing a number of analyses using statistical techniques, the values less than the reporting level must be considered. For this report, all less-than values have been converted to zero. In all tables for constituents with a reporting level, a value of zero should be interpreted as less than the reporting level of the constituent.

Results from determination of the number of bacteria in a sample of water may occasionally be reported as > (greater than) a value. For this report, the > sign was dropped and the value included in the statistics. In the summary tables showing maximum values for bacteria counts, the actual value may have been greater than the maximum shown. Again, the actual values for each analysis are available (U.S. Geological Survey, 1979-89).

WATER QUALITY OF STREAMS

There is no clear, simple, quantitative way to describe the term "water quality." In practice, the quality of a water resource is determined by various measurements of physical, chemical, and biological characteristics. Results of the measurements can be compared with water-quality criteria to judge the suitability of the water for a particular use. There are several different sets of criteria, depending upon the intended use of the water. Water that meets the criteria for one particular use will not necessarily meet the criteria for other uses.

Discussions in the subsections that follow deal with the results of measurements of selected water-quality characteristics, and relate the results to some of the criteria for certain water uses. The Rhode Island Department of Environmental Management (1988) established criteria for maintaining the quality of the waters within the State. These criteria are given if available. Among other commonly cited criteria are: Water Quality Criteria 1972 (National Academy of Sciences and National Academy of Engineering, 1972); Quality Criteria for Water (U.S. Environmental Protection Agency, 1976); Quality Criteria for Water 1986 (U.S. Environmental Protection Agency, 1986); National Interim Primary and Secondary Drinking Water Regulations (U.S. Environmental Protection Agency, 1988a, 1988b); and recommended criteria proposed in miscellaneous articles and reports.

In some cases, criteria are cited which do not apply to the given stream or are more stringent than would normally be imposed on the stream. For example, drinking-water criteria may be cited even though the stream is not used as a drinking-water source. The criteria are used to give the reader benchmarks with which to compare concentrations of constituents in the stream.

Additional confusion occurs in trying to decide if drinking-water criteria should be applied to "total," "total recoverable," or "dissolved" constituents. Most of the criteria for domestic water supplies apply to water which is delivered to the tap of the ultimate user of a public water system. Water from a stream used as a drinking-water source may have been filtered or otherwise treated to remove particulate matter. While drinking-water treated in this way may not meet the strict definition of "dissolved" given above, an analysis of the water will probably be closer to a "dissolved" analysis of the source water rather than an analysis for "total" or "total recoverable" constituents. If the drinking-water has been chemically treated, the analytical results will be quite different from the dissolved analyses of the untreated water. In this report, drinking-water criteria may be compared with "total," "total recoverable," or "dissolved" constituents. Again, drinking-water criteria are used to give the reader a benchmark with which to compare concentrations of constituents within the stream.

Major Inorganic Chemicals

The major inorganic chemicals dissolved in water often are termed "common constituents" because these substances generally dominate the total mass of dissolved material in water and have been the subject of most chemical analyses performed by the Survey in the past. A summary of data on major inorganic chemicals measured at each station is included in table 3. Also included in table 3 are physical measurements of the water such as specific conductance and temperature, biological measurements, and measurements of streamflow and suspended sediment. These summaries include all data for the period of record for each site shown in table 1.

Calcium, Magnesium, and Hardness

Calcium and magnesium are widely distributed in the common minerals found in rock and soil. The presence of calcium and magnesium along with other metallic elements such as iron, strontium, and manganese, cause hardness in water. Many industrial and domestic water users are concerned about hardness. Hard water requires more soap and synthetic detergents for home laundry and washing than does soft water, and contributes to scaling in boilers and industrial equipment. In this report, hardness is reported as an equivalent concentration of calcium carbonate, $CaCO_3$. General guidelines for classification of waters are 0 to 60 mg/L (milligrams per liter) as $CaCO_3$ is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L as very hard (Durfor and Becker, 1964).

At all the study sites, mean concentrations of calcium, magnesium, and hardness were low compared to other regions of the United States (Briggs and Ficke, 1978). Mean hardness was in the soft water category at all sites, and maximum measured hardness was in the moderately hard range at only two sites; Pawtuxet River at Cranston and Pawtuxet River at Pawtuxet. No measured concentrations during1983-88 were outside of the soft range.

Sodium

Sodium, which occurs naturally in rock and soil material, may increase in streams because of human activities. Salting of roads to remove ice and snow during winter months is one source of increased sodium and chloride concentrations. The most restrictive drinking-water criterion for sodium is 20 mg/L (U.S. Environmental Protection Agency, 1986). This criterion was set to protect individuals who may be on "very restricted sodium diets." Mean sodium concentration at Branch River at Forestdale and Pawcatuck River at Westerly meet this criteri-

Table 3.—*Summary of measurements of common constituents, nutrients, bacteria, and field measurements for each station for the period of record*

[Analyses are in milligrams per liter except as indicated. Streamflow, cubic feet per second; turbidity, nephelometric turbidity units; specific conductance, microsiemens per centimeter at 25 degrees Celsius; bacteria, colonies per 100 milliliters; and fecal coliform bacteria with membrane-filter pore-size of 0.45 and 0.7 micrometers. No data available indicated by —]

01111230 Blackstone River at Millville, Mass.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Streamflow, instantaneous (ft^3/s)	111	596.0	350	575.6	83	2830	54.6	—
Specific conductance (μS/cm)	117	244.4	248	58.0	134	369	5.4	1
pH (standard units)	117	6.49	6.5	.42	5.6	7.5	.04	—
Temperature (degrees C)	116	12.2	12.8	8.3	.5	26.5	.8	—
Turbidity (NTU)	76	3.02	2.5	2.98	.0	20	.34	1
Oxygen, dissolved	116	9.38	9.2	2.72	2.7	14.5	.25	.1
Oxygen, dissolved (percent saturation)	56	82.9	84	13.3	30	112	1.8	—
Oxygen demand:								
biochemical, 5-day	25	2.36	2.0	1.25	1.0	5.0	.25	1
chemical (high level)	33	26.2	17	25.8	0	110	4.5	10
Coliform, total, immediate (cols./100 mL)	80	11,818.6	4,550	17,319.0	0	112,000	1,936.3	1
Coliform, fecal:								
0.45 μm-mf (cols./100 mL)	17	943.6	200	1,928.6	61	7,600	467.7	1
0.7 μm-mf (cols./100 mL)	73	1,090.3	310	1783.4	70	9,200	208.7	1
Streptococci, fecal, KF agar (cols./100 mL)	88	680.3	175	1411.8	0	8,500	150.5	1
Hardness:								
(as $CaCO_3$)	49	38.5	38	8.4	21	59	1.2	.1
noncarbonate (as $CaCO_3$)	27	21.4	21	7.6	7	37	1.5	.1
Calcium, dissolved (as Ca)	61	12.3	12	2.77	6.5	19	.35	.1
Magnesium, dissolved (as Mg)	61	1.98	1.9	.36	1.1	2.8	.05	.1
Sodium, dissolved (as Na)	61	27.1	27	6.7	16	41	.8	.1
Potassium, dissolved (as K)	61	3.13	2.9	.96	1.5	5.2	.12	.1
Alkalinity (as $CaCO_3$)	41	17.8	18	5.5	8	32	.9	1
Sulfate, dissolved (as SO4)	61	19.6	17	5.7	10	35	.7	.2
Chloride, dissolved (as Cl)	64	41.9	43	10.1	24	61	1.3	.1
Fluoride, dissolved (as F)	51	.19	.2	.10	.0	.4	.02	.1
Silica, dissolved (as SiO2)	51	5.72	5.7	1.14	2.2	8.7	.16	.1
Solids:								
residue at 105 °C, total	35	156.6	150	38.1	93	255	6.4	1
residue at 105 °C, susp.	35	8.0	7	6.2	0	31	1.0	1
residue at 180 °C, diss.	49	141.6	137	31.9	87	211	4.6	1
sum of constituents, diss.	43	123.0	118	28.8	78	190	4.4	—
Nitrogen:								
total (as N)	68	3.18	2.8	2.79	1.2	24	.34	.1
dissolved (as N)	20	2.72	2.6	1.30	1.1	5.3	.29	.1
organic total (as N)	76	.942	.62	2.589	.00	23	.297	.1
organic dissolved (as N)	19	.682	.50	.633	.00	2.3	.145	.1
ammonia dissolved (as N)	43	.702	.40	.828	.00	3.3	.126	.01
ammonia total (as N)	110	.746	.53	.873	.00	4.1	.083	.01
nitrite total (as N)	102	.039	.02	.040	.00	.22	.004	.01
nitrate total (as N)	61	1.24	.93	.822	.34	3.8	.105	.01
NO_2+NO_3 total (as N)	106	1.46	1.0	.970	.36	4.5	.094	.01
NO_2+NO_3 dissolved (as N)	43	1.39	.96	.943	.12	4.5	.144	.01
Phosphorus:								
total (as P)	110	.294	.27	.155	.08	1.2	.015	.01
dissolved (as P)	47	.169	.14	.118	.00	.53	.017	.01
ortho, total (as P)	102	.183	.17	.115	.00	.51	.011	.01
Sediment, suspended:								
concentration	37	10.3	8	12.7	1	79	2.1	1
discharge (tons per day)	24	20.7	6.1	29.8	2.2	122	6.08	—

Table 3.—*Summary of measurements of common constituents, nutrients, bacteria, and field measurements for each station for the period of record (continued)*

[Analyses are in milligrams per liter except as indicated. Streamflow, cubic feet per second; turbidity, nephelometric turbidity units; specific conductance, microsiemens per centimeter at 25 degrees Celsius; bacteria, colonies per 100 milliliters; and fecal coliform bacteria with membrane-filter pore-size of 0.45 and 0.7 micrometers. No data available indicated by —]

01111500 Branch River at Forestdale, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Streamflow,								
instantaneous (ft^3/s)	143	205.1	108	386.0	17	4,050	32.3	—
Specific conductance (µS/cm)	138	77.8	78	20.3	10	184	1.7	1
pH (standard units)	104	6.54	6.5	.68	5.0	9.8	.07	—
Temperature (degrees C)	188	12.9	12.6	8.8	.0	28.5	.6	—
Turbidity (NTU)	52	1.26	1.2	.71	.00	4.0	.10	1
Oxygen, dissolved	102	10.96	10.8	2.25	4.5	15.2	.22	.1
Oxygen, dissolved								
(percent saturation)	22	101.0	101	3.9	95	111	.8	—
Oxygen demand:								
biochemical, 5-day	32	.97	1.0	.47	.00	2.0	.08	1
chemical (high level)	31	27.8	17	44.6	0	200	8.0	10
Coliform, total,								
immediate (cols./100 mL)	76	2,990.1	1,800	6,968.0	140	60,000	799.3	1
Coliform, fecal:								
0.45 µm-mf (cols./100 mL)	11	628.9	160	1,521.0	40	5,200	458.6	1
0.7 µm-mf (cols./100 mL)	67	354.6	200	742.2	0	6,000	90.7	1
Streptococci, fecal,								
KF agar (cols./100 mL)	78	134.2	52	228.8	2	1,500	25.9	1
Hardness:								
(as $CaCO_3$)	20	15.4	14	5.4	9	32	1.2	.1
noncarbonate (as $CaCO_3$)	13	6.2	6	3.3	0	11	.9	.1
Calcium, dissolved (as Ca)	26	4.56	4.3	1.76	2.5	11	.35	.1
Magnesium, dissolved (as Mg)	26	.89	.9	.25	.0	1.3	.05	.1
Sodium, dissolved (as Na)	26	9.41	8.8	3.94	4.2	26	.77	.1
Potassium, dissolved (as K)	26	1.30	1.1	1.19	.5	7	.23	.1
Alkalinity (as $CaCO_3$)	13	11.3	8	11.9	4	48	3.3	1
Sulfate, dissolved (as SO4)	26	10.1	8.4	6.31	6.6	39	1.24	.2
Chloride, dissolved (as Cl)	29	13.2	13	3.46	3.7	19	.64	.1
Fluoride, dissolved (as F)	3	.07	.0	.12	.0	.2	.07	.1
Silica, dissolved (as SiO2)	3	2.60	3.5	2.19	.1	4.2	1.27	.1
Solids:								
residue at 105 °C, total	33	61.9	60	21.8	32	158	3.8	1
residue at 105 °C, susp.	33	6.5	5	5.9	0	23	1.0	1
residue at 180 °C, diss.	3	73.7	52	43.7	45	124	25.2	1
sum of constituents, diss.	1	51.0	51	—	51	51	—	—
Nitrogen:								
total (as N)	68	.905	.0	.479	.19	2.90	.272	.1
dissolved (as N)	0	—	—	—	—	—	—	.1
organic total (as N)	68	.426	.39	.329	.00	1.9	.040	.1
organic dissolved (as N)	0	—	—	—	—	—	—	.1
ammonia dissolved (as N)	0	—	—	—	—	—	—	.01
ammonia total (as N)	103	.174	.11	.281	.00	2.60	.028	.01
nitrite total (as N)	103	.009	.00	.022	.00	.20	.002	.01
nitrate total (as N)	49	.297	.24	.285	.11	2.10	.343	.01
NO_2+NO_3 total (as N)	103	.268	.24	.232	.00	2.30	.164	.01
NO_2+NO_3 dissolved (as N)	0	—	—	—	—	—	—	.01
Phosphorus:								
total (as P)	103	.029	.02	.050	.00	.40	.005	.01
dissolved (as P)	0	—	—	—	—	—	—	.01
ortho, total (as P)	103	.011	.00	.028	.00	.26	.003	.01
Sediment, suspended:								
concentration	0	—	—	—	—	—	—	1
discharge (tons per day)	0	—	—	—	—	—	—	—

Table 3.—*Summary of measurements of common constituents, nutrients, bacteria, and field measurements for each station for the period of record (continued)*

[Analyses are in milligrams per liter except as indicated. Streamflow, cubic feet per second; turbidity, nephelometric turbidity units; specific conductance, microsiemens per centimeter at 25 degrees Celsius; bacteria, colonies per 100 milliliters; and fecal coliform bacteria with membrane-filter pore-size of 0.45 and 0.7 micrometers. No data available indicated by —]

