WATER QUALITY OF RHODE ISLAND STREAMS

By John C. Briggs and Jeffrey S. Feiffer

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4367

Prepared in cooperation with the

STATE OF RHODE ISLAND

DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

Boston, Massachusetts

1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
150 Causeway Street, Suite 1309
Boston, MA 02114-1384

Copies of this report can be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225
Telephone: (303) 236-7476

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

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

Multiply inch-pound units	By	To obtain SI Units
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume per unit time (includes flow)	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	453.6	gram (g)
	Specific conductance	
micromho per centimeter at 25°C (μmhos/cm at 25°C)	1.000	microsiemens per centimeter at 25°C (μS/cm at 25°)

WATER QUALITY OF RHODE ISLAND STREAMS

by John C. Briggs and Jeffrey S. Feiffer

ABSTRACT

Water-quality data collected from November 1979 through September 1983 at five stations within Rhode Island and one in Massachusetts show that concentrations of the common constituents were low. Mean water hardness at all sites was in the "soft" category. Sodium concentrations were less than 20 milligrams per liter at two sites and less than 35 milligrams per liter at the other sites. Mean nitrogen values for the two Blackstone River sites were in the range that could cause undesirable growths of aquatic plants. Mean phosphorus values exceeded the recommended limits for protection of aquatic life at four sites.

Trace-element concentrations in the water were generally low. Those trace elements which were found in concentrations near or exceeding any standard or criterion include cadmium, chromium, lead, iron, and manganese. High concentrations of several trace elements were found in the bottom materials at several sites. The bottom materials also contained pesticides and organic chemicals including aldrin, chlordane, DDD, DDE, DDT, dieldren, endosulfan, endrin, heptachlor, mirex, and PCB.

Results of trend analysis of total phosphorus, total nitrogen, and specific conductance show a downward trend in phosphorus at two sites; an upward trend in nitrogen at one site; and one downward trend and one upward trend in specific conductance.

INTRODUCTION

The State of Rhode Island is required by several Federal laws to monitor, compile, and analyze data on the quality of streams. For the State to meet these requirements, water-quality data are needed for preparing comprehensive water-pollution control plans, developing information on the causes and effects of increases or decreases in pollution, determining water quality of major rivers on a regular basis and appraising long-term water-quality trends, and evaluating the effects of surface-water quality management strategies.

The U.S. Geological Survey requires information on water quality to accomplish the Agency's mission to appraise the quantity, quality, and use of the Nation's water. Two of the Survey's NASQAN (National Stream Quality Accounting Network) stations are located on rivers which are located in or flow into Rhode Island. These stations are the Pawcatuck River at Westerly, R.I., and the Blackstone River at Millville, Mass. However, additional sites were needed to give better spatial coverage of the State and to supplement the information that is being 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 the project are to (1) determine the existing chemical, physical, and biological quality of Rhode Island's major streams and (2) accumulate a data base, by periodic water-quality measurements, from which changes in stream quality can be assessed.

The purpose of this report is to summarize the data that were collected for the stations from November 1978 through September 1983, the end of the 1983 water year. Data from the stations in the study have been published on a water year (October through September) basis, in the series of publications, "Water Resources Data Massachusetts and Rhode Island Water Year (year)." Additional earlier data are included in the summary. This report includes an assessment of temporal trends in selected water-quality constituents.

Description of Stream Stations

Figure 1 shows the location of the six water-quality stations chosen for the study. Table 1 lists the station number, name, period of record, location, and any remarks about the site. Five of the sites are located within the State of Rhode Island while the sixth, Blackstone River at Millville, Mass., located just upstream from the Massachusetts-Rhode Island border, provides information on the water quality of the Blackstone River as it enters Rhode Island. All six sites are located downstream of regulated stream reaches. The Pawtuxet River is heavily regulated by the Scituate Reservoir, by the Flat River Reservoir, and by powerdams. The least regulated of the rivers is the Branch River at Forestdale whose upstream dams are not being actively used for power generation.

Two sites, Blackstone River at Millville, Mass., and Pawcatuck River at Westerly, are NASQAN sites. NASQAN, the National Stream Quality Accounting Network, is a set of over 500 stations nationwide at which a large number of water-quality characteristics of rivers 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 variablility of stream quality; (3) depict the temporal variability of stream quality; and (4) detect long-term trends in stream quality.

METHODS OF STUDY

Characteristics and constituents which are 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. Once yearly, bottom materials are examined for organic constituents.

Water samples are collected using fluvial-sediment sampling techniques described by Guy and Norman (1970). Use of these techniques ensures that samples collected for analysis of total chemical constituents contain a representative subsample 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 repesentative water-suspended sediment sample has been digested by a method (usually using a dilute acid solution) that results in dissolution of only readily soluble substances. Complete dissolution of all particulate matter is not achieved by the digestion treatment and thus the determination represents something 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.

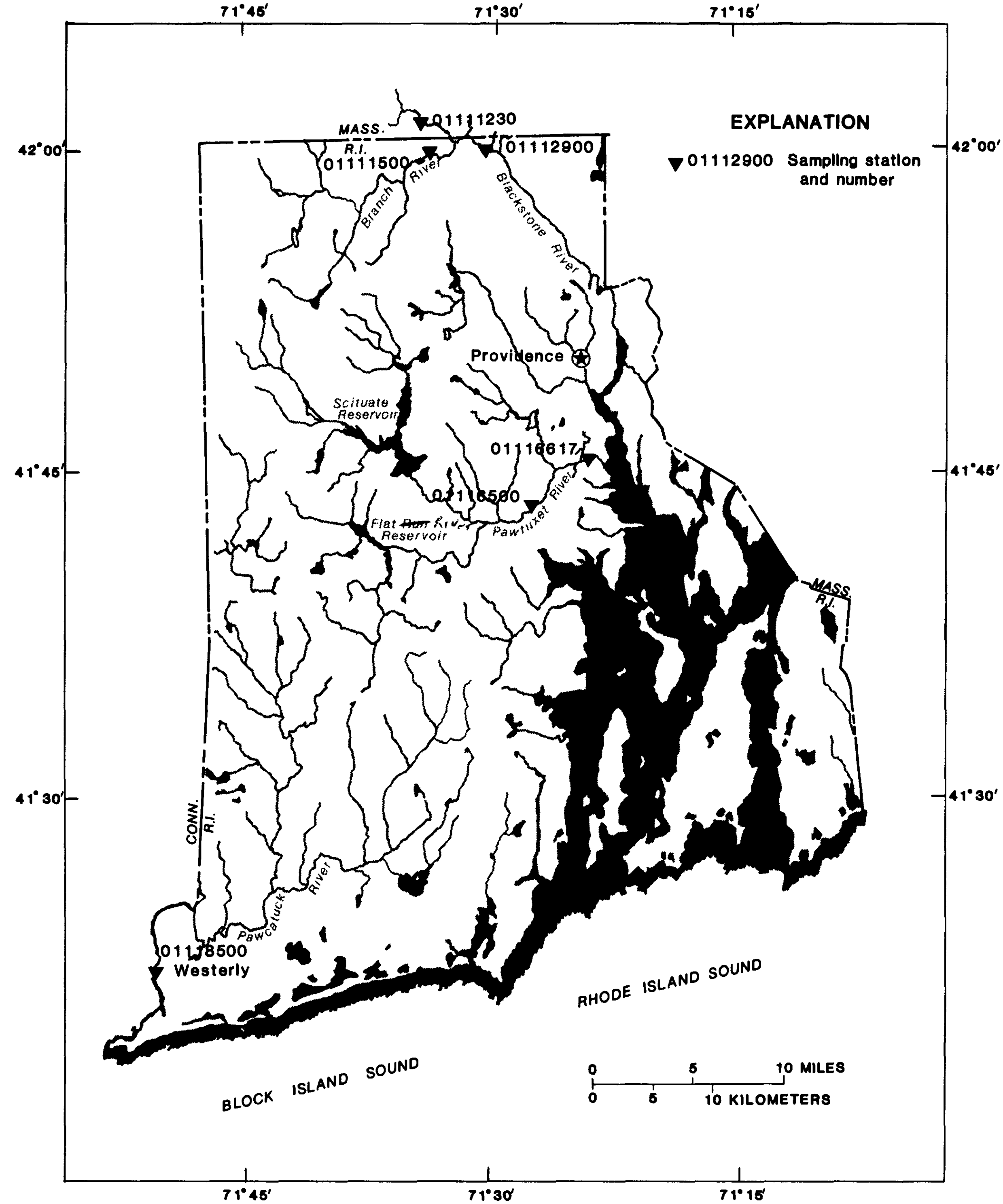

Figure 1.--Location of study area and sampling stations

Table 1.—Water quality sampling sites within the study area

Station number, station name, and period of record	Station location and remarks
01111230 Blackstone River at Millville Mass. November 1978-September 1983 Samples: 1971 and 1973 included.	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 powerdams, by West Hill Reservoir, and by other upstream reservoirs.
01111500 Branch River at Forestdale, R.I. May 1975-September 1983 Samples: 1953-58, 1965-69, and 1971-72 included.	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. November 1978-September 1983 Samples: 1970 included.	Latitude 41°58'18", longitude 71°28'14", Providence County, at milldam at Manville, and 400 feet upstream from Manville Road Bridge. Flow regulated by powerdams, by West Hill Reservoir, and by other upstream reservoirs.
01116500 Pawtuxet River at Cranston, R.I. May 1978-September 1983 Samples: 1953-58, 1961-73, and 1975-77 included.	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, drainage area 200 mi^2. Flow regulated by powerplants and the Scituate, Flat River, and other reservoirs.
01116617 Pawtuxet River at Pawtuxet, R.I. November 1978-September 1983	Latitude 41°45'51", longitude 71°23'45", Providence County, 1,300 feet upstream from the Narragansett Parkway Bridge at Pawtuxet, and 1,500 feet upstream stream from the mouth. Flow regulated by powerplants and the Scituate, Flat River, and other reservoirs.
01118500 Pawcatuck River at Westerly, R.I. April 1976-September 1983	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. Some regulation from mill dams.

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

MEASURED MONTHLY

Field determinations	Major nutrients
Discharge	Nitrogen
Water temperature	Total nitrogen
Specific conductance	Total organic nitrogen
pH	Total ammonia nitrogen
Dissolved oxygen	Total nitrite nitrogen
	Total nitrate nitrogen
Biological characteristics	Phosphorus
Fecal coliform bacteria	Total phosphorus
Fecal streptococci bacteria	Total orthophosphate
Other	
5 day biological oxygen demand (BOD)	

MEASURED TWICE YEARLY DURING LOW AND HIGH FLOW

Common constituents	Trace elements	Organic compounds
Dissolved calcium	Total alluminum	Total aldrin
Dissolved magnesium	Total arsenic	Total chlordane
Dissolved sodium	Total boron	Total DDD
Dissolved potassium	Total cadmium	Total DDE
Dissolved chloride	Total chromium	Total DDT
Dissolved sulfate	Total copper	Total dieldrin
Alkalinity	Total iron	Total endosulfan
	Total lead	Total endrin
Other	Total manganese	Total PCB
Color	Total mercury	Total PCN
Chemical oxygen demand	Total molybdinum	Total heptachlor epoxide
Total ROE (residue on evaporation) at 105°C	Total nickel	Total heptachlor
	Total selenium	Total lindane
Suspended ROE at 105°C	Total silver	Total methoxychlor
Phenols	Total zinc	Total myrex
Total oil and grease		Total perthane
		Total toxaphene

MEASURED YEARLY DURING LOW FLOW

Organic compounds in stream bottom material

Total aldrin	Total chlordane	Total DDD
Total DDE	Total DDT	Total dieldrin
Total endosulfan	Total endrin	Total PCB
Total PCN	Total heptachlor epoxide	Total heptachlor
Total lindane	Total mirex	Total methoxychlor
Total perthane	Total toxaphene	

Stream-discharge values are either from measurements made at the time of sample collection or from a stage-discharge rating (Rantz, 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 Skougstad and others (1979). samples collected for laboratory analyses were preserved in the field and immediately shipped to the Survey laboratory in Atlanta, Georgia. Sample preservation and analytical methods are described in Skougstad and others (1979), Greeson and others (1977), Greeson (1979), and Wershaw and others (1983).

Certain constituents are often 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 detection limit of the analytical procedure. Normally these results are reported and published as "less than" the detection limit of the analytical procedure used for the determination. Results of individual analyses which are published in the annual data report will often show a "less than" concentration for a particular constituent. Detection limits for any particular constituent are given in the references to analytical procedures given in the preceding paragraph. When summarizing a number of analyses using statistical techniques, these "less than" values must be taken into account. For this report, all "less than" values have been converted to zero. All tables and figures which show a zero value should be interpreted as below the detection limit of the analyses.

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, those values were treated as an absolute value. In the summary tables and in figures showing maximum values for bacteria counts, the actual value may have been greater than the maximum shown. This information is available in the individual analyses.

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 standards or criteria in order to judge the suitability of the water. 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. Among the commonly cited standards and 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); National Interim Primary and Secondary Drinking Water Regulations (U.S. Environmental Protection Agency, 1975, 1977, 1980); and recommended criteria proposed in miscellaneous articles and reports. In many cases, more stringent criteria are cited than would normally be imposed on a 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 supply apply to water which is delivered to the free flowing outlet of the ultimate user of a public water system (U.S. Environmental Protection Agency, 1975). Water from a stream used as a drinking water source may have been filtered or otherwise treated to remove particulate matter. While this water may not meet the strict definition of dissolved given above, the analyses of the water will probably be closer to a "dissolved" analyses of the source water rather than an analyses for "total" or "total recoverable" constituents unless the water has had chemical treatment. Chemical treatment may result in a water whose analytical results will be quite different from even the dissolved analyses of the untreated water. In this report, drinking water criteria may be compared with "total", "total recoverable", or "dissolved" constituents. Again, comparison with drinking water criteria 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 Geological Survey in the past. A summary of data on major inorganic chemicals measured at each of the Rhode Island stations 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.

Calcium, Magnesium, and Hardness

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 mass of calcium carbonate, $CaCO_3$. General guidelines for classification of waters are: 0 to 60 mg/L 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).

Mean concentrations of calcium, magnesium, and hardness, were low at all the Rhode Island sites. 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.

Sodium

The most restrictive drinking water criterion for sodium is 20 mg/L. This criterion was set to protect individuals who may be on "very resticted sodium diets." Mean sodium concentration at Branch River at Forestdale and Pawcatuck River at Westerly meet this criterion. 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.

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 limit of 250 mg/L for chlorides and sulfates in domestic water supplies was set by the U.S. Environmental Protection Agency (1977). The highest concentration of chloride and sulfate measured in the study area were 82 and 85 mg/L, respectively. Mean chloride concentrations were greatest in the Pawtuxet River at Cranston 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 through the reduction in the incidence of 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 varied 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 the addition 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 concentrations of ions in mass per unit volume, such as nitrogen as NO_3 (nitrate) and phophorus as PO_4 (phosphate). Other investigators report only the mass of nitrogen or phosphorus, such as nitrogen as N and phophorus as P. The latter method is used throughout this report and gives results considerably different from the former. 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 represent both "dissolved" concentrations, which include the portions in solution, and "total" concentrations, which include the dissolved plus the portions that are associated with suspended material.

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 which is 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. The U.S. Environmental Protection Agency (1976) specifies 10 mg/L as the maximum allowable concentration of nitrate nitrogen for drinking water-supplies to provide human health protection. Criteria vary on concentrations of nitrate for the protection of aquatic life; that is, levels which 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 vary from 0.10 mg/L in pristine waters to 3 mg/L in less sensitive waters. A study of 365 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 0.30 and 0.39 mg/L, respectively. Nitrate plus nitrite was used since the nitrite concentration is quite small compared to the nitrate concentration. Highest mean total nitrate plus nitrite values were in the Blackstone River at Millville, Mass. and in the Blackstone River at Manville with 1.4 and 1.1 mg/L, respectively. While these values are lower than the drinking water standard, 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 sufficent.

Total nitrogen concentrations were lowest again in the Branch River at Forestdale and in the Pawcatuck River at Westerly, with mean values of 0.93 and 0.88 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 3.2 and 2.7 mg/L.

The variability of the nitrogen concentrations in different years may be partially related to streamflow. Figure 2 shows the mean streamflow in cubic feet per second by year for the years 1979 through 1983. Figure 3 shows the annual mean total nitrogen concentration for 1979 through 1983 for the six sites. In general, the years with lower mean streamflow values had higher mean nitrogen values. Mean streamflow was lowest in 1981 at all of the sites. Mean concentrations of nitrogen were highest in 1981 at the Blackstone River at Manville (01112900), the Pawtuxet River at Cranston (01116500), the Pawtuxet River at Pawtuxet (01116617), and the Pawcatuck River at Westerly (01118500).

Phosphorus

Phosphorous data are reported as "total phosphorus as P" and "total orthophosphate phorphorus as P". Total phophorus includes all forms of phosphorus such as soluble orthophosphate, soluble hydrolyzable phophorus, soluble organic phosphorus and phosphorus associated with collodial material and both inorganic and organic suspended material. Even though orthophophate 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 phophorus may be converted by biological or chemical means into orthophosphate phosphorus.

The U.S. Environmental Protection Agency (1976) proposed a phosphorus criterion of 0.05 mg/L 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 phophorus of 0.1 mg/L for "aquatic life protection."

Orthophosphate phosphorous concentrations were lowest at the Pawcatuck River at Westerly and at the Branch River at Forestdale with mean values of 0.02 mg/L at both sites and maximum values of 0.09 and 0.26 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 0.04 and 0.05 mg/L. Highest mean total phosphorus and mean orthophosphate phosphorus concentrations was at the Pawtuxet River at Pawtuxet.

Figure 4 shows the annual mean total phorsphorus values for the six stations for the years 1979 through 1983. The concentrations varied from year to year, generally with the highest concentrations in 1981 when streamflow was lowest. Only the Branch River at Forestdale (01111500) and the Pawcatuck River at Westerly (01118500) met either the 0.05 or the 0.1 mg/L criteria. The other four sites had phophorus concentrations which exceeded the criterion.

Bacteria

There are many species of bacteria in natural waters; some are pathogenic, or disease causing, but fortunately most are harmless. People, of course, are concerned mainly about those that present threats of disease.

It is impossible to monitor for all forms of pathogens. Instead, knowing that certain disease-producing organisms move from person to person through the water, the 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 show the presence of fecal contamination, and (2) contaminated waters are likely to contain pathogens in numbers proportional to the numbers of indicator bacteria.

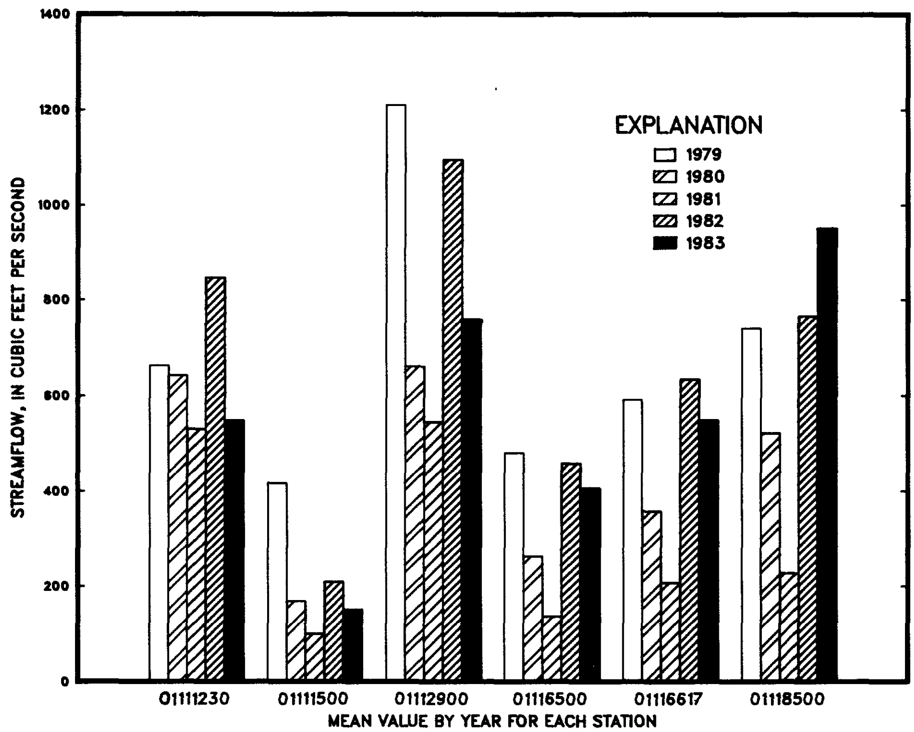

Figure 2.--Mean streamflow by station, 1979-83.

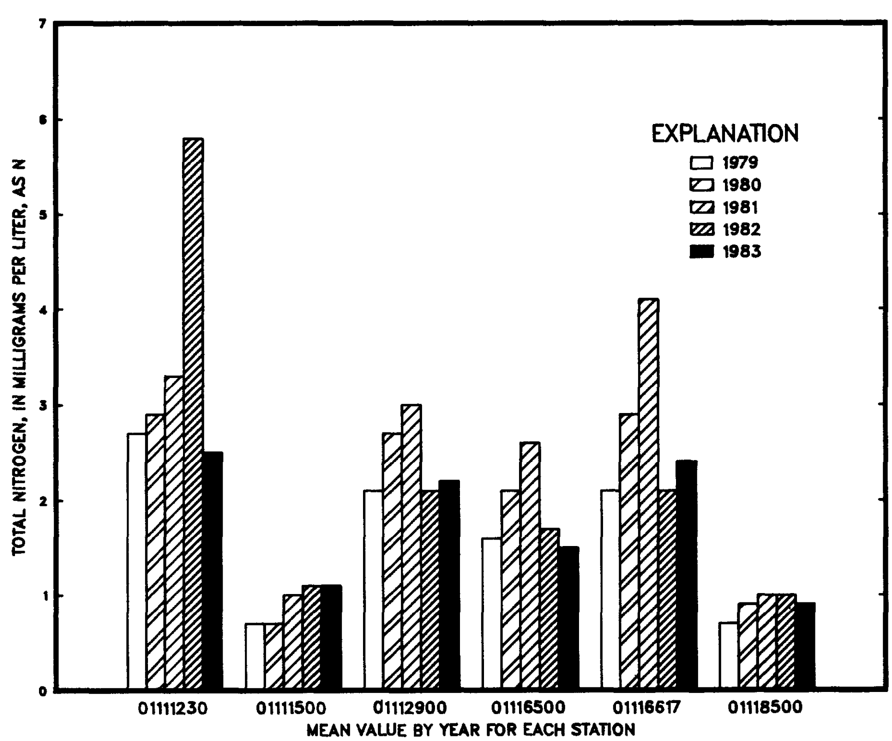

Figure 3.--Mean total nitrogen by station, 1979-83.

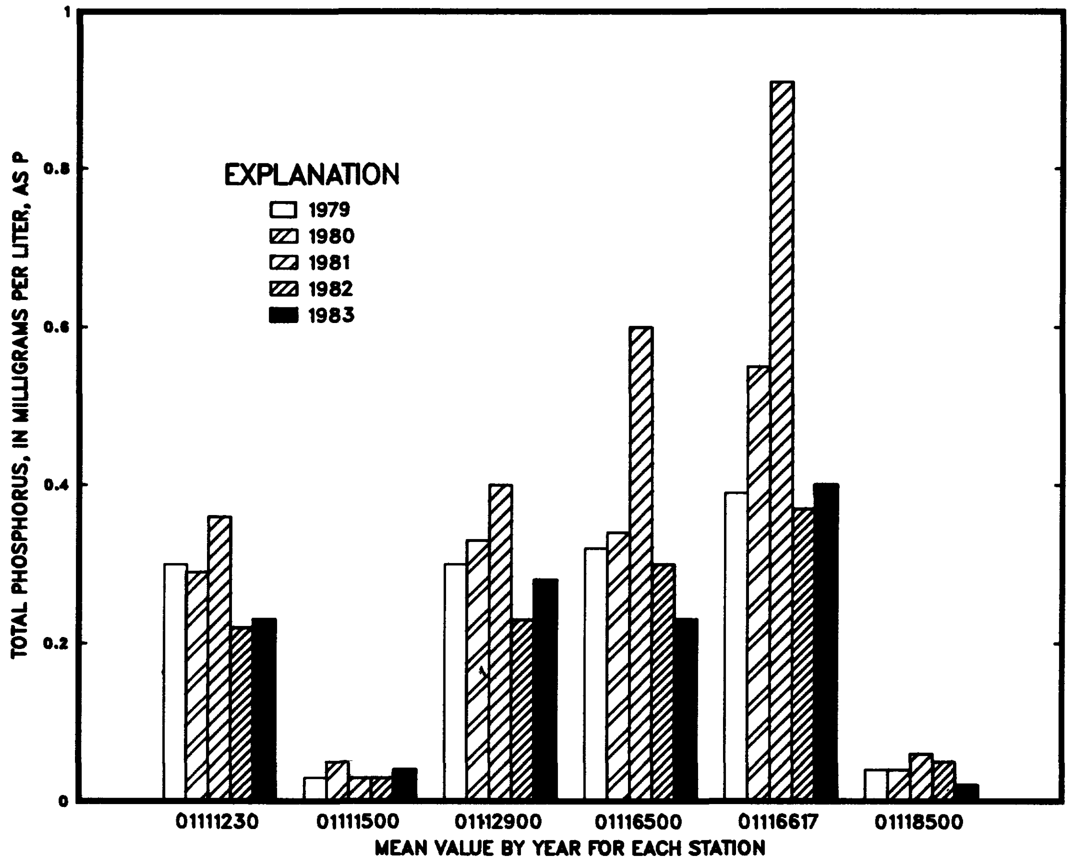

Figure 4.—Mean total phosphorus by station, 1979–83.

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 warmblooded animals, and (2) fecal streptococci bacteria which are also found in the intestines of warmblooded animals. Most standards and criteria of water quality are written in terms of fecal coliform bacteria. For body contact sports such as swimming, the U.S. Environmental Protection Agency (1976) set a criterion that the fecal coliform bacteria count should not exceed a log mean (geometric mean) of 200 per 100 ml of sample based on a minimum of five samples taken over a 30-day period. In addition, not more than 10 percent of the samples taken during the period should exceed 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.

Figures 5 and 6 show the arithmetic mean and the observed maximum number of fecal coliform bacteria per 100 ml of sample for the most recent years at the six sites. As shown in the figures, none of the sites met the body-contact criterion. However, samples collected as part of this study were not collected in sufficient quantities to meet the sampling frequency requirement of the criterion but the numbers are indicative that the water may not meet the criterion. Each of the two sites with the lowest number of counts, the Pawtuxet River at Cranston (01116500) and the Pawtuxet River at Pawtuxet (01116617), is located downstream from a wastewater-treatment plant. Their lower counts may reflect the effect of chlorinated effluent from the plants.

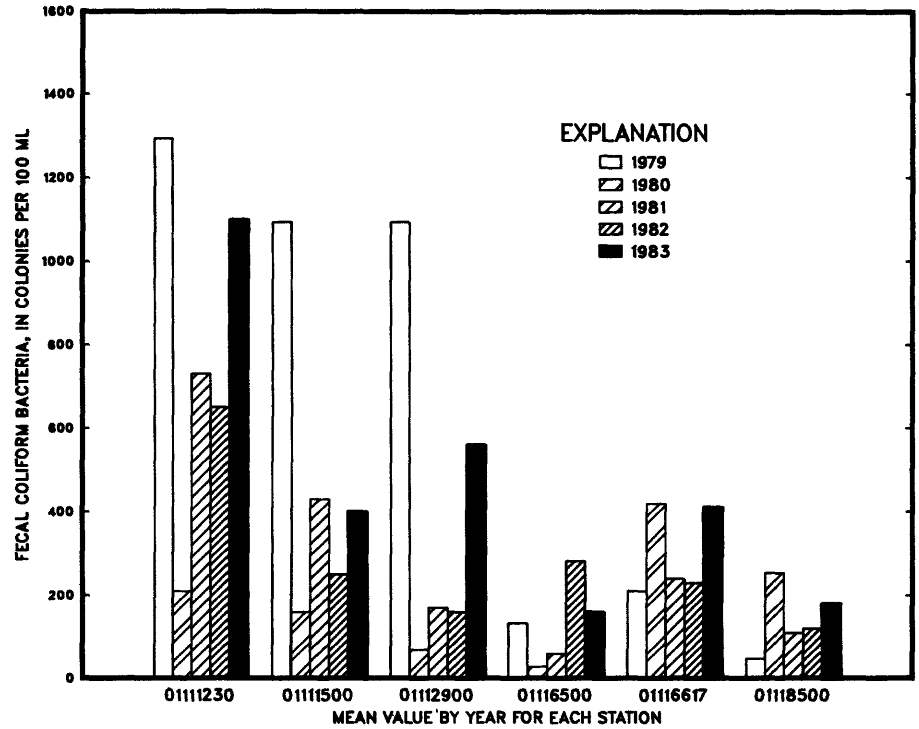

Figure 5.---Mean fecal coliform bacteria by station, 1979--83.