01112900 Blackstone River at Manville, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Streamflow, instantaneous (ft^3/s)	99	880.3	558	888.3	68	4,540	89.3	—
Specific conductance (µS/cm)	100	205.4	200	71.4	3	410	7.1	1
pH (standard units)	98	6.68	6.7	.50	5.5	7.6	.05	—
Temperature (degrees C)	100	12.5	12.5	8.9	.0	27.0	.9	—
Turbidity (NTU)	53	2.89	2.6	2.34	.4	15.0	.32	1
Oxygen, dissolved	99	10.59	10.2	2.25	5.4	15.2	.23	.1
Oxygen, dissolved (percent saturation)	23	96.8t	97	7.1	83	114	1.5	—
Oxygen demand:								
biochemical, 5-day	31	2.39	2.0	.84	1.0	4.0	.15	1
chemical (high level)	30	23.7	19	21.6	0	99	3.9	10
Coliform, total, immediate (cols./100 mL)	73	6,842.6	2,500	13,815.7	1	96,000	1,617.0	1
Coliform, fecal:								
0.45 µm-mf (cols./100 mL)	11	603.2	140	987.1	0	3,100	297.6	1
0.7 µm-mf (cols./100 mL)	62	732.2	305	1,223.8	2	6,000	155.4	1
Streptococci, fecal, KF agar (cols./100 mL)	74	198.7	39	651.0	0	4,800	75.7	1
Hardness:								
(as $CaCO_3$)	17	37.0	38	8.6	17	50	2.1	.1
noncarbonate (as $CaCO_3$)	11	19.7	21	12.1	5	44	3.6	.1
Calcium, dissolved (as Ca)	24	11.41	12	2.79	5.5	16.0	.57	.1
Magnesium, dissolved (as Mg)	24	1.85	1.8	.39	.9	2.5	.08	.1
Sodium, dissolved (as Na)	24	26.9	26	6.63	15	41	1.35	.1
Potassium, dissolved (as K)	24	3.12	3.2	.97	1.6	4.8	.20	.1
Alkalinity (as $CaCO_3$)	10	16.0	16	6.1	3	24	1.9	1
Sulfate, dissolved (as SO4)	23	20.5	19	5.8	12	34	1.2	.2
Chloride, dissolved (as Cl)	27	39.4	41	9.7	17	60	1.9	.1
Fluoride, dissolved (as F)	1	.5	.5	—	.5	.5	—	.1
Silica, dissolved (as SiO2)	1	5.6	5.6	—	5.6	5.6	—	.1
Solids:								
residue at 105 °C, total	33	135.0	135	38.9	0	217	6.8	1
residue at 105 °C, susp.	33	8.8	6	7.5	0	29	1.3	1
residue at 180 °C, diss.	0	—	—	—	—	—	—	1
sum of constituents, diss.	1	171	171	—	171	171	—	—
Nitrogen:								
total (as N)	68	2.37	2.2	1.05	1.0	5.7	.127	.1
dissolved (as N)	0	—	—	—	—	—	—	.1
organic total (as N)	69	.680	.6	.537	.00	3.6	.065	.1
organic dissolved (as N)	0	—	—	—	—	—	—	.1
ammonia dissolved (as N)	0	—	—	—	—	—	—	.01
ammonia total (as N)	101	.717	.55	.735	.03	5.2	.073	.01
nitrite total (as N)	100	.028	.02	.029	.00	.13	.003	.01
nitrate total (as N)	66	.983	.73	.584	.32	3.0	.072	.01
NO_2+NO_3 total (as N)	101	1.07	.79	.659	.00	3.1	.066	.01
NO_2+NO_3 dissolved (as N)	0	—	—	—	—	—	—	.01
Phosphorus:								
total (as P)	100	.298	.25	.166	.00	1.1	.017	.01
dissolved (as P)	0	—	—	—	—	—	—	.01
ortho, total (as P)	100	.216	.18	.152	.00	.84	.015	.01
Sediment, suspended:								
concentration	0	—	—	—	—	—	—	1
discharge (tons per day)	0	—	—	—	—	—	—	—

Table 3.—*Summary of measurements of common constituents, nutrients, bacteria, and field measurements for each station for the period of record (continued)*

[Analyses are in milligrams per liter except as indicated. Streamflow, cubic feet per second; turbidity, nephelometric turbidity units; specific conductance, microsiemens per centimeter at 25 degrees Celsius; bacteria, colonies per 100 milliliters; and fecal coliform bacteria with membrane-filter pore-size of 0.45 and 0.7 micrometers. No data available indicated by —]

01116500 Pawtuxet River at Cranston, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Streamflow, instantaneous (ft^3/s)	128	341.6	213	318.0	36	2,220	28.1	—
Specific conductance (µS/cm)	114	227.7	219	98.9	55	455	9.3	1
pH (standard units)	115	6.44	6.5	.43	5.2	7.3	.04	—
Temperature (degrees C)	191	12.4	13	7.8	.0	26.0	.56	—
Turbidity (NTU)	53	2.37	2.0	1.54	.18	8.0	.21	1
Oxygen, dissolved	111	9.08	8.8	3.12	1.1	14.2	.30	.1
Oxygen, dissolved (percent saturation)	25	85.8	91	17.0	35	105	3.4	—
Oxygen demand:								
biochemical, 5-day	31	2.55	2.0	1.55	1.0	9.0	.28	1
chemical (high level)	32	29.8	22	31.8	0	170	5.6	10
Coliform, total, immediate (cols./100 mL)	76	8,684.2	990	28,322.4	0	230,000	3,248.8	1
Coliform, fecal:								
0.45 µm-mf (cols./100 mL)	11	73.5	11	97.7	0	280	29.5	1
0.7 µm-mf (cols./100 mL)	67	331.7	34	1,176.7	0	8,500	143.8	1
Streptococci, fecal, KF agar (cols./100 mL)	75	102.3	16	312.4	0	2,000	36.1	1
Hardness:								
(as $CaCO_3$)	21	37.8	36	19.4	12	76	4.2	.1
noncarbonate (as $CaCO_3$)	16	20.2	20	14.2	0	40	3.6	.1
Calcium, dissolved (as Ca)	29	10.3	9.8	5.24	3.2	25	.97	.1
Magnesium, dissolved (as Mg)	29	2.55	1.8	1.78	.9	7.5	.33	.1
Sodium, dissolved (as Na)	29	26.4	23	14.47	4.8	57	2.69	.1
Potassium, dissolved (as K)	29	4.08	3.3	3.34	1.0	18	.62	.1
Alkalinity (as $CaCO_3$)	27	17.1	17	7.52	5	39	1.4	1
Sulfate, dissolved (as SO4)	35	29.1	22	16.1	9.5	76	2.73	.2
Chloride, dissolved (as Cl)	38	36.4	34	20.5	.0	82	3.32	.1
Fluoride, dissolved (as F)	6	.20	.2	.13	.0	.3	.05	.1
Silica, dissolved (as SiO2)	6	4.48	4.6	.84	3.2	5.8	.34	.1
Solids:								
residue at 105 °C, total	39	151.9	139	59.2	64	315	9.5	1
residue at 105 °C, susp.	33	10.6	8	10.5	0	51	1.8	1
residue at 180 °C, diss.	4	58.0	56	17.2	39	80	8.6	1
sum of constituents, diss.	4	105.5	208	97.9	34	249	49.0	—
Nitrogen:								
total (as N)	76	2.02	2.0	.963	.13	5.6	.180	.1
dissolved (as N)	0	—	—	—	—	—	—	.1
organic total (as N)	77	.605	.58	.471	.00	3.2	.054	.1
organic dissolved (as N)	0	—	—	—	—	—	—	.1
ammonia dissolved (as N)	2	.610	.61	.693	.12	1.1	.490	.01
ammonia total (as N)	109	.826	.74	.471	.00	2.6	.045	.01
nitrite total (as N)	103	.041	.02	.051	.00	.22	.005	.01
nitrate total (as N)	60	.625	.55	.312	.00	1.6	.040	.01
NO_2+NO_3 total (as N)	109	.622	.57	.334	.00	1.7	.109	.01
NO_2+NO_3 dissolved (as N)	1	.19	.19	—	.19	.19	—	.01
Phosphorus:								
total (as P)	111	.358	.31	.216	.00	1.2	.021	.01
dissolved (as P)	0	—	—	—	—	—	—	.01
ortho, total (as P)	103	.265	.23	.194	.00	1.1	.019	.01
Sediment, suspended:								
concentration	0	—	—	—	—	—	—	1
discharge (tons per day)	0	—	—	—	—	—	—	—

Table 3.—*Summary of measurements of common constituents, nutrients, bacteria, and field measurements for each station for the period of record (continued)*

[Analyses are in milligrams per liter except as indicated. Streamflow, cubic feet per second; turbidity, nephelometric turbidity units; specific conductance, microsiemens per centimeter at 25 degrees Celsius; bacteria, colonies per 100 milliliters; and fecal coliform bacteria with membrane-filter pore-size of 0.45 and 0.7 micrometers. No data available indicated by —]

01116617 Pawtuxet River at Pawtuxet, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Streamflow,								
instantaneous (ft^3/s)	97	431.9	289	429.6	45	3370	43.6	—
Specific conductance (μS/cm)	102	262.3	265	101.2	10	560	10.0	1
pH (standard units)	102	6.48	6.6	.43	5.6	7.5	.04	—
Temperature (degrees C)	104	12.6	12.5	8.0	.0	25.0	.8	—
Turbidity (NTU)	53	2.60	2.3	2.22	.40	15.0	.30	1
Oxygen, dissolved	103	8.01	8.0	3.65	.5	14.6	.36	.1
Oxygen, dissolved								
(percent saturation)	23	76.3	85	25.3	16	113	5.27	—
Oxygen demand:								
biochemical, 5-day	32	5.62	5.0	3.59	1.0	16	.64	1
chemical (high level)	31	33.9	27	25.6	0	98	4.6	10
Coliform, total,								
immediate (cols./100 mL)	77	46,800.3	14,000	138,758.2	0	1,100,000	15,813.0	1
Coliform, fecal:								
0.45 μm-mf (cols./100 mL)	11	139.7	33	233.6	4	800	70.4	1
0.7 μm-mf (cols./100 mL)	68	384.7	144	585.2	0	2,900	71.0	1
Streptococci, fecal,								
KF agar (cols./100 mL)	77	265.9	100	554.9		0	4,000	63.2
Hardness:								
(as $CaCO_3$)	16	44.8	44	13.3	19	64	3.3	.1
noncarbonate (as $CaCO_3$)	10	23.4	24	12.6	5	47	4.0	.1
Calcium, dissolved (as Ca)	24	13.1	12	5.98	5.5	35	1.22	.1
Magnesium, dissolved (as Mg)	24	3.24	2.4	2.79	1.1	15	.57	.1
Sodium, dissolved (as Na)	24	32.8	30	15.3	8.6	69	3.1	.1
Potassium, dissolved (as K)	23	4.30	4.5	1.96	1.6	10	.41	.1
Alkalinity (as $CaCO_3$)	15	22.9	23	5.1	14	31	1.3	1
Sulfate, dissolved (as SO4)	23	35.7	33	17.6	14	85	3.7	.2
Chloride, dissolved (as Cl)	26	41.7	42	14.5	20	75	2.9	.1
Fluoride, dissolved (as F)	0	—	—	—	—	—	—	
Silica, dissolved (as SiO2)	1	28	28	—	28	28	—	
Solids:								
residue at 105 °C, total	32	161.8	162	60.1	65	325	10.6	1
residue at 105 °C, susp.	33	11.2	9	8.5	0	32	1.5	1
residue at 180 °C, diss.	0	—	—	—	—	—	—	
sum of constituents, diss.	0	—	—	—	—	—	—	
Nitrogen:								
total (as N)	68	2.91	2.7	1.43	.51	6.6	.174	.1
dissolved (as N)	0	—	—	—	—	—	—	
organic total (as N)	68	.750	.70	.485	.00	2.3	.059	.1
organic dissolved (as N)	0	—	—	—	—	—	—	
ammonia dissolved (as N)	0	—	—	—	—	—	—	
ammonia total (as N)	103	1.37	1.1	.972	.00	4.8	.096	.01
nitrite total (as N)	103	.059	.04	.057	.00	.26	.006	.01
nitrate total (as N)	66	.748	.65	.569	.07	4.6	.070	.01
NO_2+NO_3 total (as N)	103	.780	.50	.526	.11	4.7	.052	.01
NO_2+NO_3 dissolved (as N)	0	—	—	—	—	—	—	
Phosphorus:								
total (as P)	103	.507	.47	.318	.00	2.0	.031	.01
dissolved (as P)	0	—	—	—	—	—	—	
ortho, total (as P)	103	.410	.37	.299	.00	1.4	.029	.01
Sediment, suspended:								
concentration	0	—	—	—	—	—	—	
discharge (tons per day)	0	—	—	—	—	—	—	

Table 3.—*Summary of measurements of common constituents, nutrients, bacteria, and field measurements for each station for the period of record (continued)*

[Analyses are in milligrams per liter except as indicated. Streamflow, cubic feet per second; turbidity, nephelometric turbidity units; specific conductance, microsiemens per centimeter at 25 degrees Celsius; bacteria, colonies per 100 milliliters; and fecal coliform bacteria with membrane-filter pore-size of 0.45 and 0.7 micrometers. No data available indicated by —]

01118500 Pawcatuck River at Westerly, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Streamflow, instantaneous (ft^3/s)	189	625.0	467	551.0	72	3750	40.1	—
Specific conductance (µS/cm)	184	99.8	93	30.9	52	222	2.3	1
pH (standard units)	155	6.63	6.6	.52	5.40	8.9	.04	—
Temperature (degrees C)	194	11.7	11.0	8.3	.0	30.0	.60	—
Turbidity (NTU)	128	1.28	1.0	.66	.0	6.0	.09	1
Oxygen, dissolved	148	10.96	10.7	2.10	6.9	15.2	.173	.1
Oxygen, dissolved (percent saturation)	127	96.1	95	10.7	63	134	1.0	—
Oxygen demand:								
biochemical, 5-day	35	1.07	1.0	.51	.0	3.0	.09	1
chemical (high level)	38	25.5	20	20.7	0	91	3.4	10
Coliform, total, immediate (cols./100 mL)	82	3,674.5	1,100	5,546.7	60	23,000	612.5	1
Coliform, fecal:								
0.45 µm-mf (cols./100 mL)	101	152.3	60	300.5	2	2,000	29.9	1
0.7 µm-mf (cols./100 mL)	59	183.5	96	291.0	1	2,000	37.9	1
Streptococci, fecal, KF agar (cols./100 mL)	139	647.6	84	2,180.3	2	22,000	184.9	1
Hardness:								
(as $CaCO_3$)	83	15.7	15	3.5	10	26	.4	.1
noncarbonate (as $CaCO_3$)	46	4.6	5	2.9	0	11	.4	.1
Calcium, dissolved (as Ca)	115	4.24	4.0	.96	2.5	6.8	.09	.1
Magnesium, dissolved (as Mg)	115	1.31	1.3	.34	.7	3.0	.03	.1
Sodium, dissolved (as Na)	87	12.0	11	5.52	5.1	34	.59	.1
Potassium, dissolved (as K)	87	1.12	1.1	.28	.4	1.9	.03	.1
Alkalinity (as $CaCO_3$)	56	12.4	11	9.3	0	58	1.2	1
Sulfate, dissolved (as SO4)	131	14.7	13	6.08	5.0	40	.53	.2
Chloride, dissolved (as Cl)	142	12.1	12	3.01	5.2	34	.25	.1
Fluoride, dissolved (as F)	69	.13	.1	.07	.0	.3	.01	.1
Silica, dissolved (as SiO2)	77	6.80	7.2	2.09	2.7	11	.24	.1
Solids:								
residue at 105 °C, total	135	77.1	74	20.4	44	172	1.8	1
residue at 105 °C, susp.	32	5.6	3	10.1	0	58	1.8	1
residue at 180 °C, diss.	133	72.2	70	19.0	43	164	1.6	1
sum of constituents, diss.	59	58.2	54	18.0	28	125	2.3	—
Nitrogen:								
total (as N)	109	.897	.82	.488	.18	4.6	.047	.1
dissolved (as N)	19	.875	.75	.319	.45	1.4	.073	.1
organic total (as N)	111	.460	.41	.314	.01	2.5	.030	.1
organic dissolved (as N)	26	.376	.34	.163	.07	.77	.032	.1
ammonia dissolved (as N)	70	.079	.03	.225	.00	1.8	.027	.01
ammonia total (as N)	124	.048	.04	.035	.00	.19	.003	.01
nitrite total (as N)	112	.006	.00	.008	.00	.03	.001	.01
nitrate total (as N)	48	.383	.32	.206	.00	.84	.030	.01
NO_2+NO_3 total (as N)	147	.400	.25	.207	.10	1.6	.017	.01
NO_2+NO_3 dissolved (as N)	47	.407	.37	.199	.00	.90	.029	.01
Phosphorus:								
total (as P)	146	.050	.04	.078	.00	.94	.006	.01
dissolved (as P)	117	.033	.04	.020	.00	.10	.002	.01
ortho, total (as P)	104	.023	.03	.020	.00	.09	.002	.01
Sediment, suspended:								
concentration	62	14.3	9	26.9	1	206	3.4	1
discharge (tons per day)	43	25.7	6.4	60.4	.66	389	9.2	—

on. Mean concentrations at the other four sites range from 26 to 33 mg/L. The highest measured concentration was 69 mg/L at Pawtuxet River at Pawtuxet. During the period 1983-88, the highest measured concentration was 42 mg/L at the Pawtuxet River at Cranston.