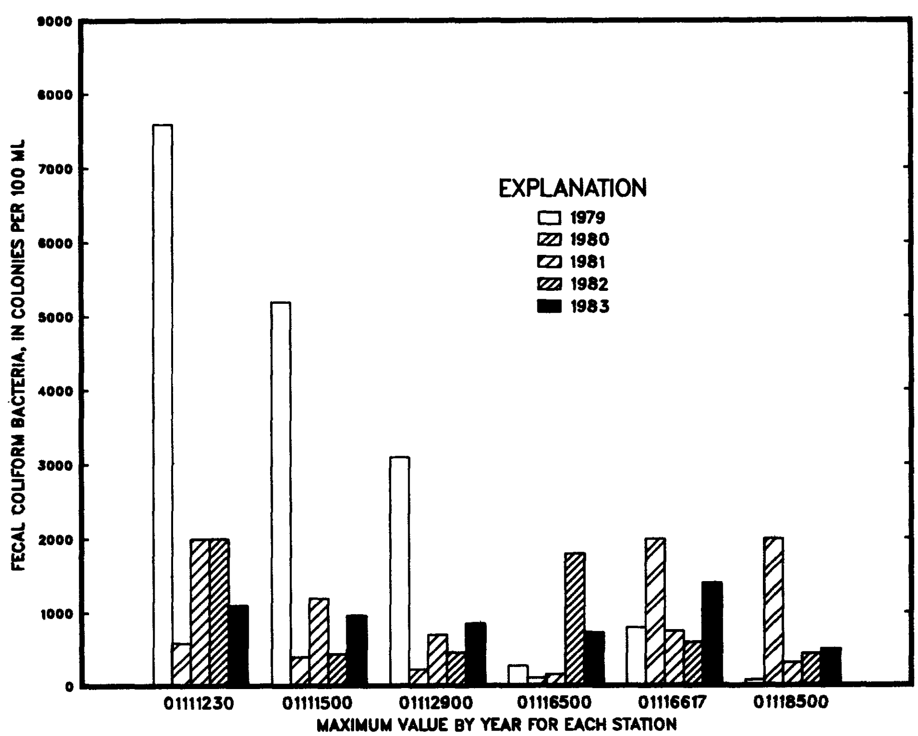

Figure 6.---Maximum fecal coliform by station, 1979--83.

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

(Analyses are in milligrams per liter except as indicated.)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01111230 Blackstone River at Millville, Mass.						
Streamflow,						
instantaneous (ft^3/s)	75	654.6	566.4	~~2.0~~ 83	2,830	65.4
Specific conductance (μmhos)	83	237.7	59.8	134	369	6.6
pH (standard units)	83	6.50	.41	5.6	7.3	.04
Temperature (degrees C)	82	10.8	8.3	.5	26.5	.9
Turbidity (NTU)	63	3.02	3.01	.00	20	.38
Oxygen, dissolved	82	9.72	2.89	2.7	14.5	.32
Oxygen demand:						
biochemical, 5-day	5	2.60	1.52	1.0	5.0	.68
chemical (high level)	23	29.9	29.7	0	110	6.2
Coliform, total,						
immed. (cols./100 ml)	40	7,851.6	11,497.0	0	61,000	1,817.8
Coliform, fecal:						
0.45 μm-MF (cols./100 ml)	17	943.6	1,928.6	61	7,600	467.7
0.7 μm-MF (cols./100 ml)	30	629.0	537.6	86	2,000	98.1
Streptococci, fecal,						
KF agar (cols./100 ml)	45	832.7	1,817.8	0	8,500	271.0
Hardness:						
(as $CaCO_3$)	43	39.2	8.6	21	59	1.3
noncarbonate ($CaCO_3$)	27	21.4	7.6	7	37	1.5
Calcium, dissolved (as Ca)	50	12.44	2.92	6.5	19	.41
Magnesium, dissolved (as Mg)	50	1.99	.38	1.1	2.8	.05
Sodium, dissolved (as Na)	50	26.5	6.65	16	41	.94
Potassium, dissolved (as K)	50	3.1	.97	1.5	5.2	.14
Alkalinity (as $CaCO_3$)	25	16.8	6.1	8	32	1.2
Sulfate, dissolved (as SO_4)	50	19.6	6.01	10	35	.85
Chloride, dissolved (as Cl)	51	40.6	10.2	24	61	1.43
Fluoride, dissolved (AS F)	43	.18	.11	.0	.4	.02
Silica, dissolved (as SiO_2)	43	5.77	1.20	2.2	8.7	.18
Solids:						
residue at 105°C, total	24	154.6	38.1	93	233	7.8
residue at 105°C, susp.	24	8.3	6.7	0	31	1.4
residue at 180°C, diss.	41	139.5	32.9	87	211	5.1
sum of constituents, diss.	37	124.0	30.4	78	190	5.0
Nitrogen:						
total (as N)	61	3.22	2.94	1.2	24	.38
dissolved (as N)	20	2.72	1.30	1.1	5.3	.290
organic total (as N)	65	.945	2.80	.00	23	.348
organic dissolved (as N)	19	.682	.633	.00	2.3	.145
ammonia dissolved (as N)	38	.753	.839	.00	3.3	.136
ammonia total (as N)	82	.810	.943	.00	4.1	.104
nitrite total (as N)	74	.030	.034	.00	.15	.004
nitrate total (as N)	51	1.25	.849	.34	3.8	.119
NO_2+NO_3 total (as N)	78	1.38	1.00	.36	4.5	.113
NO_2+NO_3 dissolved (as N)	38	1.31	.902	.12	4.5	.146
Phosphorus:						
total (as P)	84	.280	.164	.09	1.2	.018
dissolved (as P)	42	.160	.118	.00	.53	.018
ortho, total (as P)	74	.153	.110	.00	.50	.013
Sediment:						
suspended	30	10.8	13.6	1	79	2.5
discharge, suspended (t/day)	24	20.7	29.8	2.2	120	6.08

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
		01111500 Branch River at Forestdale, R. I.				
Streamflow,						
instantaneous (ft^3/s)	113	220.2	426.5	~~2.0~~ 17	4,050	40.1
Specific conductance (μmhos)	108	77.1	20.9	10	184	2.0
pH (standard units)	75	6.58	.69	5.0	9.8	.08
Temperature (degrees C)	156	12.3	8.8	.0	28.5	.7
Turbidity (NTU)	45	1.25	.78	.00	4.0	.12
Oxygen, dissolved	73	11.35	2.30	4.5	15.2	.27
Oxygen demand:						
biochemical, 5-day	16	1.00	.36	0.0	2.0	.09
chemical (high level)	22	33.0	51.9	0	200	11.07
Coliform, total						
immed. (cols./100 ml)	43	2,000.0	2,499.5	180	15,000	381.2
Coliform, fecal:						
0.45 μm-MF (cols./100 ml)	11	628.9	1,521.0	40	5,200	458.6
0.7 μm-MF (cols./100 ml)	33	331.9	285.6	35	1,200	49.7
Streptococci, fecal,						
KF agar (cols./100 ml)	44	196.9	284.9	4	1,500	42.9
Hardness:						
(as $CaCO_3$)	20	15.4	5.5	9	32	1.2
noncarbonate ($CaCO_3$)	13	6.2	3.3	0	11	.9
Calcium, dissolved (as Ca)	22	4.53	1.93	2.5	11	.41
Magnesium, dissolved (as Mg)	22	.91	.19	.6	1.3	.04
Sodium, dissolved (as Na)	22	9.28	4.28	4.2	26	.91
Potassium, dissolved (as K)	22	1.31	1.30	.5	7	.28
Alkalinity (as $CaCO_3$)	12	11.4	12.4	4	48	3.6
Sulfate, dissolved (as SO_4)	22	10.5	6.80	6.8	39	1.45
Chloride, dissolved (as Cl)	22	13.1	3.67	3.7	19	.78
Fluoride, dissolved (as F)	3	.07	.12	.0	.2	.07
Silica, dissolved (as SiO_2)	3	2.60	2.19	.1	4.2	1.27
Solids:						
residue at 105°C, total	24	57.7	11.0	32	72	2.2
residue at 105°C, susp.	24	5.9	5.5	0	23	1.1
residue at 180°C, diss.	3	73.7	43.7	45	124	25.2
sum of constituents, diss.	1	51.0	—	51	51	—
Nitrogen:						
total (as N)	57	.930	.519	.36	2.9	.069
dissolved (as N)	0	—	—	—	—	—
organic total (as N)	56	.404	.306	.00	1.9	.041
organic dissolved (as N)	0	—	—	—	—	—
ammonia dissolved (as N)	0	—	—	—	—	—
ammonia total (as N)	75	.175	.193	.00	1.1	.022
nitrite total (as N)	75	.008	.025	.00	.20	.003
nitrate total (as N)	42	.316	.307	.11	2.1	.047
NO_2+NO_3 total (as N)	75	.305	.259	.10	2.3	.030
NO_2+NO_3 dissolved (as N)	0	—	—	—	—	—
Phosphorus:						
total (as P)	75	.035	.065	.00	.40	.008
dissolved (as P)	0	—	—	—	—	—
ortho, total (as P)	75	.016	.043	.00	.26	.005
Sediment:						
suspended	0	—	—	—	—	—
discharge, suspended (t/day)	0	—	—	—	—	—

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
		01112900 Blackstone River at Manville, R. I.				
Streamflow,						
instantaneous (ft^3/s)	69	882.5	924.7	68	4,540	111.3
Specific conductance (μmhos)	70	206.9	74.2	3	410	8.9
pH (standard units)	68	6.74	.50	5.5	7.6	.06
Temperature (degrees C)	70	12.0	9.1	.0	27.0	1.1
Turbidity (NTU)	47	2.97	2.45	.40	15.0	.36
Oxygen, dissolved	69	10.65	2.33	5.4	15.2	.28
Oxygen demand:						
biochemical, 5-day	15	2.53	.92	1.0	4.0	.24
chemical (high level)	22	26.9	26.2	0	99	5.6
Coliform, total						
immed. (cols./100 ml)	43	2,607.2	4,169.3	1	20,000	635.8
Coliform, fecal:						
0.45 μm-MF (cols./100 ml)	11	603.2	987.1	0	3,100	297.6
0.7 μm-MF (cols./100 ml)	32	224.2	252.1	2	850	44.6
Streptococci, fecal,						
KF agar (cols./100 ml)	43	216.7	761.4	0	4,800	116.1
Hardness:						
(as $CaCO_3$)	16	37.8	8.6	17	50	2.2
noncarbonate ($CaCO_3$)	11	19.7	12.1	5	44	3.6
Calcium, dissolved (as Ca)	21	11.35	3.01	5.5	16	.65
Magnesium, dissolved (as Mg)	21	1.84	.41	.9	2.5	.09
Sodium, dissolved (as Na)	21	26.2	7.30	15	41	1.59
Potassium, dissolved (as K)	21	2.94	1.02	1.6	4.8	.22
Alkalinity (as $CaCO_3$)	10	16.0	6.1	3	24	1.9
Sulfate, dissolved (as SO_4)	20	20.3	5.90	12	34	1.32
Chloride, dissolved (as Cl)	22	38.5	10.7	17	60	2.28
Fluoride, dissolved (as F)	1	.5	—	.5	.5	—
Silica, dissolved (as SiO_2)	1	5.60	—	5.6	5.6	—
Solids:						
residue at 105°C, total	25	138.2	29.9	100	205	6.0
residue at 105°C, susp.	25	9.9	7.9	0	29	1.6
residue at 180°C, diss.	0	—	—	—	—	—
sum of constituents, diss.	1	171.0	—	171	171	—
Nitrogen:						
total (as N)	55	2.45	1.11	1.0	5.7	.150
dissolved (as N)	0	—	—	—	—	—
organic total (as N)	55	.692	.580	.00	3.6	.078
organic dissolved (as N)	0	—	—	—	—	—
ammonia dissolved (as N)	0	—	—	—	—	—
ammonia total (as N)	71	.719	.805	.03	5.2	.096
nitrite total (as N)	71	.029	.032	.00	.13	.004
nitrate total (as N)	53	1.00	.613	.32	3.0	.084
NO_2+NO_3 total (as N)	71	1.09	.696	.15	3.1	.083
NO_2+NO_3 dissolved (as N)	0	—	—	—	—	—
Phosphorus:						
total (as P)	71	.298	.167	.09	1.1	.020
dissolved (as P)	0	—	—	—	—	—
ortho, total (as P)	71	.200	.153	.00	.84	.018
Sediment:						
suspended	0	—	—	—	—	—
discharge, suspended (t/day)	0	—	—	—	—	—

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
			01116500 Pawtuxet River at Cranston, R. I.			
Streamflow,						
instantaneous (ft^3/s)	97	352.7	339.1	56	2,220	34.4
Specific conductance (μmhos)	85	216.9	98.8	55	455	10.7
pH (standard units)	85	6.50	.45	5.2	7.3	.05
Temperature (degrees C)	163	11.8	7.8	.0	26.0	.6
Turbidity (NTU)	47	2.44	1.61	.18	8.0	.24
Oxygen, dissolved	82	9.60	3.05	1.8	14.2	.34
Oxygen demand:						
biochemical, 5-day	16	2.31	1.08	1.0	5.0	.27
chemical (high level)	24	31.8	36.0	0	170	7.3
Coliform, total						
immed. (cols./100 ml)	42	4,942.5	10,711.2	0	52,000	1,652.8
Coliform, fecal:						
0.45 μm-MF (cols./100 ml)	11	73.5	97.7	0	280	29.5
0.7 μm-MF (cols./100 ml)	32	122.6	332.8	0	1,800	58.8
Streptococci, fecal,						
KF agar (cols./100 ml)	42	136.4	399.1	0	2,000	61.6
Hardness:						
(as $CaCO_3$)	19	38.4	20.2	12	76	4.6
noncarbonate ($CaCO_3$)	16	20.2	14.2	0	40	3.6
Calcium, dissolved (as Ca)	25	9.86	5.57	3.2	25	1.11
Magnesium, dissolved (as Mg)	25	2.76	1.83	.9	7.5	.37
Sodium, dissolved (as Na)	25	25.4	15.4	4.8	57	3.08
Potassium, dissolved (as K)	25	4.01	3.60	1.0	18	.72
Alkalinity (as $CaCO_3$)	21	15.7	6.7	5	31	1.5
Sulfate, dissolved (as SO_4)	31	28.9	17.0	9.5	76	3.05
Chloride, dissolved (as Cl)	32	36.8	21.3	4.5	82	3.76
Fluoride, dissolved (as F)	6	.20	.14	.0	.3	.05
Silica, dissolved (as SiO_2)	6	4.48	.84	3.2	5.8	.34
Solids:						
residue at 105°C, total	31	151.0	62.6	64	315	11.2
residue at 105°C, susp.	25	10.0	8.1	0	33	1.6
residue at 180°C, diss.	4	58.0	17.2	39	80	8.6
sum of constituents, diss.	4	105.5	97.9	34	249	49.0
Nitrogen:						
total (as N)	65	1.90	.898	.66	4.7	.111
dissolved (as N)	0	—	—	—	—	—
organic total (as N)	66	.507	.345	.00	1.4	.042
organic dissolved (as N)	0	—	—	—	—	—
ammonia dissolved (as N)	2	.610	.693	.12	1.1	.490
ammonia total (as N)	82	.791	.502	.00	2.6	.055
nitrite total (as N)	76	.035	.048	.00	.18	.005
nitrate total (as N)	50	.597	.322	.00	1.6	.045
NO_2+NO_3 total (as N)	82	.611	.343	.00	1.70	.038
NO_2+NO_3 dissolved (as N)	1	.190	—	.19	.19	—
Phosphorus:						
total (as P)	84	.343	.239	.00	1.20	.026
dissolved (as P)	0	—	—	—	—	—
ortho, total (as P)	76	.249	.211	.00	1.10	.024
Sediment:						
suspended	0	—	—	—	—	—
discharge, suspended (t/day)	0	—	—	—	—	—

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
			01116617 Pawtuxet River at Pawtuxet, R. I.			
Streamflow,						
instantaneous (ft^3/s)	71	479.4	497.7	136	3,370	59.1
Specific conductance (μmhos)	72	254.1	108.6	10	560	12.8
pH (standard units)	72	6.57	.41	5.7	7.5	.05
Temperature (degrees C)	74	11.3	8.2	.0	25.0	1.0
Turbidity (NTU)	47	2.67	2.29	.40	15.0	.33
Oxygen, dissolved	73	8.75	3.59	.5	14.6	.42
Oxygen demand:						
biochemical, 5-day	22	7.77	4.05	3.0	16	.86
chemical (high level)	23	40.4	28.9	0	98	6.0
Coliform, total						
immed. (cols./100 ml)	48	77,206.1	173,969.8	0	1,100,000	25,110.4
Coliform, fecal:						
0.45 μm-MF (cols./100 ml)	11	139.7	233.6	4	800	70.4
0.7 μm-MF (cols./100 ml)	40	337.5	424.2	0	2,000	67.1
Streptococci, fecal,						
KF agar (cols./100 ml)	47	341.0	674.3	0	4,000	98.4
Hardness:						
(as $CaCO_3$)	14	46.0	13.8	19	64	3.7
noncarbonate ($CaCO_3$)	10	23.4	12.6	5	47	4.0
Calcium, dissolved (as Ca)	19	11.39	4.13	5.5	19	.95
Magnesium, dissolved (as Mg)	19	2.93	1.28	1.2	5.4	.30
Sodium, dissolved (as Na)	19	33.2	16.8	13	69	3.86
Potassium, dissolved (as K)	19	4.09	2.20	1.6	10	.50
Alkalinity (as $CaCO_3$)	9	20.4	4.6	14	26	1.5
Sulfate, dissolved (as SO_4)	19	35.8	19.8	14	85	4.5
Chloride, dissolved (as Cl)	20	40.4	17.0	20	75	3.81
Fluoride, dissolved (as F)	0	—	—	—	—	—
Silica, dissolved (as SiO_2)	0	—	—	—	—	—
Solids:						
residue at 105°C, total	25	165.6	64.2	75	325	12.8
residue at 105°C, susp.	25	11.8	7.7	4	32	1.5
residue at 180°C, diss.	0	—	—	—	—	—
sum of constituents, diss.	0	—	—	—	—	—
Nitrogen:						
total (as N)	58	2.74	1.43	.51	6.6	.187
dissolved (as N)	0	—	—	—	—	—
organic total (as N)	58	.707	.505	.00	2.3	.066
organic dissolved (as N)	0	—	—	—	—	—
ammonia dissolved (as N)	0	—	—	—	—	—
ammonia total (as N)	77	1.37	1.07	.00	4.8	.122
nitrite total (as N)	77	.049	.055	.00	.26	.006
nitrate total (as N)	56	.621	.262	.07	1.4	.035
NO_2+NO_3 total (as N)	77	.683	.300	.11	1.6	.034
NO_2+NO_3 dissolved (as N)	0	—	—	—	—	—
Phosphorus:						
total (as P)	77	.501	.355	.10	2.0	.040
dissolved (as P)	0	—	—	—	—	—
ortho, total (as P)	77	.405	.332	.00	1.4	.038
Sediment:						
suspended	0	—	—	—	—	—
discharge, suspended (t/day)	0	—	—	—	—	—

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01118500 Pawcatuck River at Westerly, R. I.						
Streamflow,						
instantaneous (ft^3/s)	143	674.9	606.4	72	3,750	50.7
Specific conductance (μmhos)	141	100.1	33.1	52	222	2.8
pH (standard units)	112	6.55	.53	5.4	8.9	.05
Temperature (degrees C)	153	11.4	8.4	.0	30.0	.7
Turbidity (NTU)	89	1.34	.72	.50	6.0	.08
Oxygen, dissolved	108	11.11	2.05	6.9	15.2	.20
Oxygen demand:						
biochemical, 5-day	25	1.00	.41	0.0	2.0	.08
chemical (high level)	23	20.0	13.9	0	58	2.9
Coliform, total						
immed. (cols./100 ml)	57	4,981.9	6,198.9	78	23,000	821.0
Coliform, fecal:						
0.45 μm-MF (cols./100 ml)	60	168.9	306.7	6	2,000	39.6
0.7 μm-MF (cols./100 ml)	41	203.4	324.3	1	2,000	50.6
Streptococci, fecal,						
KF agar (cols./100 ml)	98	840.2	2,557.7	2	22,000	258.4
Hardness:						
(as $CaCO_3$)	68	15.8	3.8	10	26	.5
noncarbonate ($CaCO_3$)	47	4.6	2.9	0	11	.4
Calcium, dissolved (as Ca)	74	4.15	1.00	2.5	6.8	.12
Magnesium, dissolved (as Mg)	74	1.30	.39	.7	3.0	.05
Sodium, dissolved (as Na)	66	12.11	6.10	5.1	34	.75
Potassium, dissolved (as K)	66	1.09	.30	.4	1.9	.04
Alkalinity (as $CaCO_3$)	46	12.8	10.1	0	58	1.5
Sulfate, dissolved (as SO_4)	91	14.4	6.64	6.8	40	.70
Chloride, dissolved (as Cl)	101	12.3	3.41	5.2	34	.34
Fluoride, dissolved (as F)	55	.12	.07	.0	.3	.01
Silica, dissolved (as SiO_2)	63	6.76	2.03	2.7	11	.26
Solids:						
residue at 105°C, total	96	78.4	22.5	44	172	2.3
residue at 105°C, susp.	19	8.0	12.6	0	58	2.9
residue at 180°C, diss.	94	73.9	20.9	43	164	2.2
sum of constituents, diss.	50	58.7	19.4	28	125	2.7
Nitrogen:						
total (as N)	93	.884	.490	.18	4.6	.051
dissolved (as N)	19	.875	.319	.45	1.4	.073
organic total (as N)	93	.427	.218	.01	1.2	.023
organic dissolved (as N)	26	.376	.163	.07	.77	.032
ammonia dissolved (as N)	56	.072	.240	.00	1.8	.032
ammonia total (as N)	84	.041	.038	.00	.19	.004
nitrite total (as N)	72	.004	.006	.00	.02	.001
nitrate total (as N)	34	.405	.217	.00	.84	.037
NO_2+NO_3 total (as N)	107	.387	.222	.10	1.6	.022
NO_2+NO_3 dissolved (as N)	33	.412	.217	.00	.90	.038
Phosphorus:						
total (as P)	107	.048	.091	.00	.94	.009
dissolved (as P)	80	.030	.024	.00	.10	.003
ortho, total (as P)	64	.019	.020	.00	.09	.003
Sediment:						
suspended	48	13.5	29.7	1	206	4.3
discharge, suspended (t/day)	45	25.3	59.1	.66	389	8.8

Trace Elements

Trace elements, also frequently called minor elements, are those that commonly occur in relatively smaller amounts in natural water. Many are of concern because, even in trace quantities, they may be toxic to people, to aquatic plants and animals, or to 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 12 trace elements which are measured at the six sites. Unless otherwise stated, the criteria in the following discussion pertain to drinking water (U.S. Environmental Protection Agency, 1976).

The most stringent standard for arsenic is a maximum of 50 μg/L for domestic water supplies. Of the Rhode Island water quality sites, the highest measured concentration for arsenic was 6 μg/L at the Blackstone River at Millville, Mass.

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 standard of 1,000 μg/L.

The suggested criteria 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 the six sites, boron levels were less than the maximum acceptable limit for irrigation. The maximum concentration measured was 270 μg/L at the Blackstone River at Millville, Mass.

The drinking water standard for cadmium is 10 μg/L. This value was reached in 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 exceed the criterion for aquatic life protection of sensitive fish species of 0.4 μg/L of cadmium in soft water. The criterion for other less sensitive aquatic species is 4.0 μg/L in soft water.

Chromium has a drinking water standard of 50 μg/L but a less stringent recommended criteria for the protection of aquatic life of 100 μg/L. 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.

Drinking water criteria were set for iron and manganese not because of their 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. Several sites had iron concentrations that exceeded the drinking water standard and the largest total recoverable concentration, 1,900 μg/L at Blackstone River at Millville, Mass., and the largest dissolved concentration, 1,200 μg/L at Pawcatuck River at Westerly, exceeded the value set for the protection of aquatic life. Pawcatuck River at Westerly was the only station at which the mean concentrations of both total recoverable and dissolved manganese were below the drinking water criterion.

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.

Mercury has the lowest standard set for drinking water of any of the metals, 2 μg/L. Blackstone River at Manville had a total recoverable concentration of 1.8 μg/L which was the highest concentration measured at any of the six sites.

Selenium and silver have drinking water standards of 10 μg/L and 50 μg/L, respectively. Measured concentrations of these two constituents at the six sites were less than the standards. The largest selenium concentration was 2 μg/L at Branch River at Forestdale, and the largest silver concentration was 7 μg/L at Pawtuxet River at Pawtuxet.

Standards for zinc range from a high of 5,000 μg/L for drinking water down to a proposed level of 30-70 μg/L for the protection of the most sensitive aquatic life (Wentz, 1974, p. 27). The maximum zinc concentration was 470 μg/L at Branch River at Forestdale. However, mean concentrations were generally less than 100 μg/L.

Table 4.—Summary of measurements of trace elements for each station

(Analyses in micrograms per liter except as indicated.)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01111230 Blackstone River at Millville, Mass.						
Aluminum, total recoverable (as Al)	1	90.0	—	90	90	—
Aluminum, dissolved (as Al)	6	40.0	29.0	0	70	11.8
Arsenic, dissolved (as As)	20	2.4	1.3	0	6	.3
Arsenic, total (as As)	17	2.8	1.6	1	6	.4
Barium, dissolved (as Ba)	20	35.1	25.6	0	100	5.7
Barium, total recoverable (as Ba)	16	37.5	50.0	0	100	12.5
Beryllium, dissolved (Be)	6	.1	.2	0	5	.1
Beryllium, total recoverable (as Be)	2	.0	.0	0	0	.0
Boron, total recoverable (as B)	4	155	87.4	60	270	43.7
Cadmium, dissolved (as Cd)	20	2.5	2.3	0	8	.5
Cadmium, total recoverable (as Cd)	15	3.8	2.6	1	10	.7
Chromium, dissolved (as Cr)	20	6.3	9.2	0	30	2.1
Chromium, total recoverable (as Cr)	17	18.2	11.9	0	40	2.9
Cobalt, dissolved (as Co)	20	.5	1.0	0	3	.2
Cobalt, total recoverable (Co)	16	.9	1.2	0	4	.3
Copper, dissolved (as Cu)	20	12.1	5.9	6	31	1.3
Copper, total recoverable (as Cu)	16	24.8	7.6	15	39	1.9
Iron, total recoverable (as Fe)	17	903	412	490	1,900	100.0
Iron, dissolved (as Fe)	21	223	106	58	420	23.2
Lead, dissolved (as Pb)	20	3.4	3.0	0	14	.7
Lead, total recoverable (as Pb)	17	16.9	11.7	4	51	2.8
Lithium, dissolved (as Li)	6	8.2	10.9	0	30	4.4
Lithium, total recoverable (as Li)	2	.0	.0	0	0	.0
Manganese, total recoverable (as Mn)	18	113	49.9	30	200	11.8
Manganese, dissolved (as Mn)	21	95.4	54.0	15	230	11.8
Mercury, dissolved (as Hg)	20	.1	.1	0	2	.0
Mercury, total recoverable (as Hg)	17	.0	.0	0	1	.0
Molybdenum, dissolved (as Mo)	6	1.7	4.1	0	10	1.7
Molybdenum, total recoverable (as Mo)	1	.0	—	0	0	—
Nickel, dissolved (as Ni)	18	35.1	28.6	9	130	6.7
Nickel, total recoverable (as Ni)	16	39.7	33.1	0	130	8.3
Selenium, dissolved (as Se)	20	.1	.3	0	1	.1
Selenium, total (as Se)	17	.1	.3	0	1	.1
Silver, dissolved (as Ag)	19	.2	.5	0	2	.1
Silver, total recoverable (as Ag)	20	.1	.3	0	1	.1
Strontium, dissolved (as Sr)	6	66.8	11.1	56	86	4.5
Strontium, total recoverable (as Sr)	2	90.0	14.1	80	100	10.0
Vanadium, dissolved (as V)	6	1.0	2.4	0	6	1.0
Zinc, dissolved (as Zn)	20	76.5	48.9	30	220	10.9
Zinc, total recoverable (as Zn)	17	98.2	46.9	40	200	11.4

Table 4.—Summary of measurements of trace elements for each station (continued)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
			01111500 Branch River at Forestdale, R. I.			
Aluminum, total recoverable (as Al)	1	90.0	—	90	90	—
Aluminum, dissolved (as Al)	2	250	354	0	500	250.0
Arsenic, dissolved (as As)	0	—	—	—	—	—
Arsenic, total (as As)	9	.6	.5	0	1	.2
Barium, dissolved (as Ba)	0	—	—	—	—	—
Barium, total recoverable (as Ba)	2	.0	.0	0	0	.0
Beryllium, dissolved (Be)	0	—	—	—	—	—
Beryllium, total recoverable (as Be)	2	.0	.0	0	0	.0
Boron, total recoverable (as B)	7	25.7	19.9	0	50	7.5
Cadmium, dissolved (as Cd)	0	—	—	—	—	—
Cadmium, total recoverable (as Cd)	7	.6	.8	0	2	.3
Chromium, dissolved (as Cr)	0	—	—	—	—	—
Chromium, total recoverable (as Cr)	9	10.0	8.7	0	20	2.9
Cobalt, dissolved (as Co)	0	—	—	—	—	—
Cobalt, total recoverable (Co)	2	.0	.0	0	0	.0
Copper, dissolved (as Cu)	2	70.0	56.6	30	110	40.0
Copper, total recoverable (as Cu)	8	13.0	9.5	3	30	3.4
Iron, total recoverable (as Fe)	10	576	301	210	1000	95.3
Iron, dissolved (as Fe)	2	345	403	60	630	285.0
Lead, dissolved (as Pb)	0	—	—	—	—	—
Lead, total recoverable (as Pb)	9	8.2	9.7	1	31	3.2
Lithium, dissolved (as Li)	2	300	424	0	600	300.0
Lithium, total recoverable (as Li)	2	.0	.0	0	0	.0
Manganese, total recoverable (as Mn)	10	120	49.0	70	240	15.5
Manganese, dissolved (as Mn)	2	.0	.0	0	0	.0
Mercury, dissolved (as Hg)	0	—	—	—	—	—
Mercury, total recoverable (as Hg)	9	.0	.1	0	.1	.0
Molybdenum, dissolved (as Mo)	0	—	—	—	—	—
Molybdenum, total recoverable (as Mo)	1	1.0	—	1	1	—
Nickel, dissolved (as Ni)	0	—	—	—	—	—
Nickel, total recoverable (as Ni)	9	7.6	7.7	2	26	2.6
Selenium, dissolved (as Se)	0	—	—	—	—	—
Selenium, total (as Se)	9	.2	.7	0	2	.2
Silver, dissolved (as Ag)	0	—	—	—	—	—
Silver, total recoverable (as Ag)	7	.0	.0	0	0	.0
Strontium, dissolved (as Sr)	0	—	—	—	—	—
Strontium, total recoverable (as Sr)	2	75.0	21.2	60	90	15.0
Vanadium, dissolved (as V)	0	—	—	—	—	—
Zinc, dissolved (as Zn)	2	235	332	0	470	235.0
Zinc, total recoverable (as Zn)	9	53.3	33.9	10	120	11.3