Chloride and Sulfate

The presence of chloride can adversely affect taste in drinking water, and can cause corrosion and other problems in industrial water supplies. A large concentration of sulfate in drinking water is undesirable because of its laxative effects. To prevent these effects, a recommended criteria of 250 mg/L for chlorides and sulfates in domestic water supplies was set by the U.S. Environmental Protection Agency (EPA) (1988b). The highest concentrations of chloride and sulfate measured in the study area for the entire period of record were 82 and 85 mg/L, respectively, and 59 and 41 mg/L during the 1983-88 period. Mean chloride concentrations were greatest in the Pawtuxet River at Pawtuxet and the Blackstone River at Millville, Mass. The mean sulfate concentration was greatest in the Pawtuxet River at Pawtuxet.

Fluoride

A concentration up to about 1 mg/L of fluoride is considered to have a beneficial health effect in drinking water by reducing tooth decay. However, large concentrations of fluoride can produce dental fluorosis—mottling and chipping of tooth enamel. While there are relatively few analyses of fluoride at the six sites, the concentrations were low. Measured concentrations ranged from 0.0 to 0.5 mg/L.

Major Nutrients

The major species of nitrogen and phosphorus are commonly found at low concentrations in natural waters. Significant concentrations of nitrogen and phosphorus in streams are usually the result of inflow of municipal or industrial wastewater or runoff from agricultural areas. This nutrient enrichment is undesirable because it may lead to algal blooms, which subsequently can reduce the dissolved-oxygen concentrations.

Frequently, there is confusion caused by the units used in the reporting of concentration of nitrogen and phosphorus. Some investigators report the concentration of ions as mass of the ion's oxide per unit volume, such as nitrogen as NO_3 (nitrate) and phosphorus as PO_4 (phosphate). Other investigators report only the mass of nitrogen or phosphorus, such as nitrogen as N and phosphorus as P. The latter method is used throughout this report and gives results considerably different from the former method. For example, 1.0 mg/L of nitrate nitrogen as N, is equivalent to 4.4 mg/L of nitrate, NO_3. Differences may also be found in the schemes for reporting nitrogen and phosphorus as dissolved, suspended, or total. Data in this report are presented for "dissolved" and "total" concentrations.

Nitrogen

The most common nitrogen forms found in water are nitrate, nitrite, ammonia, and organic nitrogen. For a particular analysis, results can be summed for these constituents and reported as "nitrogen." Organic nitrogen is nitrogen included within complex carbon-containing molecules formed by plants and animals. Waste material from living organisms, as well as their remains after death, are decomposed by bacterial action releasing nitrogen compounds. Organic compounds containing nitrogen are further broken down by bacteria into ammonia. Ammonia is converted by other bacteria to nitrite and then rapidly into nitrate in the presence of oxygen.

Criteria for nitrogen in water are generally based on the nitrate concentration as N. EPA (1988a) specifies 10 mg/L as the maximum allowable concentration of nitrate nitrogen for drinking-water supplies to provide human health protection. Criteria vary on maximum concentrations of nitrate for the protection of aquatic life—that is, levels that will not lead to nuisance growths of algae and other aquatic plants. The U.S. Council on Environmental Quality (1975) used a maximum concentration of 0.6 mg/L of nitrate nitrogen as a "benchmark" level for aquatic-life protection, suggesting that higher levels are indicative of undesirable eutrophication. Other criteria for nitrate nitrogen established across the country to limit eutrophication range from 0.10 mg/L in pristine waters to 3 mg/L in less sensitive waters. A study of 346 sampling points on major rivers within the United States showed that nitrate nitrogen levels were below 1.0 mg/L at 85 percent of the sites and below 0.5 mg/L at 65 percent of the sites (Briggs and Ficke, 1978).

Mean total nitrate plus nitrite concentrations were lowest in the Branch River at Forestdale and in the Pawcatuck River at Westerly, with values of 0.268 and 0.400 mg/L, respectively. Nitrate plus nitrite data were used for comparison with the nitrate criteria since the nitrite concentration is quite small compared to the nitrate concentration. Also, there are more determinations of nitrate plus nitrite than there are of nitrate alone. Highest mean total nitrate plus nitrite values were in the Blackstone River at Millville, Mass., and in the Blackstone River at Manville with 1.46 and 1.07 mg/L, respectively. Although these values are lower than the EPA drinking-water criterion, they are in a range that could cause growth of excessive quantities of aquatic plants if the water were impounded in a lake and if the supply of other essential nutrients was sufficient. Total nitrogen concentrations were lowest again in the Branch River at Forestdale and in the Pawcatuck River at Westerly, with mean values of 0.905 and 0.897 mg/L, respectively. Highest mean concentrations were in the Blackstone River at Millville, Mass., and in the Pawtuxet River at Pawtuxet with mean concentrations of 3.18 and 2.91 mg/L.

Phosphorus

Phosphorus data are reported as "total phosphorus as P" and "total orthophosphate phosphorus as P." Total phosphorus includes all forms of phosphorus such as soluble orthophosphate, soluble hydrolyzable phosphorus, soluble organic phosphorus and phosphorus associated with colloidal material and both inorganic and organic suspended material. Even though orthophosphate phosphorus is the only phosphorus form that is readily available as a plant nutrient, the total amount of phosphorus is an important environmental measurement because phosphorus may be converted by biological or chemical means into orthophosphate phosphorus.

EPA (1976, 1986) proposed a phosphate phosphorus criterion of 0.05 mg/L as P for any stream at the point where it enters a lake or reservoir and 0.025 mg/L within the lake or reservoir. This criterion is established to prevent or control nuisance aquatic plant growth. The U.S. Council on Environmental Quality (1976, p. 27) has suggested maximum concentrations of phosphorus of 0.1 mg/L for aquatic-life protection.

Rhode Island Department of Environmental Management (1988) regulations allow no new discharges of wastes containing phosphates into or immediately upstream from lakes or ponds. Phosphates are to be removed from existing discharges to the extent that such removal is or may become technically and reasonably feasible.

Orthophosphate phosphorus concentrations were lowest at the Branch River at Forestdale and at the Pawcatuck River at Westerly with mean values of 0.011 mg/L and 0.023 mg/L respectively. Total phosphorus concentrations were lowest at the Branch River at Forestdale and the Pawcatuck River at Westerly with respective mean concentrations of 0.029 and 0.050 mg/L. Highest mean total phosphorus concentration (0.507 mg/L) and mean orthophosphate phosphorus concentration (0.410 mg/L) were measured at the Pawtuxet River at Pawtuxet.

Bacteria

Natural waters contain many species of bacteria; some are pathogenic, or disease causing, but fortunately most are harmless. People, of course, are concerned mainly about those that present a threat of disease. It is impossible to monitor for all forms of pathogens. Instead, ground and surface waters are examined for signs that these organisms may be present. Classically, this has been done by monitoring for "indicator" organisms in the so-called coliform bacterial group and, more recently, in the fecal streptococci group. The logic of the scheme is that (1) indicator bacteria, which occur in large numbers in fecal material, show the presence of fecal contamination, and (2) contaminated waters are likely to contain pathogens in numbers proportional to the numbers of indicator bacteria.

At the six stations studied, bacteria samples were collected to determine numbers of (1) fecal coliform bacteria, those members of the coliform group found in the feces of various warm-blooded animals, and (2) fecal streptococci bacteria, which are also found in the intestines of warm-blooded animals. Most criteria for water quality are written in terms of fecal coliform bacteria. For body-contact sports such as swimming, the EPA (1976) set a criterion that the fecal coliform bacteria count should not exceed a log mean (geometric mean) of 200 per

100 mL (milliliters) of sample in a minimum of five samples collected over a 30-day period. In addition, not more than 10 percent of the samples collected during the period should have a count that exceeds 400 per 100 mL. Water Quality Criteria 1972 (National Academy of Sciences and National Academy of Engineering, 1972) recommended that raw waters used as a source for public supply contain not more than 2,000 colonies of fecal coliform bacteria per 100 mL.

Rhode Island Department of Environmental Management (1988) has set the desirable goals for water quality as class C for all stations in this study except for the Branch River at Forestdale, which has a goal of class B. Class C waters are waters for boating or other secondary contact recreational activities, fish and wildlife habitat, and industrial processing and cooling. No applicable fecal coliform bacteria criteria have been established for class C waters. Class B waters in Rhode Island are used for public water supplies with appropriate treatment, agricultural uses, and bathing or other primary contact recreational activities. Fecal coliform bacteria criteria for class B waters state that the counts per 100 mL are not to exceed a median value of 200, and not more than 20 percent of the samples should exceed a value of 500.

At three sites, the Pawtuxet River at Cranston, the Pawtuxet River at Pawtuxet, and the Pawcatuck River at Westerly, median sample counts are low enough to meet the Rhode Island class B criteria. However, samples collected as part of this study were not collected at sufficient frequencies to meet the sampling frequency requirement of the criterion. Each of the two Pawtuxet River sites with low median counts is located downstream from a wastewater-treatment plant. These low median counts may reflect the discharge of chlorinated effluent from the plants into the river.

Trace Elements

Trace elements, also frequently called minor elements, are those that commonly occur in relatively small amounts in natural water. Trace elements may also be added to the stream in municipal and industrial wastes. Many are of concern because, even in trace quantities, they may be toxic to people, aquatic plants and animals, or crops when present in irrigation water. Table 4 summarizes trace-element data for the six stations. Table 5 lists selected criteria and the maximum measured concentration of 13 trace elements at the six sites. Unless otherwise stated, the criteria in the following discussion pertain to drinking water or acute aquatic-life protection (U.S. Environmental Protection Agency, 1986, 1988a, 1988b), which Rhode Island has adopted (Rhode Island Department of Environmental Management, 1988).

In table 5, those criteria listed for aquatic-life protection in soft water vary with the hardness of the water. The softer the water, the lower the aquatic-life protection value. A hardness concentration of 14 mg/L as $CaCO_3$ was used to calculate the criteria used in this report, since the sites with the softest water were the Pawcatuck River at Westerly with a median hardness concentration of 15 mg/L as $CaCO_3$ and the Branch River at Forestdale with a median concentration of 14 mg/L. These criteria represent worst-case conditions. To determine whether a value truly exceeds the criterion, the hardness of the individual sample must be used to determine the concentration for the criterion; then, this criterion value is compared to the measured value of the constituent of interest. In the following section, the term "potentially exceed" identifies values which exceeded criteria calculated using hardness concentrations of 14 mg/L as $CaCO_3$. These values may not exceed the actual criterion for the particular conditions under which they occurred.

Arsenic.—The most stringent criterion for arsenic is 50 µg/L (micrograms per liter) for domestic water supplies. Of the water-quality sites, the highest measured concentration for arsenic was only 6 µg/L at the Blackstone River at Millville, Mass.

Barium.—The maximum concentration of barium was 100 µg/L at the Blackstone River at Millville, Mass., and at the Pawcatuck River at Westerly. This is less than the drinking-water criterion of 1,000 µg/L.

Boron.—The suggested criterion for boron is a maximum of 750 µg/L for long-term irrigation on sensitive crops. While irrigation is not a major use of the water from any of the six sites, boron levels were lower than the maximum acceptable limit for irrigation use. The maximum concentration measured was 270 µg/L at the Blackstone River at Millville, Mass.

Cadmium.—The drinking-water criterion for cadmium is 10 µg/L. This value was reached in

Table 4.—*Summary of measurements of trace elements for each station for the period of record*

[Analyses are in micrograms per liter. No data available indicated by —]

01111230 Blackstone River at Millville, Mass.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Aluminum, dissolved (as Al)	16	36.3	35	20.3	0	70	5.1	10
Aluminum, total recoverable (as Al)	6	141.7	90	110.5	40	330	45.1	10
Arsenic, dissolved (as As)	31	2.1	2	1.2	0	6	.2	1
Arsenic, total (as As)	24	2.8	2	1.5	1	6	.3	1
Barium, dissolved (as Ba)	31	30.4	23	21.6	0	100	3.9	100
Barium, total recoverable (as Ba)	16	37.5	0	50.0	0	100	12.5	100
Beryllium, dissolved (Be)	17	.3	.5	.5	0	2	.1	10
Beryllium, total recoverable (as Be)	2	.0	0	.0	0	0	.0	10
Boron, total recoverable (as B)	10	111.0	100	74.6	0	270	23.6	10
Cadmium, dissolved (as Cd)	31	2.2	2	2.0	0	8	.4	1
Cadmium, total recoverable (as Cd)	22	3.4	3	2.3	1	10	.5	1
Chromium, dissolved (as Cr)	31	6.4	3	8.3	0	30	1.5	1
Chromium, total recoverable (as Cr)	24	17.3	20	11.3	0	40	2.3	1
Cobalt, dissolved (as Co)	31	.5	0	1.0	0	3	.2	3
Cobalt, total recoverable (Co)	16	.9	.5	1.2	0	4	.3	1
Copper, dissolved (as Cu)	31	11.7	11	5.3	5	31	.9	1
Copper, total recoverable (as Cu)	23	22.3	21	7.6	11	39	1.6	1
Iron, dissolved (as Fe)	32	222.1	205	103.0	58	420	18.2	10
Iron, total recoverable (as Fe)	24	842.1	735	404.4	420	1900	82.5	10
Lead, dissolved (as Pb)	31	3.7	3	3.0	0	14	.5	1
Lead, total recoverable (as Pb)	24	13.5	10	11.4	0	51	2.3	1
Lithium, dissolved (as Li)	17	4.5	4	7.3	0	30	1.8	4
Lithium, total recoverable (as Li)	2	.0	0	.0	0	0	.0	10
Manganese, dissolved (as Mn)	32	90.6	86	48.3	15	230	8.5	10
Manganese, total recoverable (as Mn)	25	108.4	120	48.7	30	200	9.7	10
Mercury, dissolved (as Hg)	31	.1	.1	.1	.0	.2	.0	.1
Mercury, total recoverable (as Hg)	24	.0	.0	.1	.0	.4	.0	.1
Molybdenum, dissolved (as Mo)	17	1.2	1	3.3	0	10	.8	1
Molybdenum, total recoverable (as Mo)	7	9.9	10	15.5	0	34	5.9	1
Nickel, dissolved (as Ni)	29	29.3	25	24.0	9	130	4.5	1
Nickel, total recoverable (as Ni)	22	36.5	30	28.9	0	130	6.2	1
Selenium, dissolved (as Se)	31	.1	0	.3	0	1	.1	1
Selenium, total (as Se)	24	.1	0	.3	0	1	.1	1
Silver, dissolved (as Ag)	30	.2	0	.5	0	2	.1	1
Silver, total recoverable (as Ag)	26	.2	0	.5	0	2	.1	1
Strontium, dissolved (as Sr)	17	65.6	66	9.1	53	86	2.2	10
Strontium, total recoverable (as Sr)	2	90.0	90	14.1	80	100	10.0	10
Vanadium, dissolved (as V)	17	.7	1	2.0	0	6	.5	6
Zinc, dissolved (as Zn)	31	68.5	57	41.1	30	220	7.4	3
Zinc, total recoverable (as Zn)	24	95.8	80	50.7	40	220	10.4	10

Table 4.—*Summary of measurements of trace elements for each station for the period of record (continued)*

[Analyses are in micrograms per liter. No data available indicated by —]

01111500 Branch River at Forestdale, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Aluminum, dissolved (as Al)	2	250.0	250	353.6	0	500	250.0	10
Aluminum, total recoverable (as Al)	5	128.0	110	65.7	60	230	29.4	10
Arsenic, dissolved (as As)	0	—	—	—	—	—	—	1
Arsenic, total (as As)	15	.5	1	.5	0	1	.1	1
Barium, dissolved (as Ba)	0	—	—	—	—	—	—	100
Barium, total recoverable (as Ba)	2	.0	0	.0	0	0	.0	100
Beryllium, dissolved (Be)	0	—	—	—	—	—	—	10
Beryllium, total recoverable (as Be)	2	.0	0	.0	0	0	.0	10
Boron, total recoverable (as B)	12	22.5	30	18.2	0	50	5.2	10
Cadmium, dissolved (as Cd)	0	—	—	—	—	—	—	1
Cadmium, total recoverable (as Cd)	13	.5	3	.7	0	2	.2	1
Chromium, dissolved (as Cr)	0	—	—	—	—	—	—	1
Chromium, total recoverable (as Cr)	15	8.7	10	8.3	0	20	2.2	1
Cobalt, dissolved (as Co)	0	—	—	—	—	—	—	3
Cobalt, total recoverable (Co)	2	.0	0	.0	0	0	.0	1
Copper, dissolved (as Cu)	2	70.0	70	56.6	30	110	40.0	1
Copper, total recoverable (as Cu)	14	9.1	5	7.4	3	24	2.0	1
Iron, dissolved (as Fe)	2	345.0	205	403.1	60	630	285.0	10
Iron, total recoverable (as Fe)	16	548.8	535	265	210	1000	66.3	10
Lead, dissolved (as Pb)	0	—	—	—	—	—	—	1
Lead, total recoverable (as Pb)	15	6.3	3	8	0	31	2.1	1
Lithium, dissolved (as Li)	2	300.0	300	424.3	0	600	300.0	4
Lithium, total recoverable (as Li)	2	.0	0	.0	0	0	.0	10
Manganese, dissolved (as Mn)	2	.0	.0	0	0	0	.0	10
Manganese, total recoverable (as Mn)	16	101.9	90	45.5	60	240	11.4	10
Mercury, dissolved (as Hg)	0	—	—	—	—	—	—	.1
Mercury, total recoverable (as Hg)	15	.0	.1	.1	.0	.2	.0	.1
Molybdenum, dissolved (as Mo)	0	—	—	—	—	—	—	1
Molybdenum, total recoverable (as Mo)	6	10.7	3	13.7	1	32	5.6	1
Nickel, dissolved (as Ni)	0	—	—	—	—	—	—	1
Nickel, total recoverable (as Ni)	14	6.3	4.5	6.4	2	26	1.7	1
Selenium, dissolved (as Se)	0	—	—	—	—	—	—	1
Selenium, total (as Se)	15	.1	0	.5	0	2	.1	1
Silver, dissolved (as Ag)	0	—	—	—	—	—	—	1
Silver, total recoverable (as Ag)	12	.2	0	.6	0	2	.2	1
Strontium, dissolved (as Sr)	0	—	—	—	—	—	—	10
Strontium, total recoverable (as Sr)	2	75.0	75	21.2	60	90	15.0	10
Vanadium, dissolved (as V)	0	—	—	—	—	—	—	6
Zinc, dissolved (as Zn)	2	235.0	235	332.3	0	470	235.0	3
Zinc, total recoverable (as Zn)	15	44.7	40	31.8	10	120	8.2	10

Table 4.—*Summary of measurements of trace elements for each station for the period of record (continued)*

[Analyses are in micrograms per liter. No data available indicated by —]

01112900 Blackstone River at Manville, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Aluminum, dissolved (as Al)	0	—	—	—	—	—	—	10
Aluminum, total recoverable (as Al)	5	124.0	90	75.4	50	210	33.7	10
Arsenic, dissolved (as As)	0	—	—	—	—	—	—	1
Arsenic, total (as As)	15	1.7	2	1.0	0	4	.2	1
Barium, dissolved (as Ba)	0	—	—	—	—	—	—	100
Barium, total recoverable (as Ba)	2	.0	0	.0	0	0	.0	100
Beryllium, dissolved (Be)	0	—	—	—	—	—	—	10
Beryllium, total recoverable (as Be)	2	.0	0	.0	0	0	.0	10
Boron, total recoverable (as B)	12	110.0	105	62.8	40	240	18.1	10
Cadmium, dissolved (as Cd)	0	—	—	—	—	—	—	1
Cadmium, total recoverable (as Cd)	13	1.5	1	1.2	0	4	.3	1
Chromium, dissolved (as Cr)	0	—	—	—	—	—	—	1
Chromium, total recoverable (as Cr)	15	19.3	20	14.9	0	50	3.8	1
Cobalt, dissolved (as Co)	0	—	—	—	—	—	—	3
Cobalt, total recoverable (Co)	2	1.5	2	2.1	0	3	1.5	1
Copper, dissolved (as Cu)	0	—	—	—	—	—	—	1
Copper, total recoverable (as Cu)	14	19.3	15.5	11.0	8	42	2.9	1
Iron, dissolved (as Fe)	1	320.0	320	—	320	320	—	10
Iron, total recoverable (as Fe)	15	670.0	570	341.8	0	1500	88.2	10
Lead, dissolved (as Pb)	0	—	—	—	—	—	—	1
Lead, total recoverable (as Pb)	15	12.9	9	11.7	2	45	3.0	1
Lithium, dissolved (as Li)	0	—	—	—	—	—	—	4
Lithium, total recoverable (as Li)	2	.0	0	.0	0	0	.0	10
Manganese, dissolved (as Mn)	1	260.0	260	—	260	260	—	10
Manganese, total recoverable (as Mn)	15	102.0	100	46.5	0	220	12.0	10
Mercury, dissolved (as Hg)	0	—	—	—	—	—	—	.1
Mercury, total recoverable (as Hg)	15	.2	.1	.5	.0	1.8	.1	.1
Molybdenum, dissolved (as Mo)	0	—	—	—	—	—	—	1
Molybdenum, total recoverable (as Mo)	6	10.8	1	16.1	0	34	6.6	1
Nickel, dissolved (as Ni)	0	—	—	—	—	—	—	1
Nickel, total recoverable (as Ni)	13	30.8	32	18.1	2	65	5.0	1
Selenium, dissolved (as Se)	0	—	—	—	—	—	—	1
Selenium, total (as Se)	15	.1	0	.3	0	1	.1	1
Silver, dissolved (as Ag)	0	—	—	—	—	—	—	1
Silver, total recoverable (as Ag)	11	.2	0	.4	0	1	.1	1
Strontium, dissolved (as Sr)	0	—	—	—	—	—	—	10
Strontium, total recoverable (as Sr)	2	90.0	90	14.1	80	100	10.0	10
Vanadium, dissolved (as V)	0	—	—	—	—	—	—	6
Zinc, dissolved (as Zn)	0	—	—	—	—	—	—	3
Zinc, total recoverable (as Zn)	15	62.7	60	39.4	0	140	10.2	10

Table 4.—*Summary of measurements of trace elements for each station for the period of record (continued)*

[Analyses are in micrograms per liter. No data available indicated by —]

01116500 Pawtuxet River at Cranston, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Aluminum, dissolved (as Al)	2	100.0	100	.0	100	100	.0	10
Aluminum, total recoverable (as Al)	7	182.9	230	99.3	0	280	37.5	10
Arsenic, dissolved (as As)	0	—	—	—	—	—	—	1
Arsenic, total (as As)	18	.8	1	.7	0	3	.2	1
Barium, dissolved (as Ba)	0	—	—	—	—	—	—	100
Barium, total recoverable (as Ba)	3	3.3	0	5.8	0	10	3.3	100
Beryllium, dissolved (Be)	0	—	—	—	—	—	—	10
Beryllium, total recoverable (as Be)	3	.0	0	.0	0	0	.0	10
Boron, total recoverable (as B)	13	50.8	50	26.3	0	100	7.3	10
Cadmium, dissolved (as Cd)	0	—	—	—	—	—	—	1
Cadmium, total recoverable (as Cd)	17	1.5	1	1.4	0	4	.3	1
Chromium, dissolved (as Cr)	0	—	—	—	—	—	—	1
Chromium, total recoverable (as Cr)	21	9.3	10	10.8	0	40	2.3	1
Cobalt, dissolved (as Co)	0	—	—	—	—	—	—	3
Cobalt, total recoverable (Co)	5	.0	0	.0	0	0	.0	1
Copper, dissolved (as Cu)	2	35.0	35	21.2	20	50	15.0	1
Copper, total recoverable (as Cu)	18	18.7	17	8.3	7	37	2.0	1
Iron, dissolved (as Fe)	3	303.3	360	201.1	80	470	116.1	10
Iron, total recoverable (as Fe)	22	639.1	645	275.8	180	1300	58.8	10
Lead, dissolved (as Pb)	0	—	—	—	—	—	—	1
Lead, total recoverable (as Pb)	19	8.4	7	6.5	0	23	1.5	1
Lithium, dissolved (as Li)	2	300.0	300	.0	300	300	.0	4
Lithium, total recoverable (as Li)	3	.0	0	.0	0	0	.0	10
Manganese, dissolved (as Mn)	3	46.7	10	72.3	0	130	41.8	10
Manganese, total recoverable (as Mn)	22	165.5	165	82.8	0	360	17.7	10
Mercury, dissolved (as Hg)	0	—	—	—	—	—	—	.1
Mercury, total recoverable (as Hg)	18	.0	0	.1	.0	.4	.0	.1
Molybdenum, dissolved (as Mo)	0	—	—	—	—	—	—	1
Molybdenum, total recoverable (as Mo)	8	7.9	1	14.0	0	32	4.9	1
Nickel, dissolved (as Ni)	0	—	—	—	—	—	—	1
Nickel, total recoverable (as Ni)	15	16.2	11	16.2	2	69	4.2	1
Selenium, dissolved (as Se)	0	—	—	—	—	—	—	1
Selenium, total (as Se)	18	.0	0	.0	0	0	.0	1
Silver, dissolved (as Ag)	0	—	—	—	—	—	—	1
Silver, total recoverable (as Ag)	13	.2	0	.4	0	1	.1	1
Strontium, dissolved (as Sr)	0	—	—	—	—	—	—	10
Strontium, total recoverable (as Sr)	3	73.3	80	30.6	40	100	17.6	10
Vanadium, dissolved (as V)	0	—	—	—	—	—	—	6
Zinc, dissolved (as Zn)	2	15.0	15	21.2	0	30	15.0	3
Zinc, total recoverable (as Zn)	18	45.6	35	29.4	20	130	6.9	10

Table 4.—*Summary of measurements of trace elements for each station for the period of record (continued)*

[Analyses are in micrograms per liter. No data available indicated by —]

01116617 Pawtuxet River at Pawtuxet, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Aluminum, dissolved (as Al)	0	—	—	—	—	—	—	10
Aluminum, total recoverable (as Al)	6	186.7	150	101.5	80	360	41.4	10
Arsenic, dissolved (as As)	0	—	—	—	—	—	—	1
Arsenic, total (as As)	15	1.3	1	1.0	0	4	.3	1
Barium, dissolved (as Ba)	0	—	—	—	—	—	—	100
Barium, total recoverable (as Ba)	2	.0	0	.0	0	0	.0	100
Beryllium, dissolved (Be)	1	.0	0	—	0	0	—	10
Beryllium, total recoverable (as Be)	2	.0	0	.0	0	0	.0	10
Boron, total recoverable (as B)	13	56.9	60	22.5	30	100	6.2	10
Cadmium, dissolved (as Cd)	1	.0	0	—	0	0	—	1
Cadmium, total recoverable (as Cd)	13	1.8	1	1.7	0	5	.5	1
Chromium, dissolved (as Cr)	1	.0	0	—	0	0	—	1
Chromium, total recoverable (as Cr)	15	11.3	10	9.2	0	30	2.4	1
Cobalt, dissolved (as Co)	0	—	—	—	—	—	—	3
Cobalt, total recoverable (Co)	2	.0	0	.0	0	0	.0	1
Copper, dissolved (as Cu)	0	—	—	—	—	—	—	1
Copper, total recoverable (as Cu)	14	22.6	20	10.5	10	47	2.8	1
Iron, dissolved (as Fe)	1	15.0	15	—	15	15	—	10
Iron, total recoverable (as Fe)	15	807.3	760	360.2	280	1600	93.0	10
Lead, dissolved (as Pb)	0	—	—	—	—	—	—	1
Lead, total recoverable (as Pb)	15	10.2	9	6.5	4	25	1.7	1
Lithium, dissolved (as Li)	0	—	—	—	—	—	—	4
Lithium, total recoverable (as Li)	2	.0	0	.0	0	0	.0	10
Manganese, dissolved (as Mn)	1	.0	0	—	0	0	—	10
Manganese, total recoverable (as Mn)	15	198.7	180	86.9	80	440	22.4	10
Mercury, dissolved (as Hg)	0	—	—	—	—	—	—	.1
Mercury, total recoverable (as Hg)	15	.1	.1	.1	.0	.3	.0	.1
Molybdenum, dissolved (as Mo)	0	—	—	—	—	—	—	1
Molybdenum, total recoverable (as Mo)	7	9.6	1	15.8	0	36	6.0	1
Nickel, dissolved (as Ni)	0	—	—	—	—	—	—	1
Nickel, total recoverable (as Ni)	15	20.7	16	13.2	3	52	3.4	1
Selenium, dissolved (as Se)	0	—	—	—	—	—	—	1
Selenium, total (as Se)	15	.0	0	.0	0	0	.0	1
Silver, dissolved (as Ag)	0	—	—	—	—	—	—	1
Silver, total recoverable (as Ag)	13	.8	0	1.9	0	7	.5	1
Strontium, dissolved (as Sr)	0	—	—	—	—	—	—	10
Strontium, total recoverable (as Sr)	2	85.0	85	21.2	70	100	15.0	10
Vanadium, dissolved (as V)	0	—	—	—	—	—	—	6
Zinc, dissolved (as Zn)	1	26.0	26	—	26	26	—	3
Zinc, total recoverable (as Zn)	15	55.3	40	28.0	20	120	7.2	10