Table 4.—Summary of measurements of trace elements for each station (continued)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01112900 Blackstone River at Manville, R. I.						
Aluminum, total recoverable (as Al)	1	50.0	—	50	50	—
Aluminum, dissolved (as Al)	0	—	—	—	—	—
Arsenic, dissolved (as As)	0	—	—	—	—	—
Arsenic, total (as As)	9	1.8	1.2	0	4	.4
Barium, dissolved (as Ba)	0	—	—	—	—	—
Barium, total recoverable (as Ba)	2	.0	.0	0	0	.0
Beryllium, dissolved (Be)	0	—	—	—	—	—
Beryllium, total recoverable (as Be)	2	.0	.0	0	0	.0
Boron, total recoverable (as B)	7	136	67.5	40	240	25.5
Cadmium, dissolved (as Cd)	0	—	—	—	—	—
Cadmium, total recoverable (as Cd)	7	1.6	1.5	0	4	.6
Chromium, dissolved (as Cr)	0	—	—	—	—	—
Chromium, total recoverable (as Cr)	9	20.0	14.1	0	50	4.7
Cobalt, dissolved (as Co)	0	—	—	—	—	—
Cobalt, total recoverable (Co)	2	1.5	2.1	0	3	1.5
Copper, dissolved (as Cu)	0	—	—	—	—	—
Copper, total recoverable (as Cu)	8	23.8	12.4	12	42	4.4
Iron, total recoverable (as Fe)	9	764	318	470	1500	106.2
Iron, dissolved (as Fe)	1	320	—	320	320	—
Lead, dissolved (as Pb)	0	—	—	—	—	—
Lead, total recoverable (as Pb)	9	16.3	13.9	5	45	4.6
Lithium, dissolved (as Li)	0	—	—	—	—	—
Lithium, total recoverable (as Li)	2	.0	.0	0	0	.0
Manganese, total recoverable (as Mn)	9	118	44.1	80	220	14.7
Manganese, dissolved (as Mn)	1	260	—	260	260	—
Mercury, dissolved (as Hg)	0	—	—	—	—	—
Mercury, total recoverable (as Hg)	9	.2	.6	0	1.8	.2
Molybdenum, dissolved (as Mo)	0	—	—	—	—	—
Molybdenum, total recoverable (as Mo)	1	1.0	—	1	1	—
Nickel, dissolved (as Ni)	0	—	—	—	—	—
Nickel, total recoverable (as Ni)	8	36.1	21.1	2	65	7.5
Selenium, dissolved (as Se)	0	—	—	—	—	—
Selenium, total (as Se)	9	.1	.3	0	1	.1
Silver, dissolved (as Ag)	0	—	—	—	—	—
Silver, total recoverable (as Ag)	6	.2	.4	0	1	.2
Strontium, dissolved (as Sr)	0	—	—	—	—	—
Strontium, total recoverable (as Sr)	2	90.0	14.1	80	100	10.0
Vanadium, dissolved (as V)	0	—	—	—	—	—
Zinc, dissolved (as Zn)	0	—	—	—	—	—
Zinc, total recoverable (as Zn)	9	78.9	40.8	30	140	13.6

Table 4.—Summary of measurements of trace elements for each station (continued)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
			01116500 Pawtuxet River at Cranston, R. I.			
Aluminum, total recoverable (as Al)	2	125	177	—	250	125.0
Aluminum, dissolved (as Al)	2	100	.0	100	100	.0
Arsenic, dissolved (as As)	0	—	—	—	—	—
Arsenic, total (as As)	12	.9	.8	0	3	.2
Barium, dissolved (as Ba)	0	—	—	—	—	—
Barium, total recoverable (as Ba)	3	3.3	5.8	0	10	3.3
Beryllium, dissolved (Be)	0	—	—	—	—	—
Beryllium, total recoverable (as Be)	3	.0	.0	0	0	.0
Boron, total recoverable (as B)	7	52.9	19.8	30	80	7.5
Cadmium, dissolved (as Cd)	0	—	—	—	—	—
Cadmium, total recoverable (as Cd)	11	1.6	1.7	0	4	.5
Chromium, dissolved (as Cr)	0	—	—	—	—	—
Chromium, total recoverable (as Cr)	15	11.7	11.6	0	40	3.0
Cobalt, dissolved (as Co)	0	—	—	—	—	—
Cobalt, total recoverable (Co)	5	.0	.0	0	0	.0
Copper, dissolved (as Cu)	2	35.0	21.2	20	50	15.0
Copper, total recoverable (as Cu)	12	21.9	8.2	13	41	2.4
Iron, total recoverable (as Fe)	16	592	215	180	860	53.7
Iron, dissolved (as Fe)	3	303	201	80	470	116.1
Lead, dissolved (as Pb)	0	—	—	—	—	—
Lead, total recoverable (as Pb)	13	10.1	7.0	1	23	1.9
Lithium, dissolved (as Li)	2	300	.0	300	300	.0
Lithium, total recoverable (as Li)	3	.0	.0	0	0	.0
Manganese, total recoverable (as Mn)	16	179	92.0	0	360	23.0
Manganese, dissolved (as Mn)	3	46.7	72.3	0	130	41.8
Mercury, dissolved (as Hg)	0	—	—	—	—	—
Mercury, total recoverable (as Hg)	12	.0	.0	0	1	.0
Molybdenum, dissolved (as Mo)	0	—	—	—	—	—
Molybdenum, total recoverable (as Mo)	2	.0	.0	0	0	.0
Nickel, dissolved (as Ni)	0	—	—	—	—	—
Nickel, total recoverable (as Ni)	9	19.9	19.9	2	69	6.6
Selenium, dissolved (as Se)	0	—	—	—	—	—
Selenium, total (as Se)	12	.0	.0	0	0	.0
Silver, dissolved (as Ag)	0	—	—	—	—	—
Silver, total recoverable (as Ag)	7	.1	.4	0	1	.1
Strontium, dissolved (as Sr)	0	—	—	—	—	—
Strontium, total recoverable (as Sr)	3	73.3	30.6	40	100	17.6
Vanadium, dissolved (as V)	0	—	—	—	—	—
Zinc, dissolved (as Zn)	2	15.0	21.2	0	30	15.0
Zinc, total recoverable (as Zn)	12	53.3	33.4	20	130	9.6

Table 4.—Summary of measurements of trace elements for each station (continued)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01116617 Pawtuxet River at Pawtuxet, R. I.						
Aluminum, total recoverable (as Al)	1	80.0	—	80	80	—
Aluminum, dissolved (as Al)	0	—	—	—	—	—
Arsenic, dissolved (as As)	0	—	—	—	—	—
Arsenic, total (as As)	9	1.3	1.2	0	4	.4
Barium, dissolved (as Ba)	0	—	—	—	—	—
Barium, total recoverable (as Ba)	2	.0	.0	0	0	.0
Beryllium, dissolved (Be)	0	—	—	—	—	—
Beryllium, total recoverable (as Be)	2	.0	.0	0	0	.0
Boron, total recoverable (as B)	7	65.7	25.1	30	100	9.5
Cadmium, dissolved (as Cd)	0	—	—	—	—	—
Cadmium, total recoverable (as Cd)	7	2.4	2.1	0	5	.8
Chromium, dissolved (as Cr)	0	—	—	—	—	—
Chromium, total recoverable (as Cr)	9	12.2	8.3	0	20	2.8
Cobalt, dissolved (as Co)	0	—	—	—	—	—
Cobalt, total recoverable (Co)	2	.0	.0	0	0	.0
Copper, dissolved (as Cu)	0	—	—	—	—	—
Copper, total recoverable (as Cu)	8	26.5	8.2	16	38	2.9
Iron, total recoverable (as Fe)	9	777	330	280	1400	109.9
Iron, dissolved (as Fe)	0	—	—	—	—	—
Lead, dissolved (as Pb)	0	—	—	—	—	—
Lead, total recoverable (as Pb)	9	10.7	6.8	4	25	2.3
Lithium, dissolved (as Li)	0	—	—	—	—	—
Lithium, total recoverable (as Li)	2	.0	.0	—	0	.0
Manganese, total recoverable (as Mn)	9	226	99.3	110	440	33.1
Manganese, dissolved (as Mn)	0	—	—	—	—	—
Mercury, dissolved (as Hg)	0	—	—	—	—	—
Mercury, total recoverable (as Hg)	9	.1	.1	0	.2	.0
Molybdenum, dissolved (as Mo)	0	—	—	—	—	—
Molybdenum, total recoverable (as Mo)	1	.0	—	0	0	—
Nickel, dissolved (as Ni)	0	—	—	—	—	—
Nickel, total recoverable (as Ni)	9	23.4	15.2	3	52	5.1
Selenium, dissolved (as Se)	0	—	—	—	—	—
Selenium, total (as Se)	9	.0	.0	0	0	.0
Silver, dissolved (as Ag)	0	—	—	—	—	—
Silver, total recoverable (as Ag)	7	1.1	2.6	0	7	1.0
Strontium, dissolved (as Sr)	0	—	—	—	—	—
Strontium, total recoverable (as Sr)	2	85.0	21.2	70	100	15.0
Vanadium, dissolved (as V)	0	—	—	—	—	—
Zinc, dissolved (as Zn)	0	—	—	—	—	—
Zinc, total recoverable (as Zn)	9	65.6	30.0	30	120	10.0

Table 4.—Summary of measurements of trace elements for each station (continued)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
		01118500 Pawcatuck River at Westerly, R. I.				
Aluminum, total recoverable (as Al)	3	13.3	23.1	0	40	13.3
Aluminum, dissolved (as Al)	8	78.8	62.2	0	170	22.0
Arsenic, dissolved (as As)	25	.5	.6	0	2	.1
Arsenic, total (as As)	23	1.0	.6	0	2	.1
Barium, dissolved (as Ba)	25	17.4	17.7	0	79	3.5
Barium, total recoverable (as Ba)	20	21.0	40.8	0	100	9.1
Beryllium, dissolved (Be)	6	.0	.0	0	0	.0
Beryllium, total recoverable (as Be)	2	.0	.0	0	0	.0
Boron, total recoverable (as B)	5	46.0	34.4	0	80	15.4
Cadmium, dissolved (as Cd)	49	.7	.8	0	3	.1
Cadmium, total recoverable (as Cd)	22	1.3	2.5	0	10	.5
Chromium, dissolved (as Cr)	50	2.3	4.3	0	20	.6
Chromium, total recoverable (as Cr)	24	13.3	10.1	0	30	2.1
Cobalt, dissolved (as Co)	25	.6	1.0	0	3	.2
Cobalt, total recoverable (Co)	21	.7	1.1	0	3	.3
Copper, dissolved (as Cu)	89	4.9	12.1	0	100	1.3
Copper, total recoverable (as Cu)	25	8.8	12.7	1	60	2.5
Iron, total recoverable (as Fe)	28	449	221	130	1,100	41.8
Iron, dissolved (as Fe)	35	304	196	120	1,200	33.1
Lead, dissolved (as Pb)	48	2.1	1.9	0	9	.3
Lead, total recoverable (as Pb)	22	7.3	7.1	0	34	1.5
Lithium, dissolved (as Li)	8	12.5	35.4	0	100	12.5
Lithium, total recoverable (as Li)	4	25.0	50.0	0	100	25.0
Manganese, total recoverable (as Mn)	28	41.1	25.1	0	110	4.8
Manganese, dissolved (as Mn)	34	37.8	21.4	0	100	3.7
Mercury, dissolved (as Hg)	25	.1	.2	0	.7	.0
Mercury, total recoverable (as Hg)	23	.1	.1	0	.3	.0
Molybdenum, dissolved (as Mo)	6	.0	.0	0	0	.0
Molybdenum, total recoverable (as Mo)	1	1.0	—	1	1	—
Nickel, dissolved (as Ni)	43	1.4	1.8	0	10	.3
Nickel, total recoverable (as Ni)	17	3.8	3.9	0	14	.9
Selenium, dissolved (as Se)	25	.0	.0	0	0	.0
Selenium, total (as Se)	23	.0	.0	0	0	.0
Silver, dissolved (as Ag)	25	.0	.0	0	0	.0
Silver, total recoverable (as Ag)	27	.2	1.0	0	5	.2
Strontium, dissolved (as Sr)	6	28.0	5.1	23	37	2.1
Strontium, total recoverable (as Sr)	2	80.0	14.1	70	90	10.0
Vanadium, dissolved (as V)	6	4.2	10.2	0	25	4.2
Zinc, dissolved (as Zn)	89	12.6	16.8	0	100	1.8
Zinc, total recoverable (as Zn)	26	30.8	36.2	0	190	7.1

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

(Criteria are from the U.S. Environmental Protection Agency, 1976, unless otherwise noted.)

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 (health)	6/6	1/—	4/—	3/—	4/—	2/2
BARIUM 1,000 µg/L for domestic water supply (health)	100/100	0/—	0/—	10/—	0/—	100/79
BORON 750 µg/L for long-term irrigation on sensitive crops	270/—	50/—	240/—	80/—	100/—	80/—
CADMIUM 10 µg/L for domestic water supply (health) 0.4 µg/L for sensitive aquatic species in soft water 4.0 µg/L for other, less sensitive, aquatic species	10/8	2/—	4/—	4/—	5/—	10/3
CHROMIUM 50 µg/L for domestic water supply (health) 100 µg/L for freshwater aquatic life	40/30	20/—	50/—	40/—	20/—	30/20
IRON 300 µg/L for domestic water supply (welfare) 1,000 µg/L for freshwater aquatic life	1,900/420	1,000/630	1,500/320	860/470	1,400/—	1,200/1,100
LEAD 50 µg/L for domestic water supply (health)	51/14	31/—	45/—	23/—	25/—	34/9
MANGANESE 50 µg/L for domestic water supply (welfare)	200/230	240/0	230/260	360/130	440/—	110/100
MERCURY 2.0 µg/L for domestic water supply (health) 0.05 µg/L for freshwater aquatic life and wildlife	0.1/0.2	0.1/—	1.8/—	0.1/—	0.2/—	0.3/0.7
SELENIUM 10 µg/L for domestic water supply (health)	1/1	2/1	1/—	0/—	0/—	0/0
SILVER 50 µg/L for domestic water supply (health)	1/2	0/—	1/—	1/—	7/—	5/0
ZINC 5000 µg/L for domestic water supply (welfare) 30 to 70 µg/L for sensitive freshwater aquatic life (Wentz, 1974, p. 27)	200/220	120/470	140/—	130/30	120/—	190/100

Organic Compounds

A limited number of organic compounds were analyzed 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 which is less than the drinking water standard of 4 µg/L (U.S. Environmental Protection Agency, 1976). Dieldrin was found at three sites; the Blackstone River at Millville, Mass., the Blackstone River at Manville, and the Pawtuxet River at Cranston. The maximum concentration was 0.01 µg/L. PCBs (polychlorinated biphenyls) 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.

Phenols (phenolic compounds) include a wide variety of organic chemicals which all have 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 which contributes to lowered dissolved oxygen in the stream. The U.S. Environmental Protection Agency (1976) sets a criterion of 1 µg/L for domestic water supply and to protect against tainting of fish flesh. Phenols in excess of this criterion were measured at all six sites. The highest measured concentration was 86 µg/L at Pawtuxet River at Pawtuxet. Phenols were present in each sample collected from this site.

Constituents in Bottom Materials

Generally, samples of the bottom materials at all six sites were collected during low-flow periods and analyzed for selected trace elements and organic compounds. While there are no standards or criteria for allowable concentrations of these compounds in bottom material, their presence in high concentrations may indicate past or present entry of the materials into the rivers.

Bottom materials often are relatively stationary during periods of low to medium flow. During high flow periods or floods, bottom materials may be resuspended by the higher velocity water and carried downstream where they will be redeposited when the velocity of the water diminishes. In this way, consitutents associated with the bottom material which enter upstream may be distributed downstream.

Table 7 summarizes the bottom material data for the six sites. Data within a site exhibit a wide range in concentration. Bottom materials are seldom distributed uniformly which makes obtaining a "representative" sample or even a duplicate sample difficult. High flows can redistribute bottom material so that another sample collected at the same site at a later time may give entirely different results.

Higher concentrations of elements such as 2,000 µg/g 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 values 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, and lindane at one. In the bottom material, chlordane, DDD, DDE, DDT, and PCBs were found at all sites, dieldrin at five sites, and aldrin, endosulfan, endrin, heptachor, and mirex at one or more sites. One high concentration of PCB, 5,400 µg/kg, was found at Pawtuxet River at Pawtuxet. Subsequent samples contained lower concentrations of PCB.

Table 6.—Summary of measurements of organic compounds for each station

(Analyses in micrograms per liter except as indicated.)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01111230 Blackstone River at Millville, Mass.						
Carbon, organic total (mg/L as C)	24	6.67	1.90	3.8	11	0.39
Phenols, total	14	1.4	1.7	0	5	.4
Methylene blue active substance (mg/L)	5	.160	.134	.10	.40	.060
Oil and grease, total recoverable extraction gravimetric (mg/L)	16	.9	1.5	0	6	.4
PCB, total	6	.02	.04	.0	.1	.02
Napthalenes, polychlorinated, total	6	.00	.00	.0	.0	.00
Aldrin, total	6	.00	.00	.0	.0	.00
Chlordane, total	6	.00	.00	.0	.0	.00
DDD, total	6	.00	.00	.0	.0	.00
DDE, total	6	.00	.00	.0	.0	.00
DDT, total	6	.00	.00	.0	.0	.00
Dieldrin, total	6	.005	.005	.0	.01	.002
Endosulfan, total	6	.00	.00	.0	.0	.00
Endrin, total	6	.00	.00	.0	.0	.00
Heptachlor, total	6	.00	.00	.0	.0	.00
Heptachlor epoxide, total	6	.00	.00	.0	.0	.00
Lindane, total	6	.00	.00	.0	.0	.00
Methoxychlor, total	5	.00	.00	.0	.0	.00
Mirex, total	5	.00	.00	.0	.0	.00
Perthane, total	6	.00	.00	.0	.0	.00
Toxaphene, total	6	.00	.00	.0	.0	.00

Table 6.—Summary of measurements of organic compounds for each station (continued)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
		01111500 Branch River at Forestdale, R. I.				
Carbon, organic total (mg/L as C)	12	5.71	1.42	3.9	8.3	0.41
Phenols, total	14	1.4	3.3	0	12	.9
Methylene blue active substance (mg/L)	9	.000	.000	.00	.00	.000
Oil and grease, total recoverable extraction gravimetric (mg/L)	16	.4	1.0	0	4	.3
PCB, total	6	.00	.00	.0	.0	.00
Napthalenes, polychlorinated, total	6	.00	.00	.0	.0	.00
Aldrin, total	6	.00	.00	.0	.0	.00
Chlordane, total	6	.00	.00	.0	.0	.00
DDD, total	6	.00	.00	.0	.0	.00
DDE, total	6	.00	.00	.0	.0	.00
DDT, total	6	.00	.00	.0	.0	.00
Dieldrin, total	6	.00	.00	.0	.0	.00
Endosulfan, total	6	.00	.00	.0	.0	.00
Endrin, total	6	.00	.00	.0	.0	.00
Heptachlor, total	6	.00	.00	.0	.0	.00
Heptachlor epoxide, total	6	.00	.00	.0	.0	.00
Lindane, total	6	.00	.00	.0	.0	.00
Methoxychlor, total	5	.00	.00	.0	.0	.00
Mirex, total	5	.00	.00	.0	.0	.00
Perthane, total	6	.00	.00	.0	.0	.00
Toxaphene, total	6	.00	.00	.0	.0	.00

Table 6.—Summary of measurements of organic compounds for each station (continued)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
		01112900 Blackstone River at Manville, R. I.				
Carbon, organic total (mg/L as C)	12	6.82	1.59	5.0	9.7	0.46
Phenols, total	16	5.6	11.2	0	45	2.8
Methylene blue active substance (mg/L)	10	.130	.067	.10	.30	.021
Oil and grease, total recoverable extraction gravimetric (mg/L)	17	.6	1.0	0	3	.2
PCB, total	5	.08	.11	.0	.2	.05
Napthalenes, polychlor-inated, total	5	.00	.00	.0	.0	.00
Aldrin, total	5	.00	.00	.0	.0	.00
Chlordane, total	5	.00	.00	.0	.0	.00
DDD, total	5	.00	.00	.0	.0	.00
DDE, total	5	.00	.00	.0	.0	.00
DDT, total	5	.00	.00	.0	.0	.00
Dieldrin, total	5	.006	.005	.00	.01	.002
Endosulfan, total	5	.00	.00	.0	.0	.00
Endrin, total	5	.00	.00	.0	.0	.00
Heptachlor, total	5	.00	.00	.0	.0	.00
Heptachlor epoxide, total	5	.00	.00	.0	.0	.00
Lindane, total	5	.004	.009	.00	.02	.004
Methoxychlor, total	5	.00	.00	.0	.0	.00
Mirex, total	5	.00	.00	.0	.0	.00
Perthane, total	5	.00	.00	.0	.0	.00
Toxaphene, total	5	.00	.00	.0	.0	.00

Table 6.—Summary of measurements of organic compounds for each station (continued)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
		01116500 Pawtuxet River at Cranston, R. I.				
Carbon, organic total (mg/L as C)	12	7.13	2.58	4.6	14	0.75
Phenols, total	19	3.5	4.7	0	15	1.1
Methylene blue active substance (mg/L)	10	.140	.052	.10	.20	.016
Oil and grease, total recoverable extraction gravimetric (mg/L)	17	1.1	1.7	0	6	.4
PCB, total	8	.64	1.09	.0	2.8	.38
Napthalenes, polychlorinated, total	8	.00	.00	.0	.0	.00
Aldrin, total	8	.00	.00	.0	.0	.00
Chlordane, total	8	.00	.00	.0	.0	.00
DDD, total	8	.00	.00	.0	.0	.00
DDE, total	8	.00	.00	.0	.0	.00
DDT, total	8	.00	.00	.0	.0	.00
Dieldrin, total	8	.001	.004	.00	.01	.001
Endosulfan, total	7	.00	.00	.0	.0	.00
Endrin, total	8	.00	.00	.0	.0	.00
Heptachlor, total	8	.00	.00	.0	.0	.00
Heptachlor epoxide, total	8	.00	.00	.0	.0	.00
Lindane, total	8	.00	.00	.0	.0	.00
Methoxychlor, total	5	.00	.00	.0	.0	.00
Mirex, total	5	.00	.00	.0	.0	.00
Perthane, total	7	.00	.00	.0	.0	.00
Toxaphene, total	8	.00	.00	.0	.0	.00

Table 6.—Summary of measurements of organic compounds for each station (continued)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
			01116617 Pawtuxet River at Pawtuxet, R. I.			
Carbon, organic total (mg/L as C)	12	10.96	4.49	5.5	18	1.30
Phenols, total	15	31.5	27.8	1	86	7.2
Methylene blue active substance (mg/L)	10	.180	.042	.10	.20	.013
Oil and grease, total recoverable extraction gravimetric (mg/L)	16	.6	.9	0	3	.2
PCB, total	4	1.48	2.03	.0	4.3	1.01
Napthalenes, polychlor-inated, total	4	.00	.00	.0	.0	.00
Aldrin, total	4	.00	.00	.0	.0	.00
Chlordane, total	4	.00	.00	.0	.0	.00
DDD, total	4	.00	.00	.0	.0	.00
DDE, total	4	.00	.00	.0	.0	.00
DDT, total	4	.00	.00	.0	.0	.00
Dieldrin, total	4	.00	.00	.0	.0	.00
Endosulfan, total	4	.00	.00	.0	.0	.00
Endrin, total	4	.00	.00	.0	.0	.00
Heptachlor, total	4	.00	.00	.0	.0	.00
Heptachlor epoxide, total	4	.00	.00	.0	.0	.00
Lindane, total	4	.00	.00	.0	.0	.00
Methoxychlor, total	3	.00	.00	.0	.0	.00
Mirex, total	3	.00	.00	.0	.0	.00
Perthane, total	4	.00	.00	.0	.0	.00
Toxaphene, total	4	.00	.00	.0	.0	.00

Table 6.—Summary of measurements of organic compounds for each station (continued)

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
			01118500 Pawcatuck River at Westerly, R. I.			
Carbon, organic total (mg/L as C)	88	7.42	3.78	3.4	32	0.40
Phenols, total	14	.6	2.4	0	9	.6
Methylene blue active substance (mg/L)	26	.017	.037	.00	.10	.007
Oil and grease, total recoverable extraction gravimetric (mg/L)	16	.4	.8	0	3	.2
PCB, total	6	.00	.00	.0	.0	.00
Napthalenes, polychlorinated, total	6	.00	.00	.0	.0	.00
Aldrin, total	6	.00	.00	.0	.0	.00
Chlordane, total	6	.00	.00	.0	.0	.00
DDD, total	6	.00	.00	.0	.0	.00
DDE, total	6	.00	.00	.0	.0	.00
DDT, total	6	.00	.00	.0	.0	.00
Dieldrin, total	6	.00	.00	.0	.0	.00
Endosulfan, total	6	.00	.00	.0	.0	.00
Endrin, total	6	.00	.00	.0	.0	.00
Heptachlor, total	6	.00	.00	.0	.0	.00
Heptachlor epoxide, total	6	.00	.00	.0	.0	.00
Lindane, total	6	.00	.00	.0	.0	.00
Methoxychlor, total	5	.00	.00	.0	.0	.00
Mirex, total	5	.00	.00	.0	.0	.00
Perthane, total	6	.00	.00	.0	.0	.00
Toxaphene, total	6	.00	.00	.0	.0	.00

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
			01111230 Blackstone River at Millville, Mass.			
			(The following analyses are in micrograms per gram except as indicated.)			
C.O.D., total in bottom material (mg/kg)	11	23,900	36,000	4,600	130,000	10,900
Aluminum, recoverable from bottom material	2	6,300	6,650	1,600	11,000	4,700
Arsenic, total in bottom material	7	.7	1.3	0	3	.5
Barium, recoverable from bottom material	2	130	156	20	240	110
Beryllium, recoverable from bottom material	2	.0	.0	0	0	.0
Boron, recoverable from bottom material	3	.0	.0	0	0	.0
Cadmium, recoverable from bottom material	7	19.0	30.3	0	80	11.5
Chromium, recoverable from bottom material	7	127	168	10	450	63.7
Cobalt, recoverable from bottom material	7	5.7	15.1	0	40	5.7
Copper, recoverable from bottom material	7	163	230	21	640	86.9
Iron, recoverable from bottom material	7	11,600	14,700	2,700	44,000	5,550
Lead, recoverable from bottom material	7	125	93.0	38	260	35.2
Manganese, recoverable from bottom material	7	471	823	40	2,300	311
Mercury, recoverable from bottom material	7	.13	.34	.0	.9	.13
Molybdenum, recoverable from bottom material	3	13,700	23,700	0	41,000	13,700
Nickel, recoverable from bottom material	5	58.0	86.1	0	200	38.5
Selenium, total in bottom material	7	.3	.5	0	1	.2
Silver, recoverable from bottom material	5	.8	1.8	0	4	.8
Strontium, recoverable from bottom material	2	40.0	42.4	10	70	30.0
Vanadium, total in bottom material	0	—	—	—	—	—
Zinc, recoverable from bottom material	7	424	716	40	2,000	270

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01111230 Blackstone River at Millville, Mass. (continued)						
(The following analyses are in micrograms per kilogram.)						
Aldrin, total in bottom material	6	0.00	0.00	0.0	0.0	0.00
Chlordane, total in bottom material	6	16.5	21.4	2.0	55	8.74
DDD, total in bottom material	6	8.91	10.6	1.3	27	4.35
DDE, total in bottom material	6	.68	1.06	.0	2.1	.43
DDT, total in bottom material	6	1.32	1.41	.0	4.0	.57
Dieldrin, total in bottom material	6	78.9	177	2.7	440	72.3
Endosulfan, total in bottom material	4	.00	.00	.0	.0	.00
Endrin, total in bottom material	6	.00	.00	.0	.0	.00
Heptachlor, total in bottom material	6	.05	.12	.0	.3	.05
Heptachlor epoxide, total in bottom material	6	.00	.00	.0	.0	.00
Lindane, total in bottom material	6	.00	.00	.0	.0	.00
Methoxychlor, total in bottom material	6	.00	.00	.0	.0	.00
Mirex, total in bottom material	4	.00	.00	.0	.0	.00
PCB, total in bottom material	6	101	153	.0	410	62.5
PCN, total in bottom material	4	.00	.00	.0	.00	.00
Perthane, total in bottom material	4	.00	.00	.0	.00	.00
Toxaphene, total in bottom material	6	.00	.00	.0	.00	.00