Table 4.—*Summary of measurements of trace elements for each station for the period of record (continued)*

[Analyses are in micrograms per liter. No data available indicated by —]

01118500 Pawcatuck River at Westerly, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Aluminum, dissolved (as Al)	23	85.2	90	50.9	0	200	10.6	10
Aluminum, total recoverable (as Al)	11	123.6	90	106.7	0	310	32.2	10
Arsenic, dissolved (as As)	40	.4	0	.8	0	4	.1	1
Arsenic, total (as As)	31	.8	1	.7	0	2	.1	1
Barium, dissolved (as Ba)	40	16.3	15	14.2	0	79	2.2	100
Barium, total recoverable (as Ba)	20	21.0	0	40.8	0	100	9.1	100
Beryllium, dissolved (Be)	21	.1	1	.3	0	1	.1	10
Beryllium, total recoverable (as Be)	2	.0	0	.0	0	0	.0	10
Boron, total recoverable (as B)	11	39.1	40	30.2	0	80	9.1	10
Cadmium, dissolved (as Cd)	95	.4	0	.7	0	3	.1	1
Cadmium, total recoverable (as Cd)	30	1.1	0	2.2	0	10	.4	1
Chromium, dissolved (as Cr)	96	1.7	0	3.9	0	21	.4	1
Chromium, total recoverable (as Cr)	32	12.2	10	10.0	0	30	1.8	1
Cobalt, dissolved (as Co)	40	.3	0	.8	0	3	.1	3
Cobalt, total recoverable (Co)	21	.7	0	1.1	0	3	.3	1
Copper, dissolved (as Cu)	135	4.0	2	10.0	0	100	.9	1
Copper, total recoverable (as Cu)	33	7.7	5	11.2	1	60	2.0	1
Iron, dissolved (as Fe)	51	285.9	250	170.0	120	1200	23.8	10
Iron, total recoverable (as Fe)	36	444.4	400	225.3	130	1100	37.6	10
Lead, dissolved (as Pb)	94	1.4	1	1.9	0	10	.2	1
Lead, total recoverable (as Pb)	30	7.1	6	7.4	0	34	1.3	1
Lithium, dissolved (as Li)	23	6.0	0	20.8	0	100	4.3	4
Lithium, total recoverable (as Li)	4	25.0	0	50.0	0	100	25.0	10
Manganese, dissolved (as Mn)	50	35.6	30	18.8	0	100	2.7	10
Manganese, total recoverable (as Mn)	36	41.1	40	26.7	0	120	4.5	10
Mercury, dissolved (as Hg)	40	.2	.2	.2	.0	.7	.0	.1
Mercury, total recoverable (as Hg)	31	.1	.3	.2	.0	.6	.0	.1
Molybdenum, dissolved (as Mo)	22	.0	0	.2	0	1	.0	1
Molybdenum, total recoverable (as Mo)	9	4.1	1	10.1	0	31	3.4	1
Nickel, dissolved (as Ni)	89	1.2	1	1.5	0	10	.2	1
Nickel, total recoverable (as Ni)	24	3.1	2	3.5	0	14	.7	1
Selenium, dissolved (as Se)	40	.0	0	.0	0	0	.0	1
Selenium, total (as Se)	31	.0	0	.0	0	0	.0	1
Silver, dissolved (as Ag)	40	.0	0	.0	0	0	.0	1
Silver, total recoverable (as Ag)	36	.2	0	.9	0	5	.1	1
Strontium, dissolved (as Sr)	21	30.5	30	5.0	23	40	1.1	10
Strontium, total recoverable (as Sr)	2	80.0	80	14.1	70	90	10.0	10
Vanadium, dissolved (as V)	21	1.2	0	5.5	0	25	1.2	6
Zinc, dissolved (as Zn)	135	12.7	10	12.8	0	90	1.1	3
Zinc, total recoverable (as Zn)	34	28.2	20	33.2	0	190	5.7	10

Table 5.—*Selected criteria and the maximum concentration (total recoverable and dissolved) for selected trace elements for each station for the period of record*

[Criteria are from the U.S. Environmental Protection Agency (1986, 1988a, 1988b). Soft water indicates water with a hardness (as $CaCO_3$) of 14 mg/L. No data available indicated by —]

Trace elements and selected criteria	**Maximum concentration, in micrograms per liter Total recoverable/dissolved**					
	Blackstone River at Millville	Branch River at Forestdale	Blackstone River at Manville	Pawtuxet River at Cranston	Pawtuxet River at Pawtuxet	Pawcatuck River at Westerly
Arsenic 50 µg/L for domestic water supply 360 µg/L for aquatic life protection (acute)	6/6	1/—	4/—	3/—	4/—	2/4
Barium 1,000 µg/L for domestic water supply	100/100	0/—	0/—	10/—	0/—	100/79
Boron 750 µg/L for long-term irrigation of sensitive crops	270/—	50/—	240/—	100/—	100/0	80/—
Cadmium 10 µg/L for domestic water supply 0.4 µg/L for aquatic life protection (acute) in soft water	10/8	2/—	4/—	4/—	5/0	10/3
Chromium 50 µg/L for domestic water supply 16 µg/L for aquatic life protection (acute)	40/30	20/—	50/—	40/—	30/0	30/20
Copper 1,000 µg/L for domestic water supply 2.8 µg/L for aquatic life protection (acute) in soft water	39/31	24/110	42/—	37/50	47/—	60/100
Iron 300 µg/L for domestic water supply 1,000 µg/L for aquatic life protection	1,900/420	1,000/630	1,500/320	1,300/470	1,600/15	1,100/1,200
Lead 50 µg/L for domestic water supply 6.7 µg/L for aquatic life protection (acute) in soft water	51/14	31/—	45/—	23/—	25/—	34/10
Manganese 50 µg/L for domestic water supply	200/230	240/0	220/260	360/130	440/0	120/100
Mercury 2.0 µg/L for domestic water supply 2.4 µg/L for aquatic life protection (acute) in soft water	0.4/0.2	0.2/—	1.8/—	0.4/—	0.3/—	0.6/0.7
Selenium 10 µg/L for domestic water supply 270 µg/L for aquatic life protection (acute)	1/1	2/—	1/—	0/—	0/—	0/0
Silver 50.0 µg/L for domestic water supply 0.14 µg/L for aquatic life protection (acute) in soft water	2/2	2/—	1/—	1/—	7/—	5/0
Zinc 5,000 µg/L for domestic water supply 22 µg/L for aquatic life protection (acute) in soft water	220/220	120/470	140/—	130/30	120/26	190/90

samples from both Blackstone River at Millville, Mass., and Pawcatuck River at Westerly in the total recoverable phase. The maximum dissolved value was 8 µg/L at Blackstone River at Millville, Mass., and 3 µg/L at Pawcatuck River at Westerly. These values potentially exceed the criterion for aquatic-life protection of sensitive fish species of 0.4 µg/L of cadmium in soft water.

Chromium.—The chromium criterion for drinking water is 50 µg/L but a more stringent recommended criterion for the protection of aquatic life is 16 µg/L. These criteria are for the Cr^{6+} ion of chromium. Chromium values shown in table 4 are for all forms of chromium, not just the Cr^{6+} ion. The maximum total recoverable chromium measured at any of the six sites was 50 µg/L at Blackstone River at Manville. All other total recoverable measurements were less than 50 µg/L as were the dissolved values. All sites had maximum values which may potentially exceed the aquatic-life protection limit.

Copper.—The drinking-water criterion for copper is 1,000 µg/L but the criterion for acute aquatic-life protection in soft water is 2.8 µg/L. None of the sites had maximum values close to the drinking-water criterion. All of the sites had mean values that potentially exceed the aquatic life criterion and all except the Pawcatuck River at Westerly had median values that potentially exceed the criterion.

Iron and Manganese.—Drinking-water criteria were set for iron and manganese not because of the toxic effects of the metals but rather to eliminate the discoloration of porcelain plumbing fixtures and staining of laundry. Limits of 300 µg/L for iron and 50 µg/L for manganese were established to prevent these problems. A criterion of 1,000 µg/L for iron for the protection of aquatic life has been suggested. All sites had total iron concentrations that exceeded the drinking-water criterion and were at or exceeded the limit for aquatic-life protection. The largest total recoverable concentration was 1,900 µg/L at Blackstone River at Millville, Mass. and the largest dissolved concentration was 1,200 µg/L at Pawcatuck River at Westerly, which exceeded the value set for the protection of aquatic life. Pawcatuck River at Westerly was the only station at which the median concentrations of both total recoverable and dissolved manganese were below the drinking-water criterion.

Lead.—The criterion for lead in drinking water is 50 µg/L. The highest measured total recoverable concentration of lead was 51 µg/L at Blackstone River at Millville, Mass. The highest dissolved concentration was 14 µg/L also at Blackstone River at Millville, Mass. Lead values at all sites potentially exceed the acute aquatic-life protection criterion of 6.7 µg/L.

Mercury.—The criterion for drinking water is the most stringent of any of the metals, 2 µg/L; the acute aquatic-life protection criterion is 2.4 µg/L. At the Blackstone River at Manville, the maximum total recoverable concentration was 1.8 µg/L—the highest concentration measured at any of the six sites.

Selenium.—Measured maximum values of selenium for both the total recoverable phase and the dissolved phase were well below both the drinking-water criterion of 10 µg/L and the acute aquatic-life protection criterion of 270 µg/L.

Silver.—The drinking-water criterion of 50 µg/L was never exceeded at the sites. For soft water, however, the acute aquatic-life protection criterion of 0.14 µg/L was potentially exceeded at all of the sites.

Zinc.—Criteria for zinc range from a high of 5,000 µg/L for drinking water to a low of 22 µg/L for the acute aquatic-life protection in soft water. The maximum dissolved zinc concentration was 470 µg/L at Branch River at Forestdale. Median concentrations at all sites except the Pawcatuck River at Westerly potentially exceed the aquatic-life protection criterion.

Organic Compounds

Analyses were performed for a limited number of organic compounds and are summarized in table 6. The analyses included the material that was dissolved and the material that was sorbed to suspended particulate matter. Many of these were organochlorine compounds such as DDT, which tend to persist in the environment even though they are no longer used or manufactured.

Of the pesticides, lindane was detected at the Blackstone River at Manville with a maximum concentration of 0.02 µg/L and at the Blackstone River at Millville, Mass. and at the Pawtuxet River at Pawtuxet with a concentration of 0.01 µg/L. Dieldrin was found at three sites—the Blackstone River at Millville, Mass., the Blackstone River at Manville, and the Pawtuxet River at Cranston. The max-

Table 6.—*Summary of measurements of organic compounds for each station for the period of record*

[Analyses in micrograms per liter except as indicated]

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
01111230 Blackstone River at Millville, Mass.								
Carbon, organic total (mg/L as C)	24	6.67	6.2	1.90	3.8	11	0.39	.1
Phenols, total	21	1.5	1	1.6	0	5	.4	1
Methylene blue active substance (mg/L)	5	.160	.00	.134	.10	.40	.060	.01
Oil and grease, total recoverable extraction gravimetric (mg/L)	23	.8	0	1.3	0	6	.3	1
PCB, total	13	.01	.0	.03	.0	.1	.01	.1
Napthalenes, polychlorinated, total	13	.00	.0	.00	.0	.0	.00	.1
Aldrin, total	13	.000	.00	.000	.00	.00	.000	.01
Chlordane, total	13	.000	.00	.000	.00	.00	.000	.01
DDD, total	13	.000	.00	.000	.00	.00	.000	.01
DDE, total	13	.000	.00	.000	.00	.00	.000	.01
DDT, total	13	.000	.00	.000	.00	.00	.000	.01
Dieldrin, total	13	.002	.00	.004	.00	.01	.001	.01
Endosulfan, total	13	.000	.00	.000	.00	.00	.000	.01
Endrin, total	13	.000	.00	.000	.00	.00	.000	.01
Heptachlor, total	13	.000	.00	.000	.00	.00	.000	.01
Heptachlor epoxide, total	13	.000	.00	.000	.00	.00	.00	.01
Lindane, total	13	.001	.00	.003	.00	.01	.001	.01
Methoxychlor, total	12	.000	.00	.000	.00	.00	.000	.01
Mirex, total	12	.000	.00	.000	.00	.00	.000	.01
Perthane, total	13	.00	.0	.00	.0	.0	.00	.1
Toxaphene, total	13	.0	0	.0	0	0	.0	1
01111500 Branch River at Forestdale, R.I.								
Carbon, organic total (mg/L as C)	12	5.71	5.3	1.42	3.9	8.3	0.41	.1
Phenols, total	20	1.4	1	2.9	0	12	.6	1
Methylene blue active substance (mg/L)	9	.000	.00	.000	.00	.00	.000	.01
Oil and grease, total recoverable extraction gravimetric (mg/L)	22	.5	0	.9	0	4	.2	1
PCB, total	12	.00	.0	.00	.0	.0	.00	.1
Napthalenes, polychlorinated, total	12	.00	.0	.00	.0	.0	.00	.1
Aldrin, total	12	.000	.00	.000	.00	.00	.000	.01
Chlordane, total	12	.000	.00	.000	.00	.00	.000	.01
DDD, total	12	.000	.00	.000	.00	.00	.000	.01
DDE, total	12	.000	.00	.000	.00	.00	.000	.01
DDT, total	12	.000	.00	.000	.00	.00	.000	.01
Dieldrin, total	12	.000	.00	.000	.00	.00	.000	.01
Endosulfan, total	12	.000	.00	.000	.00	.00	.000	.01
Endrin, total	12	.000	.00	.000	.00	.00	.000	.01
Heptachlor, total	12	.000	.00	.000	.00	.00	.000	.01
Heptachlor epoxide, total	12	.000	.00	.000	.00	.00	.000	.01
Lindane, total	12	.000	.00	.000	.00	.00	.000	.01
Methoxychlor, total	11	.000	.00	.000	.00	.00	.000	.01
Mirex, total	11	.000	.00	.000	.00	.00	.000	.01
Perthane, total	12	.00	.0	.00	.0	.0	.00	.1
Toxaphene, total	12	.0	0	.0	0	0	.0	1

Table 6.—*Summary of measurements of organic compounds for each station for the period of record (continued)*

[Analyses in micrograms per liter except as indicated]

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
01112900 Blackstone River at Manville, R.I.								
Carbon, organic total (mg/L as C)	12	6.82	6.2	1.59	5.0	9.7	0.46	.1
Phenols, total	21	5.1	2	9.8	0	45	2.1	1
Methylene blue active substance (mg/L)	10	.130	.00	.067	.10	.30	.021	.01
Oil and grease, total recoverable extraction gravimetric (mg/L)	22	.5	0	.9	0	3	.2	1
PCB, total	12	.03	.0	.08	.0	.2	.02	.1
Napthalenes, polychlorinated, total	12	.00	.0	.00	.0	.0	.00	.1
Aldrin, total	11	.000	.00	.000	.00	.00	.000	.01
Chlordane, total	12	.000	.00	.000	.00	.00	.000	.01
DDD, total	11	.000	.00	.000	.00	.00	.000	.01
DDE, total	11	.000	.00	.000	.00	.00	.000	.01
DDT, total	11	.000	.00	.000	.00	.00	.000	.01
Dieldrin, total	11	.003	.00	.005	.00	.01	.001	.01
Endosulfan, total	11	.000	.00	.000	.00	.00	.000	.01
Endrin, total	11	.000	.00	.000	.00	.00	.000	.01
Heptachlor, total	11	.000	.00	.000	.00	.00	.000	.01
Heptachlor epoxide, total	11	.000	.00	.000	.00	.00	.000	.01
Lindane, total	11	.002	.00	.006	.00	.02	.002	.01
Methoxychlor, total	11	.000	.00	.000	.00	.00	.000	.01
Mirex, total	11	.000	.00	.000	.00	.00	.000	.01
Perthane, total	12	.00	.0	.00	.0	.0	.00	.1
Toxaphene, total	12	.0	0	.0	0	0	.0	1
01116500 Pawtuxet River at Cranston, R.I.								
Carbon, organic total (mg/L as C)	12	7.13	7.3	2.58	4.6	14	0.75	.1
Phenols, total	25	4.2	3	4.8	0	15	1.0	1
Methylene blue active substance (mg/L)	10	.140	.10	.052	.10	.20	.016	.01
Oil and grease, total recoverable extraction gravimetric (mg/L)	23	.9	0	1.5	0	6	.3	1
PCB, total	13	.39	.1	.89	.0	2.8	.25	.1
Napthalenes, polychlorinated, total	13	.00	.0	.00	.0	.0	.00	.1
Aldrin, total	13	.000	.00	.000	.00	.00	.000	.01
Chlordane, total	13	.000	.00	.000	.00	.00	.000	.01
DDD, total	13	.000	.00	.000	.00	.00	.000	.01
DDE, total	13	.000	.00	.000	.00	.00	.000	.01
DDT, total	13	.000	.00	.000	.00	.00	.000	.01
Dieldrin, total	13	.001	.00	.003	.00	.01	.001	.01
Endosulfan, total	12	.000	.00	.000	.00	.00	.000	.01
Endrin, total	13	.000	.00	.000	.00	.00	.000	.01
Heptachlor, total	13	.000	.00	.000	.00	.00	.000	.01
Heptachlor epoxide, total	13	.000	.00	.000	.00	.00	.000	.01
Lindane, total	13	.000	.00	.000	.00	.00	.000	.01
Methoxychlor, total	10	.000	.00	.000	.00	.00	.000	.01
Mirex, total	10	.000	.00	.000	.00	.00	.000	.01
Perthane, total	12	.00	.0	.00	.0	.0	.00	.1
Toxaphene, total	13	.0	0	.0	0	0	.0	1

Table 6.—*Summary of measurements of organic compounds for each station for the period of record (continued)*

[Analyses in micrograms per liter except as indicated]

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
01116617 Pawtuxet River at Pawtuxet, R.I.								
Carbon, organic total (mg/L as C)	12	10.96	10.5	4.49	5.5	18	1.30	.1
Phenols, total	21	24.8	13	26.0	0	86	5.7	1
Methylene blue active substance (mg/L)	10	.180	.10	.042	.10	.20	.013	.01
Oil and grease, total recoverable extraction gravimetric (mg/L)	22	.5	0	.8	0	3	.2	1
PCB, total	10	.59	.1	1.40	.0	4.3	.44	.1
Napthalenes, polychlorinated, total	10	.00	.0	.00	.0	.0	.00	.1
Aldrin, total	10	.000	.00	.000	.00	.00	.000	.01
Chlordane, total	10	.000	.00	.000	.00	.00	.000	.01
DDD, total	10	.000	.00	.000	.00	.00	.000	.01
DDE, total	10	.000	.00	.000	.00	.00	.000	.01
DDT, total	10	.000	.00	.000	.00	.00	.000	.01
Dieldrin, total	10	.000	.00	.000	.00	.00	.000	.01
Endosulfan, total	10	.000	.00	.000	.00	.00	.000	.01
Endrin, total	10	.000	.00	.000	.00	.00	.000	.01
Heptachlor, total	10	.002	.00	.006	.00	.02	.002	.01
Heptachlor epoxide, total	10	.000	.00	.000	.00	.00	.000	.01
Lindane, total	10	.001	.00	.003	.00	.01	.001	.01
Methoxychlor, total	9	.000	.00	.000	.00	.00	.000	.01
Mirex, total	9	.000	.00	.000	.00	.00	.000	.01
Perthane, total	10	.00	.0	.00	.0	.0	.00	.1
Toxaphene, total	10	.0	0	.0	0	0	.0	1
01118500 Pawcatuck River at Westerly, R.I.								
Carbon, organic total (mg/L as C)	132	7.21	6.4	3.38	2.9	32	0.30	.1
Phenols, total	23	1.2	1	2.2	0	9	.5	1
Methylene blue active substance (mg/L)	26	.017	.00	.037	.00	.10	.007	.01
Oil and grease, total recoverable extraction gravimetric (mg/L)	24	.3	0	.7	0	3	.1	1
PCB, total	15	.00	.0	.00	.0	.0	.00	.1
Napthalenes, polychlorinated, total	15	.00	.0	.00	.0	.0	.00	.1
Aldrin, total	15	.000	.00	.000	.00	.00	.000	.01
Chlordane, total	15	.000	.00	.000	.00	.00	.000	.01
DDD, total	15	.000	.00	.000	.00	.00	.000	.01
DDE, total	15	.000	.00	.000	.00	.00	.000	.01
DDT, total	15	.000	.00	.000	.00	.00	.000	.01
Dieldrin, total	15	.000	.00	.000	.00	.00	.000	.01
Endosulfan, total	15	.000	.00	.000	.00	.00	.000	.01
Endrin, total	15	.000	.00	.000	.00	.00	.000	.01
Heptachlor, total	15	.000	.00	.000	.00	.00	.000	.01
Heptachlor epoxide, total	15	.000	.00	.000	.00	.00	.000	.01
Lindane, total	15	.000	.00	.000	.00	.00	.000	.01
Methoxychlor, total	14	.000	.00	.000	.00	.00	.000	.01
Mirex, total	14	.000	.00	.000	.00	.00	.000	.01
Perthane, total	15	.00	.0	.00	.0	.0	.00	.1
Toxaphene, total	15	.0	0	.0	0	0	.0	1

imum concentration was 0.01 µg/L, which is below the acute freshwater aquatic life criterion (U.S. Environmental Protection Agency, 1986) but above the chronic criterion of 0.0019 µg/L. Polychlorinated biphenyls (PCBs) were found at the same three sites with maximum concentrations of 0.1, 0.2, and 2.8 µg/L, respectively, and at the Pawtuxet River at Pawtuxet with a maximum concentration of 4.3 µg/L. Criteria for PCBs are 2 µg/L for the acute freshwater aquatic-life protection and 0.014 µg/L for chronic exposure. Heptachlor was detected at the Pawtuxet River at Pawtuxet with a maximum concentration of 0.02 µg/L.

Phenols (phenolic compounds) include a wide variety of organic chemicals, all of which incorporate an aromatic ring as the basic chemical structure. Phenols arise from the distillation of coal and wood; from oil refineries; chemical plants; livestock dips; human and other organic wastes; hydrolysis, chemical oxidation, and microbial degradation of pesticides; and from naturally occurring sources and substances. Some compounds strongly resist biological degradation and can be transported long distances in water. Others may be rapidly broken down by biological action, contributing to lowered dissolved oxygen in the stream. The Rhode Island Department of Environmental Management (1988) has set aquatic-life protection criteria for phenols of 251 µg/L and 5.6 µg/L for acute and chronic exposure, respectively. Phenols in excess of the chronic criterion were measured at all sites except for the Blackstone River at Millville, Mass. The highest measured concentration was 86 µg/L at Pawtuxet River at Pawtuxet. The median concentration, 13 µg/L at Pawtuxet River at Pawtuxet exceeds the chronic criterion.

Constituents in Bottom Materials

Most samples of bottom materials at all six sites were collected during periods of low streamflow and analyzed for selected trace elements and organic compounds. Although no criteria for allowable concentrations of these compounds in bottom material have been set, their presence in high concentrations may indicate past or present introduction of the materials into the rivers.

Bottom materials are relatively stationary during periods of low to medium flow. During periods of high flow or floods, bottom materials may be resuspended by the increased water velocity and carried downstream where they are then redeposited as the velocity of the water diminishes. In this way, constituents associated with the bottom material are distributed downstream.

Table 7 summarizes the bottom-material data for the six sites. Data at a given site exhibit a wide range in concentration. Because bottom materials are seldom distributed uniformly, a "representative" sample or even a duplicate sample is difficult to collect. High flows can redistribute bottom material so that another sample collected at the same site at a later time may contain entirely different concentrations of the constituents of interest.

High concentrations of elements, such as 2,000 µg/g (microgram per gram) of zinc, 450 µg/g of chromium, and 41,000 µg/g of molybdenum at Blackstone River at Millville, Mass., probably derived from wastes which entered the river some time in the past. Lead concentrations were also elevated at several of the sites.

Organic compounds are often sorbed onto sediment particles and move downstream with the sediments. In the water column, PCBs were found at four of the six sites, dieldrin at three sites, lindane at two sites, and heptachlor at one site. In the bottom material, chlordane, DDD, DDE, DDT, dieldrin, and PCBs were found at all sites and aldrin, endosulfan, endrin, heptachlor, heptachlor epoxide, lindane, methoxychlor, and mirex were found at one or more sites. One high concentration of PCBs, 5,400 µg/kg (microgram per kilogram), was found in 1978 at the Pawtuxet River at Pawtuxet. Subsequent samples at this site contained lower concentrations of PCBs but the concentrations were always well above the reporting level.

TRENDS IN WATER QUALITY

One of the most frequently asked questions, "Is water quality getting better or worse?" is one of the most difficult questions to answer. The very nature of water quality means that there will be a considerable variability in constituent concentrations over a period of time. How is one able to look at the record of analytical data and decide if there is a meaningful change in the concentration of the constituent?

The simplest way to identify a change is to compare the data over a period of time. Is the concentration of a given constituent increasing or

Table 7.—*Summary of measurements of constituents in the bottom material for each station for the period of record*

[No data available indicated by —]

01111230 Blackstone River at Millville, Mass.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting limit
Chemical oxygen demand, (mg/kg)	11	23,900	12,000	36,000	4,600	130,000	10,900	100
Aluminum, recoverable (µg/g)	2	6,300	6,300	6,650	1,600	11,000	4,700	10
Arsenic, total (µg/g)	7	.7	0	1.3	0	3	.5	1
Barium, recoverable (µg/g)	2	130	130	156	20	240	110	10
Beryllium, recoverable (µg/g)	2	.0	0	.0	0	0	.0	10
Boron, recoverable (µg/g)	3	.0	0	.0	0	0	.0	10
Cadmium, recoverable (µg/g)	7	19.0	4	30.3	0	80	11.5	10
Chromium, recoverable (µg/g)	7	127	20	168	10	450	63.7	10
Cobalt, recoverable (µg/g)	7	5.7	0	15.1	0	40	5.7	10
Copper, recoverable (µg/g)	7	163	30	230	21	640	86.9	10
Iron, recoverable (µg/g)	7	11,600	5,600	14,700	2,700	44,000	5,550	1
Lead, recoverable (µg/g)	7	125	120	93.0	38	260	35.2	10
Manganese, recoverable (µg/g)	7	471	100	823	40	2,300	311	1
Mercury, recoverable (µg/g)	7	.13	.0	.34	.0	.9	.13	.01
Molybdenum, recoverable (µg/g)	3	13,700	0	23,700	0	41,000	13,700	10
Nickel, recoverable (µg/g)	5	58.0	10	86.1	0	200	38.5	10
Selenium, total (µg/g)	7	.3	0	.5	0	1	.2	1
Silver, recoverable (µg/g)	5	.8	0	1.8	0	4	.8	1
Strontium, recoverable (µg/g)	2	40.0	40	42.4	10	70	30.0	1
Vanadium, total (µg/g)	0	—	—	—	—	—	—	1
Zinc, recoverable (µg/g)	7	424	80	716	40	2,000	270	1
Aldrin, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Chlordane, total (µg/kg)	9	13.9	0	18.8	0	55	6.26	1
DDD, total (µg/kg)	9	9.10	.0	11.6	.0	28	3.88	.1
DDE, total (µg/kg)	9	4.59	.0	8.28	.0	25	2.76	.1
DDT, total (µg/kg)	9	1.74	.0	1.95	.0	5.8	.65	.1
Dieldrin, total (µg/kg)	9	52.7	.0	145	.1	440	48.5	.1
Endosulfan, total (µg/kg)	7	.00	.0	.00	.0	.0	.00	.1
Endrin, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Heptachlor, total (µg/kg)	9	.04	.0	.10	.0	.3	.03	.1
Heptachlor epoxide, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Lindane, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Methoxychlor, total (µg/kg)	9	.26	.0	.77	.0	2.3	.26	.1
Mirex, total (µg/kg)	7	11.9	.1	31.4	.0	83	11.9	.1
PCB, total (µg/kg)	9	75.2	50	127	.0	410	42.4	1
PCN, total (µg/kg)	7	.0	0	.0	0	0	.0	1
Perthane, total (µg/kg)	7	.0	0	.0	0	0	.0	1
Toxaphene, total (µg/kg)	9	0	0	0	0	0	0	10

Table 7.—*Summary of measurements of constituents in the bottom material for each station for the period of record (continued)*

[No data available indicated by —]