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01111500 Branch River at Forestdale, R. I.						
(The following analyses are in micrograms per gram except as indicated.)						
C.O.D., total in bottom material (mg/kg)	11	36,400	31,800	2,000	120,000	9,590
Aluminum, recoverable from bottom material	2	4,450	3,460	2,000	6,900	2,450
Arsenic, total in bottom material	7	.1	.4	0	10	.1
Barium, recoverable from bottom material	2	45	35	20	70	25
Beryllium, recoverable from bottom material	2	.0	.0	0	0	.0
Boron, recoverable from bottom material	5	4.0	8.9	0	20	4.0
Cadmium, recoverable from bottom material	7	4.6	7.4	0	20	2.8
Chromium, recoverable from bottom material	7	24.3	17.2	0	50	6.5
Cobalt, recoverable from bottom material	7	.0	.0	0	0	.0
Copper, recoverable from bottom material	7	55.7	58.8	0	180	22.2
Iron, recoverable from bottom material	7	5,040	3,390	1,800	11,000	1,280
Lead, recoverable from bottom material	7	43.0	21.3	20	70	8.1
Manganese, recoverable from bottom material	7	155	117	30	370	44.3
Mercury, recoverable from bottom material	7	.02	.02	.0	.1	.01
Molybdenum, recoverable from bottom material	2	.0	.0	0	0	.0
Nickel, recoverable from bottom material	7	14.1	19.8	0	50	7.5
Selenium, total in bottom material	7	.4	.8	0	2	.3
Silver, recoverable from bottom material	6	.0	.0	0	0	.0
Strontium, recoverable from bottom material	2	20.0	14.1	10	30	10.0
Vanadium, total in bottom material	0	—	—	—	—	—
Zinc, recoverable from bottom material	7	135	131	20	400	49.5

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
	01111500 Branch River at Forestdale, R. I. (continued)					
	(The following analyses are in micrograms per kilogram.)					
Aldrin, total in bottom material	6	0.00	0.00	0.0	0.0	0.00
Chlordane, total in bottom material	6	15.8	17.9	.0	49	7.29
DDD, total in bottom material	6	14.2	18.4	.0	48	7.50
DDE, total in bottom material	6	.95	2.05	.0	5.1	.84
DDT, total in bottom material	6	3.27	5.18	.0	13	2.11
Dieldrin, total in bottom material	6	.35	.64	.0	1.6	.26
Endosulfan, total in bottom material	4	.00	.00	.0	.0	.00
Endrin, total in bottom material	6	.00	.00	.0	.0	.00
Heptachlor, total in bottom material	6	.00	.00	.0	.0	.00
Heptachlor epoxide, total in bottom material	6	.00	.00	.0	.0	.00
Lindane, total in bottom material	6	.00	.00	.0	.0	.00
Methoxychlor, total in bottom material	6	.00	.00	.0	.0	.00
Mirex, total in bottom material	4	109	145	.0	310	72.6
PCB, total in bottom material	6	114	234	3.0	590	95.3
PCN, total in bottom material	4	.00	.00	.0	.0	.00
Perthane, total in bottom material	4	.00	.00	.0	.0	.00
Toxaphene, total in bottom material	6	.00	.00	.0	.0	.00

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
			01112900 Blackstone River at Manville, R. I.			
			(The following analyses are in micrograms per gram except as indicated.)			
C.O.D., total in bottom material (mg/kg)	11	25,600	41,700	4,400	150,000	12,600
Aluminum, recoverable from bottom material	1	1700	—	1700	1700	—
Arsenic, total in bottom material	6	.0	.0	0	0	.0
Barium, recoverable from bottom material	1	40	—	40	40	—
Beryllium, recoverable from bottom material	2	.0	.0	0	0	.0
Boron, recoverable from bottom material	5	4.0	8.9	0	20	4.0
Cadmium, recoverable from bottom material	6	1.0	1.7	0	4	.7
Chromium, recoverable from bottom material	6	13.3	8.2	0	20	3.3
Cobalt, recoverable from bottom material	6	1.7	4.1	0	10	1.7
Copper, recoverable from bottom material	6	29.0	10.5	14	40	4.3
Iron, recoverable from bottom material	6	3,280	1,400	1,900	5,700	573.5
Lead, recoverable from bottom material	6	44.3	18.6	23	70	7.6
Manganese, recoverable from bottom material	6	52.2	21.0	30	80	8.6
Mercury, recoverable from bottom material	6	.01	.02	.0	.1	.01
Molybdenum, recoverable from bottom material	1	.0	—	0	0	—
Nickel, recoverable from bottom material	6	5.0	8.4	0	20	3.4
Selenium, total in bottom material	6	.0	.0	0	0	.0
Silver, recoverable from bottom material	5	.0	.0	0	0	.0
Strontium, recoverable from bottom material	1	20.0	—	20	20	—
Vanadium, total in bottom material	0	—	—	—	—	—
Zinc, recoverable from bottom material	6	400	784	30	2,000	320

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01112900 Blackstone River at Manville, R. I. (continued)						
(The following analyses are in micrograms per kilogram.)						
Aldrin, total in bottom material	6	0.00	0.00	0.0	0.0	0.00
Chlordane, total in bottom material	6	20.2	19.6	.0	50	8.01
DDD, total in bottom material	6	18.0	22.7	.0	48	9.25
DDE, total in bottom material	6	5.38	8.40	.0	22	3.43
DDT, total in bottom material	6	1.68	1.93	.0	5.0	.79
Dieldrin, total in bottom material	6	11.6	14.5	.0	35	5.91
Endosulfan, total in bottom material	4	.00	.00	.0	.0	.00
Endrin, total in bottom material	6	.00	.00	.0	.0	.00
Heptachlor, total in bottom material	6	.02	.04	.0	.1	.02
Heptachlor epoxide, total in bottom material	6	.00	.00	.0	.0	.00
Lindane, total in bottom material	6	.00	.00	.0	.0	.00
Methoxychlor, total in bottom material	6	.00	.00	.0	.0	.00
Mirex, total in bottom material	4	.00	.00	.0	.0	.00
PCB, total in bottom material	6	117	98.1	26	280	40.1
PCN, total in bottom material	4	.00	.00	.0	.0	.00
Perthane, total in bottom material	4	.00	.00	.0	.0	.00
Toxaphene, total in bottom material	6	.00	.00	.0	.0	.00

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01116500 Pawtuxet River at Cranston, R. I.						
(The following analyses are in micrograms per gram except as indicated.)						
C.O.D., total in bottom material (mg/kg)	17	12,800	12,000	1,700	47,000	2,920
Aluminum, recoverable from bottom material	3	2,100	1,060	900	2,900	611
Arsenic, total in bottom material	7	.0	.0	0	0	.0
Barium, recoverable from bottom material	3	23	16	8	40	9.3
Beryllium, recoverable from bottom material	3	.0	.0	0	00	.0
Boron, recoverable from bottom material	6	3.7	8.0	0	20	3.3
Cadmium, recoverable from bottom material	7	.7	1.3	0	3	.5
Chromium, recoverable from bottom material	12	5.5	6.5	0	20	1.9
Cobalt, recoverable from bottom material	8	.1	.4	0	1	.1
Copper, recoverable from bottom material	8	36.9	32.9	10	90	11.6
Iron, recoverable from bottom material	8	4,410	2,170	900	7,000	769
Lead, recoverable from bottom material	8	67.0	94.2	10	290	33.3
Manganese, recoverable from bottom material	8	76.5	36.1	23	140	12.8
Mercury, recoverable from bottom material	7	.05	.12	.0	.3	.04
Molybdenum, recoverable from bottom material	3	.0	.0	0	0	.0
Nickel, recoverable from bottom material	8	6.0	8.5	0	20	3.0
Selenium, total in bottom material	7	.0	.0	0	0	.0
Silver, recoverable from bottom material	7	.1	.4	0	1	.1
Strontium, recoverable from bottom material	3	7.0	5.2	1	10	3.0
Vanadium, total in bottom material	1	9.0	—	9	9	—
Zinc, recoverable from bottom material	7	41.6	25.7	18	90	9.7

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
	01116500 Pawtuxet River at Cranston, R. I. (continued)					
	(The following analyses are in micrograms per kilogram.)					
Aldrin, total in bottom material	6	0.17	0.41	0.0	1.0	0.17
Chlordane, total in bottom material	6	5.00	2.61	3.0	10	1.06
DDD, total in bottom material	6	3.32	6.30	.0	16	2.57
DDE, total in bottom material	6	.73	.96	.0	2.4	.39
DDT, total in bottom material	6	.55	.84	.0	2.1	.34
Dieldrin, total in bottom material	6	.05	.08	.0	.2	.03
Endosulfan, total in bottom material	4	.00	.00	.0	.0	.00
Endrin, total in bottom material	6	.00	.00	.0	.0	.00
Heptachlor, total in bottom material	6	.08	.20	.0	.5	.08
Heptachlor epoxide, total in bottom material	6	.00	.00	.0	.0	.00
Lindane, total in bottom material	6	.00	.00	.0	.0	.00
Methoxychlor, total in bottom material	6	.00	.00	.0	.0	.00
Mirex, total in bottom material	4	.00	.00	.0	.0	.00
PCB, total in bottom material	6	23.2	25.2	4.0	68	10.3
PCN, total in bottom material	4	.00	.00	.0	.0	.00
Perthane, total in bottom material	4	.00	.00	.0	.0	.00
Toxaphene, total in bottom material	6	.00	.00	.0	.0	.00

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01116617 Pawtuxet River at Pawtuxet, R. I.						
(The following analyses are in micrograms per gram except as indicated.)						
C.O.D., total in bottom material (mg/kg)	11	58,300	95,700	4,900	330,000	28,900
Aluminum, recoverable from bottom material	2	4,550	2,190	3,000	6,100	1,550
Arsenic, total in bottom material	7	.1	.4	0	1	.1
Barium, recoverable from bottom material	2	110	99	40	180	70
Beryllium, recoverable from bottom material	2	1.0	1.4	0	2	1.0
Boron, recoverable from bottom material	5	4.0	8.9	0	20	4.0
Cadmium, recoverable from bottom material	7	1.6	2.7	0	6	1.0
Chromium, recoverable from bottom material	7	35.7	27.0	10	90	10.2
Cobalt, recoverable from bottom material	7	.0	.0	0	0	.0
Copper, recoverable from bottom material	7	116.9	150	30	450	56.8
Iron, recoverable from bottom material	7	5,560	4,310	2,400	15,000	1,630
Lead, recoverable from bottom material	7	69.4	67.0	20	210	25.3
Manganese, recoverable from bottom material	7	81.6	68.7	32	230	26.0
Mercury, recoverable from bottom material	7	.01	.03	.0	.1	.01
Molybdenum, recoverable from bottom material	2	.0	.0	0	0	.0
Nickel, recoverable from bottom material	7	17.3	17.1	0	50	6.5
Selenium, total in bottom material	7	.0	.0	0	0	.0
Silver, recoverable from bottom material	6	1.0	1.5	0	3	.6
Strontium, recoverable from bottom material	2	25.0	21.2	10	40	15.0
Vanadium, total in bottom material	0	—	—	—	—	—
Zinc, recoverable from bottom material	7	228	343	40	1,000	130

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01116617 Pawtuxet River at Pawtuxet, R. I. (continued)						
(The following analyses are in micrograms per kilogram.)						
Aldrin, total in bottom material	6	0.00	0.00	0.0	0.0	0.00
Chlordane, total in bottom material	6	31.2	46.6	.0	110	19.0
DDD, total in bottom material	6	32.9	63.0	.0	160	25.7
DDE, total in bottom material	6	.55	.88	.0	2.0	.36
DDT, total in bottom material	6	3.42	7.64	.0	19	3.12
Dieldrin, total in bottom material	6	5.57	8.94	.0	22	3.65
Endosulfan, total in bottom material	3	3.67	6.35	.0	11	3.67
Endrin, total in bottom material	6	1.25	3.06	.0	7.5	1.25
Heptachlor, total in bottom material	6	.08	.20	.0	.5	.08
Heptachlor epoxide, total in bottom material	6	.00	.00	.0	.0	.00
Lindane, total in bottom material	6	.00	.00	.0	.0	.00
Methoxychlor, total in bottom material	6	.00	.00	.0	.0	.00
Mirex, total in bottom material	3	.00	.00	.0	.0	.00
PCB, total in bottom material	6	986	2,160	19	5,400	884
PCN, total in bottom material	3	.00	.00	.0	.0	.00
Perthane, total in bottom material	3	.00	.00	.0	.0	.00
Toxaphene, total in bottom material	6	.00	.00	.0	.0	.00

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01118500 Pawcatuck River at Westerly, R. I.						
(The following analyses are in micrograms per gram except as indicated.)						
C.O.D., total in bottom material (mg/kg)	12	19,600	25,900	2,800	96,000	7,490
Aluminum, recoverable from bottom material	2	1,450	212	1,300	1,600	150
Arsenic, total in bottom material	5	.0	.0	0	0	.0
Barium, recoverable from bottom material	2	10	14	0	20	10
Beryllium, recoverable from bottom material	2	.0	.0	0	0	.0
Boron, recoverable from bottom material	2	.0	.0	0	0	.0
Cadmium, recoverable from bottom material	5	.0	.0	0	0	.0
Chromium, recoverable from bottom material	5	6.0	5.5	0	10	2.5
Cobalt, recoverable from bottom material	5	.0	.0	0	0	.0
Copper, recoverable from bottom material	5	4.6	8.7	0	20	3.9
Iron, recoverable from bottom material	5	1,750	890	740	3,100	398
Lead, recoverable from bottom material	5	98.4	213	0	480	95.4
Manganese, recoverable from bottom material	5	88.2	109	13	280	48.8
Mercury, recoverable from bottom material	5	.10	.23	.0	.5	.10
Molybdenum, recoverable from bottom material	2	.0	.0	0	0	.0
Nickel, recoverable from bottom material	4	1.2	2.5	0	5	1.2
Selenium, total in bottom material	5	.0	.0	0	0	.0
Silver, recoverable from bottom material	6	.0	.0	0	0	.0
Strontium, recoverable from bottom material	2	15.0	7.1	10	20	5.0
Vanadium, total in bottom material	0	—	—	—	—	—
Zinc, recoverable from bottom material	5	13.8	9.1	8	30	4.1

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

Constituent	Number of samples	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
01118500 Pawcatuck River at Westerly, R. I. (continued)						
(The following analyses are in micrograms per kilogram.)						
Aldrin, total in bottom material	6	0.00	0.00	0.0	0.0	0.00
Chlordane, total in bottom material	6	.33	.82	.0	2.0	.33
DDD, total in bottom material	6	.90	2.20	.0	5.4	.90
DDE, total in bottom material	6	.18	.30	.0	.7	.12
DDT, total in bottom material	6	.05	.12	.0	.3	.05
Dieldrin, total in bottom material	6	.00	.00	.0	.0	.00
Endosulfan, total in bottom material	4	.00	.00	.0	.0	.00
Endrin, total in bottom material	6	.00	.00	.0	.0	.00
Heptachlor, total in bottom material	6	.00	.00	.0	.0	.00
Heptachlor epoxide, total in bottom material	6	.00	.00	.0	.0	.00
Lindane, total in bottom material	6	.00	.00	.0	.0	.00
Methoxychlor, total in bottom material	6	.00	.00	.0	.0	.00
Mirex, total in bottom material	4	.00	.00	.0	.0	.00
PCB, total in bottom material	6	.33	.82	.0	2.0	.33
PCN, total in bottom material	4	.00	.00	.0	.0	.00
Perthane, total in bottom material	4	.00	.00	.0	.0	.00
Toxaphene, total in bottom material	6	.00	.00	.0	.0	.00

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 over a period of time there will be a considerable variability in the constituent concentrations. How then is one able to look at the record of analytical data and decide if there is a change in the concentration of the constituent? The simplest way to look for a change is to compare the data over time. Is a given constituent increasing or decreasing? 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 in a particular river, dissolved solids concentration may decrease with an increase in flow and increase as the flow diminishes. If one examines the record of dissolved solids over time there may, for example, seem to be a decrease over the period of record in dissolved solids concentration. In this case, the record may have begun during a dry period when streamflow was below normal and ended during a wet period with streamflow above normal. There is a trend but it is related to the flow of water in the stream. While this information may be useful, the primary concern of most water managers and the public is to know if the efforts to clean up water pollution sources are having a positive effect.