01111500 Branch River at Forestdale, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting level
Chemical oxygen demand, (mg/kg)	11	36,400	32,000	31,800	2,000	120,000	9,590	100
Aluminum, recoverable (µg/g)	2	4,450	4,300	3,460	2,000	6,900	2,450	10
Arsenic, total (µg/g)	7	.1	0	.4	0	1	.1	1
Barium, recoverable (µg/g)	2	45	45	35	20	70	25	10
Beryllium, recoverable (µg/g)	2	.0	0	.0	0	0	.0	10
Boron, recoverable (µg/g)	5	4.0	0	8.9	0	20	4.0	10
Cadmium, recoverable (µg/g)	7	4.6	0	7.4	0	20	2.8	10
Chromium, recoverable (µg/g)	7	24.3	20	17.2	0	50	6.5	10
Cobalt, recoverable (µg/g)	7	.0	0	.0	0	0	.0	10
Copper, recoverable (µg/g)	7	55.7	40	58.8	0	180	22.2	10
Iron, recoverable (µg/g)	7	5,040	3,400	3,390	1,800	11,000	1,280	1
Lead, recoverable (µg/g)	7	43.0	37	21.3	20	70	8.1	10
Manganese, recoverable (µg/g)	7	155	150	117	30	370	44.3	1
Mercury, recoverable (µg/g)	7	.02	.0	.02	.0	.1	.01	.01
Molybdenum, recoverable (µg/g)	2	.0	0	.0	0	0	.0	10
Nickel, recoverable (µg/g)	7	14.1	0	19.8	0	50	7.5	10
Selenium, total (µg/g)	7	.4	0	.8	0	2	.3	1
Silver, recoverable (µg/g)	6	.0	0	.0	0	0	.0	1
Strontium, recoverable (µg/g)	2	20.0	20	14.1	10	30	10.0	1
Vanadium, total (µg/g)	0	—	—	—	—	—	—	1
Zinc, recoverable (µg/g)	7	135	95	131	20	400	49.5	1
Aldrin, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Chlordane, total (µg/kg)	9	13.8	0	16.5	0	49	5.5	1
DDD, total (µg/kg)	9	17.2	.0	22.7	.0	62	7.58	.1
DDE, total (µg/kg)	9	5.19	.0	9.25	.0	26	3.08	.1
DDT, total (µg/kg)	9	2.88	.0	4.39	.0	13	1.46	.1
Dieldrin, total (µg/kg)	9	.39	.0	.55	.0	1.6	.18	.1
Endosulfan, total (µg/kg)	7	.00	.0	.00	.0	.0	.00	.1
Endrin, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Heptachlor, total (µg/kg)	9	.07	.0	.20	.0	.6	.07	.1
Heptachlor epoxide, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Lindane, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Methoxychlor, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Mirex, total (µg/kg)	7	105	5.0	143	.0	310	54.2	.1
PCB, total (µg/kg)	9	88.0	31	189	3.0	590	63.0	1
PCN, total (µg/kg)	7	.0	0	.0	0	0	.0	1
Perthane, total (µg/kg)	7	.0	0	.0	0	0	.0	1
Toxaphene, total (µg/kg)	9	0	0	0	0	0	0	10

Table 7.—*Summary of measurements of constituents in the bottom material for each station for the period of record (continued)*

[No data available indicated by —]

01112900 Blackstone River at Manville, R.I.								
Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting level
Chemical oxygen demand, (mg/kg)	10	26,740	14,000	43,700	4,400	150,000	13,800	100
Aluminum, recoverable (µg/g)	1	1,700	1,700	—	1,700	1,700	—	10
Arsenic, total (µg/g)	6	.0	0	.0	0	0	.0	1
Barium, recoverable (µg/g)	1	40	40	—	40	40	—	10
Beryllium, recoverable (µg/g)	2	.0	0	.0	0	0	.0	10
Boron, recoverable (µg/g)	5	4.0	0	8.9	0	20	4.0	10
Cadmium, recoverable (µg/g)	6	1.0	0	1.7	0	4	.7	10
Chromium, recoverable (µg/g)	6	13.3	15	8.2	0	20	3.3	10
Cobalt, recoverable (µg/g)	6	1.7	0	4.1	0	10	1.7	10
Copper, recoverable (µg/g)	6	29.0	30	10.5	14	40	4.3	10
Iron, recoverable (µg/g)	6	3,280	3,000	1,400	1,900	5700	574	1
Lead, recoverable (µg/g)	6	44.3	41	18.6	23	70	7.6	10
Manganese, recoverable (µg/g)	6	52	50	30	80	8.6	1	
Mercury, recoverable (µg/g)	6	.01	.0	.02	.0	.01	.01	.01
Molybdenum, recoverable (µg/g)	1	.0	0	—	0	0	—	10
Nickel, recoverable (µg/g)	6	5.0	0	8.4	0	20	3.4	10
Selenium, total (µg/g)	6	.0	0	.0	0	0	.0	1
Silver, recoverable (µg/g)	5	.0	0	.0	0	0	.0	1
Strontium, recoverable (µg/g)	1	20.0	20	—	20	20	—	1
Vanadium, total (µg/g)	0	—	—	—	—	—	—	1
Zinc, recoverable (µg/g)	6	400	88	784	30	2,000	320	1
Aldrin, total (µg/kg)	8	.00	.0	.00	.0	.0	.00	.1
Chlordane, total (µg/kg)	9	24.6	0	28.0	0	84	9.3	1
DDD, total (µg/kg)	9	18.6	.0	18.8	.0	48	6.28	.1
DDE, total (µg/kg)	9	10.7	.0	17.9	.0	55	5.96	.1
DDT, total (µg/kg)	9	3.73	.0	5.97	.0	19	1.99	.1
Dieldrin, total (µg/kg)	9	11.0	.0	11.9	.0	35	3.95	.1
Endosulfan, total (µg/kg)	7	.00	.0	.00	.0	.0	.00	.1
Endrin, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Heptachlor, total (µg/kg)	8	.01	.0	.04	.0	.1	.01	.1
Heptachlor epoxide, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Lindane, total (µg/kg)	9	.56	.0	1.67	.0	5.0	.56	.1
Methoxychlor, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Mirex, total (µg/kg)	6	.00	.0	.00	.0	.0	.00	.1
PCB, total (µg/kg)	9	198	96	233	26	780	77.8	1
PCN, total (µg/kg)	7	.0	0	.0	0	0	.0	1
Perthane, total (µg/kg)	7	.0	0	.0	0	0	.0	1
Toxaphene, total (µg/kg)	9	0	0	0	0	0	0	10

Table 7.—*Summary of measurements of constituents in the bottom material for each station for the period of record (continued)*

[No data available indicated by —]

01116500 Pawtuxet River at Cranston, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting level
Chemical oxygen demand, (mg/kg)	17	12,800	8,100	12,000	1,700	47,000	2,920	100
Aluminum, recoverable (µg/g)	3	2,100	2,500	1,060	900	2900	611	10
Arsenic, total (µg/g)	7	.0	0	.0	0	0	.0	1
Barium, recoverable (µg/g)	3	23	20	16	80	400	9.3	10
Beryllium, recoverable (µg/g)	3	.0	0	.0	0	0	.0	10
Boron, recoverable (µg/g)	6	3.7	0	8.0	0	20	3.3	10
Cadmium, recoverable (µg/g)	7	.7	0	1.3	0	3	.5	10
Chromium, recoverable (µg/g)	12	5.5	4	6.5	0	20	1.9	10
Cobalt, recoverable (µg/g)	8	.1	0	.4	0	1	.1	10
Copper, recoverable (µg/g)	8	36.9	24	32.9	10	90	11.6	10
Iron, recoverable (µg/g)	8	4,410	4,950	2,170	900	7000	769	1
Lead, recoverable (µg/g)	8	67.0	36	94.2	10	290	33.3	10
Manganese, recoverable (µg/g)	8	76.5	66	36.1	23	140	12.8	1
Mercury, recoverable (µg/g)	7	.05	.0	.12	.0	.3	.04	.01
Molybdenum, recoverable (µg/g)	3	.0	0	.0	0	0	.0	10
Nickel, recoverable (µg/g)	8	6.0	0	8.5	0	200	3.0	10
Selenium, total (µg/g)	7	.0	0	.0	0	0	.0	1
Silver, recoverable (µg/g)	7	.1	0	.4	0	1	.1	1
Strontium, recoverable (µg/g)	3	7.0	10	5.2	.1	10	3.0	1
Vanadium, total (µg/g)	1	9.0	9	—	9	9	—	1
Zinc, recoverable (µg/g)	7	41.6	30	25.7	18	90	9.7	1
Aldrin, total (µg/kg)	9	.11	.0	.33	.0	1.0	.11	.1
Chlordane, total (µg/kg)	9	5.8	0	4.4	3	16	1.5	1
DDD, total (µg/kg)	9	4.60	.0	6.00	.0	16	2.00	.1
DDE, total (µg/kg)	9	3.36	.0	8.16	.0	25	2.72	.1
DDT, total (µg/kg)	9	8.16	.0	22.5	.0	68	7.48	.1
Dieldrin, total (µg/kg)	9	.03	.0	.07	.0	.2	.02	.1
Endosulfan, total (µg/kg)	7	.00	.0	.00	.0	.0	.00	.1
Endrin, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Heptachlor, total (µg/kg)	9	.11	.0	.22	.0	.5	.07	.1
Heptachlor epoxide, total (µg/kg)	9	.02	.0	.07	.0	.2	.02	.1
Lindane, total (µg/kg)	9	3.22	.0	9.67	.0	29	3.22	.1
Methoxychlor, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Mirex, total (µg/kg)	7	.00	.0	.00	.0	.0	.00	.1
PCB, total (µg/kg)	9	46.2	14	75.5	4.0	240	25.2	1
PCN, total (µg/kg)	7	.0	0	.0	0	0	.0	1
Perthane, total (µg/kg)	7	2.7	1	7.2	0	19	2.7	1
Toxaphene, total (µg/kg)	9	0	0	0	0	0	0	10

Table 7.—*Summary of measurements of constituents in the bottom material for each station for the period of record (continued)*

[No data available indicated by —]

01116617 Pawtuxet River at Pawtuxet, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting level
Chemical oxygen demand, (mg/kg)	11	58,300	19,000	95,700	4,900	330,000	28,900	100
Aluminum, recoverable (µg/g)	2	4,550	4,550	2,190	3,000	6,100	1,550	10
Arsenic, total (µg/g)	7	.1	0	.4	0	1	.1	1
Barium, recoverable (µg/g)	2	110	110	99.0	40	180	70	10
Beryllium, recoverable (µg/g)	2	1.0	1	1.4	0	2	1.0	10
Boron, recoverable (µg/g)	5	4.0	0	8.9	0	20	4.0	10
Cadmium, recoverable (µg/g)	7	1.6	0	2.7	0	6	1.0	10
Chromium, recoverable (µg/g)	7	35.7	30	27.0	10	90	10.2	10
Cobalt, recoverable (µg/g)	7	.0	0	.0	0	0	.0	10
Copper, recoverable (µg/g)	7	116.9	80	150	30	450	56.8	10
Iron, recoverable (µg/g)	7	5,560	4,200	4,310	2,400	15,000	1,630	1
Lead, recoverable (µg/g)	7	69.4	54	67.0	20	210	25.3	10
Manganese, recoverable (µg/g)	7	81.6	50	68.7	32	230	26.0	1
Mercury, recoverable (µg/g)	7	.01	.0	.03	.0	.1	.01	.01
Molybdenum, recoverable (µg/g)	2	.0	0	.0	0	0	.0	10
Nickel, recoverable (µg/g)	7	17.3	20	17.1	0	50	6.5	10
Selenium, total (µg/g)	7	.0	0	.0	0	0	.0	1
Silver, recoverable (µg/g)	6	1.0	0	1.5	0	3	.6	1
Strontium, recoverable (µg/g)	2	25.0	25	21.2	10	40	15.0	1
Vanadium, total (µg/g)	0	—	—	—	—	—	—	1
Zinc, recoverable (µg/g)	7	228	120	343	40	1,000	130	1
Aldrin, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Chlordane, total (µg/kg)	9	22.3	0	39.2	0	110	13.1	1
DDD, total (µg/kg)	9	23.0	.0	52.0	.0	160	17.3	.1
DDE, total (µg/kg)	9	.60	.0	.93	.0	2.1	.31	.1
DDT, total (µg/kg)	9	2.62	.0	6.18	.0	19	2.06	.1
Dieldrin, total (µg/kg)	9	3.73	.0	7.58	.0	22	2.53	.1
Endosulfan, total (µg/kg)	6	2.20	.0	4.40	.0	11	1.80	.1
Endrin, total (µg/kg)	9	.83	.0	2.50	.0	7.5	.83	.1
Heptachlor, total (µg/kg)	9	.23	.0	.54	.0	1.6	.18	.1
Heptachlor epoxide, total (µg/kg)	9	.04	.0	.13	.0	.4	.04	.1
Lindane, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Methoxychlor, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Mirex, total (µg/kg)	6	.00	.0	.00	.0	.0	.00	.1
PCB, total (µg/kg)	9	690	60	1770	19	5,400	589	1
PCN, total (µg/kg)	6	.0	0	.0	0	0	.0	1
Perthane, total (µg/kg)	6	.0	0	.0	0	0	.0	1
Toxaphene, total (µg/kg)	9	0	0	0	0	0	0	10

Table 7.—*Summary of measurements of constituents in the bottom material for each station for the period of record (continued)*

[No data available indicated by —]

01118500 Pawcatuck River at Westerly, R.I.

Constituent	Number of samples	Mean	Median	Standard deviation	Minimum value	Maximum value	Standard error of mean	Reporting level
Chemical oxygen demand, (mg/kg)	12	19,600	8,000	25,900	2,800	96,000	7,490	100
Aluminum, recoverable (µg/g)	2	1,450	1,450	212	1,300	1,600	150	10
Arsenic, total (µg/g)	5	.0	0	.0	0	0	.0	1
Barium, recoverable (µg/g)	2	10	10	14	0	200	10	10
Beryllium, recoverable (µg/g)	2	.0	0	.0	0	0	.0	10
Boron, recoverable (µg/g)	2	.0	0	.0	0	0	.0	10
Cadmium, recoverable (µg/g)	5	.0	0	.0	0	0	.0	10
Chromium, recoverable (µg/g)	5	6.0	10	5.5	0	10	2.5	10
Cobalt, recoverable (µg/g)	5	.0	0	.0	0	0	.0	10
Copper, recoverable (µg/g)	5	4.6	0	8.7	0	20	3.9	10
Iron, recoverable (µg/g)	5	1,750	1,800	890	740	3,100	398	1
Lead, recoverable (µg/g)	5	98.4	0	213	0	480	95.4	10
Manganese, recoverable (µg/g)	5	88.2	40	109	13	280	48.8	1
Mercury, recoverable (µg/g)	5	.10	.0	.23		.0	.5	.10
Molybdenum, recoverable (µg/g)	2	.0	0	.0	0	0	.0	10
Nickel, recoverable (µg/g)	4	1.2	0	2.5	0	5	1.2	10
Selenium, total (µg/g)	5	.0	0	.0	0	0	.0	1
Silver, recoverable (µg/g)	6	.0	0	.0	0	0	.0	1
Strontium, recoverable (µg/g)	2	15.0	15	7.1	10	20	5.0	1
Vanadium, total (µg/g)	0	—	—	—	—	—	—	1
Zinc, recoverable (µg/g)	5	13.8	10	9.1	8	30	4.1	1
Aldrin, total (µg/kg)	10	.00	.0	.00	.0	.0	.00	.1
Chlordane, total (µg/kg)	10	1.1	0	1.7	0	5	.55	1
DDD, total (µg/kg)	10	.80	.0	1.68	.0	5.4	.53	.1
DDE, total (µg/kg)	10	.30	.0	.45	.0	1.3	.14	.1
DDT, total (µg/kg)	10	.11	.0	.18	.0	.4	.06	.1
Dieldrin, total (µg/kg)	10	.03	.0	.07	.0	.2	.02	.1
Endosulfan, total (µg/kg)	8	.02	.0	.07	.0	.2	.02	.1
Endrin, total (µg/kg)	10	.00	.0	.00	.0	.0	.00	.1
Heptachlor, total (µg/kg)	10	.00	.0	.00	.0	.0	.00	.1
Heptachlor epoxide, total (µg/kg)	10	.01	.0	.03	.0	.1	.01	.1
Lindane, total (µg/kg)	10	.00	.0	.00	.0	.0	.00	.1
Methoxychlor, total (µg/kg)	9	.00	.0	.00	.0	.0	.00	.1
Mirex, total (µg/kg)	8	.00	.0	.00	.0	.0	.00	.1
PCB, total (µg/kg)	10	.50	.0	1.08	.0	3.0	.34	1
PCN, total (µg/kg)	8	.0	0	.0	0	0	.0	1
Perthane, total (µg/kg)	8	.0	0	.0	0	0	.0	1
Toxaphene, total (µg/kg)	10	.0	0	.0	0	0	.0	10

decreasing? The concentrations of water-quality constituents, such as dissolved solids, are difficult to compare over time because they often are related to the flow of water in the stream. For example, the dissolved-solids concentration in a particular river generally decreases with an increase in flow and increases as the flow diminishes. Examining the record over a period of years may show the dissolved-solids concentration decreasing. If the record began during a drought period when streamflow was below normal and ended during a wet period with streamflow above normal, a trend is apparent. However it is related to the flow of water in the stream and not to a change in the input of the dissolved solids from their source. While this information may be useful, it does not answer the primary concern of most water managers and the public—namely, are the efforts to clean up sources of contaminants improving water quality?