The seasonality of the data also is important. For example, streamflows are commonly lowest in the late summer and early fall. If a water-quality constituent varies with streamflow then the constituent will be at a higher (or lower) concentration during the late summer and early fall. Conversely, at times of the year when streamflow is high, the concentration will be at a lower (or higher) level.

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

> "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 resticted to those pairs of data which are multiples of 12 months apart. Since comparision 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 using total phophorus, total nitrogen, and specific conductance at the six sites. 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 discharge. Specific conductance, while not a concentration value, has been treated as one for this analysis. A series of 14 different relationships (Crawford and others, 1983) was tested for each of the constituents at each of the six sites. However, if a relationship existed at the site, either of the following best fit the data:

(1) $C = a + b(Q)$ linear

(2) $C = a + b \ln(Q)$ log-linear

Where C is the predicted concentration, Q is the discharge, 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 slope of the equation (whether b is positive or negative) 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 with discharge. The regression type was marked "highly significant" where p is less than or equal to 0.01, and 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, R^2 (R squared in the table). The closer R^2 is to 1.0, the better the equation fits the data.

A negative discharge-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 discharge-total phosphorus relationship indicating that erosion and transport of total phophorus at high flows is the dominant process.

After the discharge-constituent relationship was determined, the next step was to run the Seasonal Kendall test on the discharge, concentration, transport, and the flow-adjusted concentration. Transport, which was computed for total nitrogen and phophorus but not for specific conductance, is the product of the concentration and the discharge multiplied by a constant, 0.002697, to give transport of the constituent 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.

Results

As Smith and others (1982) 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." Trends in discharge indicated what has happened to the amount of water in the river during the period of record. Generally this may 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, this would reveal a trend in discharge. Trends in concentration indicate what has happened over the period of record to the concentration. This can be of importance if the concentration is close

Table 8.—Trend results for each station

(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. Slope is marked with a plus (+) for a positive discharge-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 micromhos, per year divided by the average value in milligrams per liter (tons per day or micromhos) and multiplied by 100. The units in all cases are percent of mean per year.)

TOTAL PHOSPHORUS

Station number	Station name	Discharge: Mean (cubic feet per second)	Discharge: Trend (percent per year)	Concentration: Mean (milligrams per liter)	Concentration: Trend (percent per year)	Transport: Mean (tons per year)	Transport: Trend (percent per year)	Flow-adjusted concentration: Trend (percent per year)	Regression (R squared)	Regression (type)	Regression (slope)
01111230	Blackstone River at Millville, Mass.	655	-3.69	0.28	-7.14 hs	0.40	-6.93 s	-1.31	0.15 hs	linear	—
01111500	Branch River at Forestdale, R. I.	220	-.64	.037	-6.76 hs	.02	-4.85 s	—	no relationship		
01112900	Blackstone River at Manville, R. I.	883	1.93	.30	-2.50	.56	1.96	-.95	.31 hs	loglin	—
01116500	Pawtuxet River at Cranston, R. I.	360	-.38	.34	-5.59	.22	.15	-1.36	.46 hs	loglin	—
01116617	Pawtuxet River at Pawtuxet, R. I.	479	1.04	.50	-1.17	.43	3.17	1.01	.46 hs	loglin	—
01118500	Pawcatuck River at Westerly, R. I.	667	1.26 s	.05	-10.00 hs	.07	-3.57	-3.22	.08 hs	loglin	—

TOTAL NITROGEN

Station number	Station name	Discharge: Mean (cubic feet per second)	Discharge: Trend (percent per year)	Concentration: Mean (milligrams per liter)	Concentration: Trend (percent per year)	Transport: Mean (tons per year)	Transport: Trend (percent per year)	Flow-adjusted concentration: Trend (percent per year)	Regression (R squared)	Regression (type)	Regression (slope)
01111230	Blackstone River at Millville, Mass.	655	-3.69	3.22	0.26	5.48	6.88	—	no relationship		
01111500	Branch River at Forestdale, R. I.	220	-.64	.93	6.45 s	.39	10.1 s	4.66 s	0.06 s	linear	—
01112900	Blackstone River at Manville, R. I.	883	1.93	2.45	.00	4.39	3.10	3.46	.52 hs	loglin	—
01116500	Pawtuxet River at Cranston, R. I.	360	-.38	1.90	3.16	1.29	2.49	.67	.54 hs	loglin	—
01116617	Pawtuxet River at Pawtuxet, R. I.	479	1.04	2.74	7.30	2.58	.78	1.98	.55 hs	loglin	—
01118500	Pawcatuck River at Westerly, R. I.	667	1.26 s	.88	.00	1.26	.44	.24	.28 hs	loglin	—

SPECIFIC CONDUCTANCE

Station number	Station name	Discharge: Mean (cubic feet per second)	Discharge: Trend (percent per year)	Concentration: Mean (micromhos)	Concentration: Trend (percent per year)	Flow-adjusted concentration: Trend (percent per year)	Regression (R squared)	Regression (type)	Regression (slope)
01111230	Blackstone River at Millville, Mass.	655	-3.69	238	-0.71	-1.61	0.46 hs	linear	—
01111500	Branch River at Forestdale, R. I.	220	-.64	77	-1.46	-1.35 s	.26 hs	loglin	—
01112900	Blackstone River at Manville, R. I.	883	1.93	207	-1.93	-2.36	.35 hs	loglin	—
01116500	Pawtuxet River at Cranston, R. I.	360	-.38	217	.92	.54	.64 hs	loglin	—
01116617	Pawtuxet River at Pawtuxet, R. I.	479	1.04	254	-.02	1.36	.58 hs	loglin	—
01118500	Pawcatuck River at Westerly, R. I.	667	1.26 s	100	.00	1.92 hs	.58 hs	loglin	—

to an established criteria or standard. Trends in transport indicate what changes have occurred in the flux of substances through the river system, suggesting what might be happening to the rates of output from various sources of the constituent. For example, if a new wastewater treatment plant were installed which removed a significant part of the phosphorus formerly introduced into the stream, a trend in the transport would be detected. This trend might also be seen in the concentration but it might be masked by the variations in flow. The flow-adjusted concentration, which is the actual concentration minus the expected concentration using the discharge-constituent relationship, also should show a downward trend. If the processes other than flow which contribute the constituent to the river have not changed during the period of record, the flow-adjusted concentration will fluctuate randomly about zero. If the flow conditions change during the period of record they will be compensated for and will not affect the determination of a trend. Trends in the flow-adjusted concentration indicate that changes have occurred in the processes that deliver the constituent to the river.

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 micromhos, per year divided by the average value in milligrams per liter (tons per day or micromhos) 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.

Results for total phosphorus show significant downward trends in concentration and transport at the Blackstone River at Millville, Mass. However, neither the discharge nor the flow-adjusted concentration show a significant trend. Neither nitrogen or specific conductance showed any significant trends at the station.

Branch River at Forestdale also showed significant downward trends in phosphorus concentration and transport. Total nitrogen, however, showed a significant upward trend in concentration, transport, and flow-adjusted concentration. Specific conductance showed a significant downward trend for flow-adjusted concentration.

The only other site that showed any significant trends was the Pawcatuck River at Westerly. This site showed an upward trend in discharge, a downward trend in total phosphorus concentration, and an upward trend in flow-adjusted concentration for specific conductance.

SUMMARY

Concentrations of the common constituents were low at all Rhode Island stream sites between November 1979 and September 1983. The mean hardness at all sites was in the "soft" category although the maximum hardness might be in the moderately hard range. Mean sodium values met the most stringent drinking water criterion of 20 mg/L at the Branch River at Forestdale and the Pawcatuck River at Westerly. Mean concentrations at the other sites were slightly higher.

Nitrogen concentrations (total nitrate plus nitrite and total nitrogen) were lowest in the Branch River at Forestdale and the Pawcatuck River at Westerly while the mean total nitrate plus nitrite concentrations for the Blackstone River at Millville, Mass., and the Blackstone River at Manville were in the range that could cause undesirable growth of aquatic plants. Total phosphorus values were also lowest on the Branch River at Forestdale and the Pawcatuck River at Westerly. At the other sites, mean total phosphorus values were sufficiently high to potentially allow undesirable growth of aquatic plants if the waters were impounded.

Fecal coliform bacteria counts were high at all sites which indicated that the sites would not have met the criterion for body contact sports. Bacteria samples were not collected with sufficent frequency to indicate if the requirements of the criterion were met.

Trace element concentrations in the stream were generally low. Those trace elements which were found in concentrations near or exceeding any standard or criterion include cadmium, chromium, lead, iron, and manganese. Cadmium concentrations were found at the drinking water standard of 10 µg/L at the Blackstone River at Millville, Mass., and the Pawcatuck River at Westerly. A total chromium concentration was at the drinking water standard of 50 µg/L at one site, the Blackstone River at Millville, Mass. Lead concentrations exceeded the drinking water standard of 50 µg/L at the Blackstone River at Millville, Mass. Manganese concentrations exceeded the drinking water standard at all sites and iron at several sites. High concentrations of trace elements in bottom materials were found at several sites including the Blackstone River at Millville, Mass.

Several pesticides and other organic compounds were found at the sites. Lindane, dieldrin, and PCB were found in the water. Phenols were found at all of the sites in excess of the 1 µg/L criterion for domestic water supplies and to protect against fish flesh tainting. Other organic compounds found in the bottom material samples, included aldrin, chlordane, DDD, DDE, DDT, dieldren, endosulfan, endrin, heptachlor, mirex, and PCB. One bottom material sample from the Pawtuxet River at Pawtuxet had a PCB concentration of 5400 µg/kg.

Results of trend analysis of total phosphorus, total nitrogen, and specific conductance show a downward trend in phosphorus at Blackstone River at Millville, Mass., and Branch River at Forestdale. The Branch River at Forestdale had an upward trend in nitrogen. Specific conductance showed a downward trend at Branch River at Forestdale and an upward trend at Pawcatuck River at Westerly.

REFERENCES CITED

Briggs, J. C., and Ficke, J. F., 1978, Quality of rivers of the United States, 1975 water year—based on the National Stream Quality Accounting Network (NASQAN): U.S. Geological Survey Open-File Report 78-200, 436 p.

Crawford, C. G., Slack, J. R., and Hirsch, R. M., 1983, Nonparametric tests for trends in water-quality data using the Statistical Analysis System: U.S. Geological Survey Open-File Report 83-550, 102 p.

Durfor, C. N., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Survey Water-Supply Paper 1812, 364 p.

Greeson, P. E., ed., 1979, A supplement to—Methods for collection and analysis of aquatic biological and microbiological samples (U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A4): U.S. Geological Survey Open-File Report 79-1279, 92 p.

Greeson, P. E., Ehlke, T. A., Irwin, G. A., Lium B. W., and Slack, K. V., eds., 1977, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A4, 332 p.

Guy, H. P., and Norman, V. W., 1970, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C2, 59 p.

Hirsch, R. M., Slack, J. R., and Smith, R. A., 1982, Techniques of trend analysis for monthly water quality data: Water Resources Research, v. 18, no. 1, p. 107-121.

National Academy of Sciences and National Academy of Engineering, 1972 [1974], Water quality criteria 1972: Washington, D.C., U.S. Government Printing Office, Ecological Research Series, EPA-R3-73-033-March 1973, 594 p.

Rantz, S. E., and others, 1982, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Skougstad, M. W., Fishman, M. J., Friedman, L. C., Erdmann, D. E., and Duncan, S. S., eds., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 626 p.

Smith, R. A., Hirsch, R. M., and Slack, J. R., 1982, A study of trends in total phosphorus measurements at NASQAN stations: U.S. Geological Survey Water-Supply Paper 2190, 34 p.

U.S. Council on Environmental Quality, 1975, Environmental quality, 1975—Sixth annual report of the Council on Environmental Quality: Washington, D.C., U.S. Government Printing Office, 763 p.

_____1976, Environmental quality, 1976—Seventh annual report of the council on Environmental Quality: Washington, D.C., U.S. Government Printing Office, 378 p.

U.S. Environmental Protection Agency, 1975, National interim primary drinking water regulations: Federal Register, v.40, no. 248, Dec. 24, 1975, p. 59566-59588.

_____1976, Quality criteria for water: U.S. Environmental Protection Agency, 256 p.

_____1977, National secondary drinking water regulations: Federal Register, v. 42, no. 62, March 31, 1977, p. 17143-17147.

_____1980, Interim primary drinking water regulations: Federal Register, v. 45, no. 168, Aug. 27, 1980, p. 57332-57357.

Wentz, D. A., 1974, Effect of mine drainage on the quality of streams in Colorado, 1971-72: Denver, Colorado Water Conservation Board, Colorado Water Resources Circular 21, 117 p., 3 pl.

Wershaw, R. L., Fishman, M. J., Grabbe, R. R., and Lowe, L. E., eds., 1983, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, (released as Open-File Report 82-1004), 173 p.

Wood, W. W., 1976, Guidlines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey Techniques of Water-Resources Investigations, book 1, chap. D2, 24 p.