The seasonality of data collection also increases the difficulty in comparing data. Streamflows are commonly lowest in the late summer and early fall. If dissolved-solids concentrations vary with streamflow as in the previous example, then concentrations will be higher than average in samples collected during the late summer and early fall. Conversely, at times of the year when streamflow is high, the concentration will be lower than average. If samples were collected in late summer and fall for several years and then later were collected during the spring during high flows, a trend for decrease in concentration would again be apparent. Again, this trend is related to the season during which the data were collected and not to a change in the input of the dissolved solids from their source.

Statisticians have identified other problems in trend detection, including skewness and the serial correlation of the data. To avoid all of these problems, Hirsch and others (1982) derived a modification of Kendall's Tau test known as the Seasonal Kendall test. Smith and others (1982, p. 5-6) briefly describe the test as follows:

> The null hypothesis for this test is that the random variable is independent of time. The only necessary background assumption is that the random variable is independent and identically distributed (with any distribution). In this test, all possible pairs of data values are compared; if the later value (in time) is higher, a plus is scored; if the later value is lower, a minus is scored. If there is no trend in the data, the odds are 50-50 that a value is higher (or lower) than one of its predecessors. In the absence of a trend, the number of pluses should be about the same as the number of minuses. If, however, there are many more pluses than minuses, the values later in the series are more frequently higher than those earlier in the series, and so an uptrend is likely. Similarly, if there are many more minuses than pluses, a downtrend is likely.
>
> As discussed above, the one common pattern to water-quality variables is that they have a period of one year (other periodicities may exist). Comparing, for example, a January value with a May value does not contribute any information about the existence of a trend, if a seasonal cycle of a 1-year period exists. Thus, we define the Seasonal Kendall test to be the Kendall's Tau test restricted to those pairs of data which are multiples of 12 months apart. Since comparisons are made only between data from the same month of the year, the problem of seasonality is avoided. Thus, the background assumptions given above are relaxed. The random variable may be nonidentically distributed, provided that the distributions 12 months apart are identical.

Method

Table 8 shows the results of the Seasonal Kendall test applied to total phosphorus and total nitrogen concentrations and specific conductance. The methods used are fully described in Crawford and others (1983) and Smith and others (1982). Briefly, the first step is to determine if the concentration of the constituent is related to the streamflow. Specific conductance, although not a concentration, has been treated as one for this analysis. Fourteen different relationships (Crawford and others, 1983)

Table 8.—*Trend results for each station for the period of record*

[Trends and regressions are marked with "hs" for highly significant when p is less than or equal to 0.01, and with "s" for significant when p is less than or equal to 0.1. Regression type loglin is log-linear. Slope is marked with a plus (+) for a positive streamflow-constituent relationship, and with a minus (-) for a negative relationship. The term "Trend (percent per year)" is the slope as milligrams per liter, tons per day, or microsiemens per centimeter, per year divided by the average value in milligrams per liter (tons per day or microsiemens per centimeter) and multiplied by 100. The units in all cases are percent of mean per year. No data available indicated by —]

		Total Phosphorus									
Station number	Station name	Streamflow		Concentration		Transport		Flow-adjusted concentration			
		Mean (cubic feet per second)	Trend (percent per year)	Mean (milligrams per liter)	Trend (percent per year)	Mean (tons per year)	Trend (percent per year)	Trend (percent per year)	Regression		
									R^2	Type	Slope
01111230	Blackstone River at Millville, Mass.	596	-3.67 hs	0.29	-1.72	0.36	-4.49 s	-0.57	0.24 hs	loglin	-
01111500	Branch River at Forestdale, R.I.	205	.34	.03	.00 hs	.01	-2.12	—	—	none	—
01112900	Blackstone River at Manville, R.I.	880	1.02	.30	-1.67	.53	.05	-1.15	.28 hs	loglin	-
01116500	Pawtuxet River at Cranston, R.I.	342	-.52	.36	.00	.22	-.01	-.02	.41 hs	loglin	-
01116617	Pawtuxet River at Pawtuxet, R.I.	432	-1.60	.51	.00	.41	-2.14	-1.62	.36 hs	loglin	-
01118500	Pawcatuck River at Westerly, R.I.	625	.48	.07	.00 hs	.10	-.72	—	—	none	—

		Total Nitrogen									
Station number	Station name	Streamflow		Concentration		Transport		Flow-adjusted concentration			
		Mean (cubic feet per second)	Trend (percent per year)	Mean (milligrams per liter)	Trend (percent per year)	Mean (tons per year)	Trend (percent per year)	Trend (percent per year)	Regression		
									R^2	Type	Slope
01111230	Blackstone River at Millville, Mass.	596	-3.67 hs	3.18	-0.39	4.96	-2.32 s	—	—	none	—
01111500	Branch River at Forestdale, R.I.	205	.34	1.18	2.75 s	.40	5.80 s	—	—	none	—
01112900	Blackstone River at Manville, R.I.	880	1.02	2.37	-1.81	4.42	2.30	-.04	.49 hs	loglin	-
01116500	Pawtuxet River at Cranston, R.I.	342	-.52	2.19	3.65	1.32	.63	1.21	.28 hs	loglin	-
01116617	Pawtuxet River at Pawtuxet, R.I.	432	-1.60	2.91	3.44	2.43	-1.03	.81	.62 hs	loglin	-
01118500	Pawcatuck River at Westerly, R.I.	625	.48	.90	.22	1.28	1.31	.88	.20 hs	loglin	-

		Specific Conductance									
Station number	Station name	Streamflow		Concentration		Transport		Flow-adjusted concentration			
		Mean (cubic feet per second)	Trend (percent per year)	Mean (microsiemens)	Trend (percent per year)	Mean (tons per year)	Trend (percent per year)	Trend (percent per year)	Regression		
									R^2	Type	Slope
01111230	Blackstone River at Millville, Mass.	596	-3.67 hs	244	1.24 s	—	—	0.39	0.51 hs	loglin	-
01111500	Branch River at Forestdale, R.I.	205	.34	78	.51	—	—	.52	.34 hs	loglin	-
01112900	Blackstone River at Manville, R.I.	880	1.02	205	.00	—	—	.23	.24 hs	linear	-
01116500	Pawtuxet River at Cranston, R.I.	342	-.52	228	1.89 s	—	—	.98	.64 hs	loglin	-
01116617	Pawtuxet River at Pawtuxet, R.I.	432	-1.60	262	1.19	—	—	-.23	.58 hs	loglin	-
01118500	Pawcatuck River at Westerly, R.I.	625	.48	100	.25	—	—	.58 s	.57 hs	loglin	-

were tested for each of the constituents at each of the six sites. However, if a relationship existed at the site, either a linear or a log-linear relationship best fit the data. The following equations define these relationships:

$$C = a + b(Q) \text{ linear} \qquad (1)$$

$$C = a + b \ln (Q) \text{ log-linear} \qquad (2)$$

where C is the predicted concentration; Q is the streamflow, in cubic feet per second; and a and b are constants. In table 8, the type of relationship is given under the heading "Flow-adjusted concentration," along with the sign of the slope of the equation (whether b is positive or negative but not the actual value of b) for each station and constituent. These equations are labeled with "hs," highly significant, and "s" significant, depending on the p value where p is the probability of erroneously rejecting the null hypothesis that $b=0$—that is, there is no relationship of concentration to streamflow. The regression was marked "hs," highly significant, where p is less than or equal to 0.01, and "s," significant, where p is less than or equal to 0.1. While regression p values provide an appropriate basis for deciding when to make adjustments for flow dependency (Smith and others, 1982), a measure of the predictability of the concentration of the constituent based on flow is given by the proportion of variance explained or R^2. The closer R^2 is to 1.0, the better the equation fits the data. A negative streamflow-constituent relationship, which is the case for all three constituents and all sites, generally indicates that dilution either of point-source contributions or of subsurface sources is the dominant process. Smith and others (1982) found that this negative relationship for total phosphorus is generally limited to forested basins along the east coast, the Great Lakes, and the California coast. Nationwide, the majority of rivers have a positive streamflow-total phosphorus relationship, indicating that erosion and transport of total phosphorus at high flows is the dominant process.

After the streamflow-constituent relationship was determined, the next step was to run the Seasonal Kendall test on the streamflow, concentration, transport, and the flow-adjusted concentration. Transport, which was computed for total nitrogen and phosphorus but not for specific conductance, is the product of the concentration and the streamflow multiplied by a constant, 0.002697, to give constituent transport in tons per day. The flow-adjusted concentration is the actual concentration minus the expected concentration for that particular analysis calculated using one of the equations given above and indicated on the table.

As Smith and others (1982, p. 20) point out, trend analyses ". . . will never reveal the cause of a change in stream quality, but they can lead to improved understanding of the kinds of causes to look for." Generally, trends in streamflow will be related to natural variations of flow based on the variations in rainfall. However, if diversion of water from the basin were begun or increased during the period of record, a trend in streamflow would be apparent. Trends in concentration can be important if the concentration is close to an established criterion. Trends in transport reflect changes in the flux of substances through the river system and suggest what might be happening to the rates of output from various sources of the constituent. For example, if a newly installed wastewater-treatment plant removed a significant part of the phosphorus formerly introduced into the stream, a downward trend in phosphorus transport would be apparent. A downward trend might or might not be seen in the concentrationif the trend were masked by the variations in flow. Trends in the flow-adjusted concentration indicate that changes have occurred in the processes that deliver the constituent to the river. Using this phosphorus example, a downward flow-adjusted concentration trend should be apparent.

Results

Table 8 shows the results of the Seasonal Kendall test. The trend values are shown in percentage terms for ease of comparison. The term "Trend (percent per year)" is the slope as milligrams per liter, tons per day, or microsiemens (per centimeter at 25 degrees Celsius) per year divided by the average value in milligrams per liter (tons per day or microsiemens) and multiplied by 100. The units in all cases are percent of mean per year. For the flow-adjusted concentration, the units are percent of mean concentration per year. Those slopes that are statistically significant at the 10 percent level are marked with an "s," and those at the 1 percent level by an "hs," corresponding to significant and highly significant, respectively.

Trends at the Blackstone River at Millville, Mass., the Branch River at Forestdale, and the Pawcatuck River at Westerly, three sites at which statistically significant trends were found and reported in the previous Rhode Island report (Briggs and Feiffer, 1986), are again apparent with the additional 5 years of data. Streamflow had a downward trend for the Blackstone River at Millville, Mass., for the period of record. The trend also was downward for transport of phosphorus and nitrogen but the trend for specific conductance was upward for the Millville site. Trends in the flow-adjusted concentrations for the Millville site were not significant, indicating that the observed trends are probably flow dependent. A downward trend in phosphorus concentration reported for the Branch River at Forestdale in the previous report disappeared with additional data and the results now show no change in phosphorus concentration. Nitrogen concentration and transport for the Forestdale site continue to have an upward trend. For the Pawcatuck River at Westerly, phosphorus concentrations also show no change. The flow-adjusted trend for specific conductance at the Westerly site has a small upward trend, which may indicate an increase in the dissolved solids entering the stream independent of the volume of flow. Specific conductance showed an upward trend at the Pawtuxet River at Cranston.

SUMMARY

Compared to other parts of the United States, streams in Rhode Island have low concentrations of common constituents. Concentrations of sodium, for example, never exceeded 42 mg/L for the period 1983-88. Water hardness is generally in the soft range. At several sites, concentrations of major plant nutrients, nitrogen and phosphorus, were in the range which might cause undesirable eutrophication if the waters were impounded. For the six sites, the lowest concentrations of nitrogen and phosphorus species were at the Branch River at Forestdale and at the Pawcatuck River at Westerly.

Median fecal coliform bacteria counts were below 200 per 100 mL for the Pawcatuck River at Westerly, the Pawtuxet River at Pawtuxet and the Pawtuxet River at Cranston. The two Pawtuxet River sites are downstream from waste treatment plants which may discharge chlorinated effluent, lowering the bacteria counts.

Maximum trace element concentrations which are at or exceed drinking-water criteria were found at several sites. Maximum cadmium concentrations were at the drinking-water criterion at the Blackstone River at Millville, Mass., and at the Pawcatuck River at Westerly. Lead concentrations slightly exceeded the drinking-water criterion at the Blackstone River at Millville, Mass.

Maximum trace element concentrations which potentially exceed acute aquatic-life protection criteria at all sites were cadmium, chromium, copper, lead, and silver. Median concentrations of zinc potentially exceed the criterion for the Blackstone River at Millville, Mass., the Blackstone River at Manville, and the Branch River at Forestdale.

Several organic compounds were found in the water column. PCBs were found at four of the six sites, dieldrin at three sites, lindane at two sites, and heptachlor at one site. In bottom materials, chlordane, DDD, DDE, DDT, dieldrin, and PCBs were found at all sites and aldrin, endosulfan, endrin, heptachlor, heptachlor epoxide, lindane, methoxychlor, and mirex at one or more sites. One high concentration of PCB, 5,400 μg/kg, was found at the Pawtuxet River at Pawtuxet.

Trend analyses were performed on total phosphorus and nitrogen concentrations, specific conductance, and streamflow. Results show a downward streamflow trend for the Blackstone River at Millville, Mass. The trend was also downward for transport of phosphorus and nitrogen but the trend for specific conductance was upward for the Millville site. At the Branch River at Forestdale, trend analysis show no change in phosphorus concentration over time. Concentration and transport for nitrogen at the Forestdale site continues to have an upward trend found earlier. For the Pawcatuck River at Westerly, phosphorus concentrations also show no change over time. The flow-adjusted trend for specific conductance at the Westerly site is slightly upward.

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