QUALITY OF WATER FROM PUBLIC-SUPPLY WELLS IN MASSACHUSETTS, 1975-86

By Thomas J. Trombley

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	*By*	*To obtain*
	Length	
inch (in.)	25.4	millimeter
	Area	
square mile (mi^2)	2.590	square kilometer
	Temperature	
degree Fahreinheit (°F)	$^oC = 5/9\ (^oF - 32)$ $^oF = 9/5\ (^oC) + 32$	degree Celsius (°C)

Water-Quality Units

milligrams per liter (mg/L)

microsiemens per centimeter at 25 degrees Celsius (µS/cm)

Quality of Water from Public-Supply Wells in Massachusetts, 1975-86

By Thomas J. Trombley

ABSTRACT

The variability in the quality of water from public-supply wells in Massachusetts was evaluated by statistical and graphical methods. Nearly all of the public-supply wells in the Commonwealth derived water from stratified glacial-drift deposits. The water-quality data included results of 8,300 inorganic analyses of samples collected from 1975 through 1986. The data were grouped into 31 Commonwealth water-resources planning basins and subbasins that generally coincide with surface-water drainage divides.

In general, analysis of the data shows that water from public-supply wells in Massachusetts is of good quality and suitable for human consumption, but slightly acidic (pH values, about 6.3 to 6.6 standard units) and poorly buffered [bicarbonate concentrations, about 20 to 40 mg/L (milligrams per liter)]. The water typically has chloride concentrations of about 30 to 33 mg/L, and nitrate concentrations of about 0.3 to 0.7 mg/L. Water quality is affected by local geology and anthropogenic sources. For example, the highest median values for pH and bicarbonate are found in ground water in planning basins underlain by carbonate rocks; in the Hoosic and Housatonic basins, median pH exceeds 7.0, and the median bicarbonate concentration exceeds 75 mg/L. The lowest median values for pH (6.1) and bicarbonate concentration (8.5 mg/L) are found in water from thick sand and gravel deposits on Cape Cod that are derived primarily from schists, gneisses, and granitic rocks. Median chloride concentrations are highest, due primarily to highway deicing salts, in ground water from the Mystic (58 mg/L), the Quinebaug (50 mg/L), and the Blackstone (26 mg/L) basins. The highest nitrate and ammonia concentrations are found in ground water from five urbanized basins in eastern Massachusetts.

Kendall seasonal correlations with time indicate that pH is decreasing in four basins, possibly indicating a connection with acidic precipitation. Specific conductance is increasing in eight basins. Trends in specific conductance generally are in response to changes in bicarbonte, chloride, and (or) sulfate concentration.

INTRODUCTION

The quality of the public ground-water supplies has become a major concern in Massachusetts during the last few years. Ground water is the primary source of public supply for about 165 communities and a secondary source of supply for an additional 33 communities. Degradation of ground-water quality is a threat to public health, and the removal of ground-water supplies from service has created shortages, requiring development of new sources, expensive treatment, stresses to other areas of the environment, and interbasin transfer of water, among others. By 1985, about 100 wells in the Commonwealth had been closed because of contamination; 56 of those wells were closed because of contamination with organic compounds (Special Legislative Commission on Water Supply, 1986; Frimpter, 1988).

The Massachusetts Department of Environmental Protection (DEP) requires analysis of water samples from each public supply for common inorganic constituents and some metals at least once a year. Samples are also collected periodically for analysis of volatile organic compounds (VOC). Since June 1986, the VOC analyses have been conducted by Commonwealth certified laboratories. Until now, this information was used only to identify exceedance of recommended public-health standards for drinking water. The Massachusetts Divisions of Water Pollution Control and Water Supply (WSSC Project 87-10) and the U.S. Geological Survey have undertaken a cooperative study to evaluate water quality and areal and temporal variations in water quality in public-supply wells in Massachusetts.

Purpose and Scope

The purposes of this report are (1) to describe the water quality of the public ground-water supplies in Massachusetts; (2) to evaluate the areal and temporal trends in water quality; and (3) to relate the water-quality trends to general causative factors, such as geology, population density, highway deicing salts, and others.

The scope of the study was to evaluate statistically water quality and water-quality trends from a data set consisting of 8,300 annual inorganic analyses of samples from public-supply wells in 233 municipalities throughout the Commonwealth for the period 1975-86. The data were grouped for analysis into 31 Commonwealth water-resources planning basins and major subbasins.

Physical Setting

General

The Commonwealth is divided into 28 water-resources planning basins (fig. 1) by the Massachusetts Water Resources Commission, some of which are divided further into two or three subbasins for a total of 34 basins and subbasins. Of these, 31 basins have been developed for public ground-water supply.

The population of Massachusetts is concentrated in the eastern one-third of the Commonwealth, as indicated by figure 2, which shows the centroids of the 1980 census tracts (data from files of the U.S. Bureau of the Census, 1985) in Massachusetts, and by table 1, which lists summary data for each of the Commonwealth water-resources planning basins. Each census tract contains about 1,000 people. Basins with a large population density as shown in table 1 are the Merrimack (basin 13), the Concord and Sudbury (basin 14b), the Shawsheen (basin 15), the North Coastal (basin 18), the Mystic (basin 19a), the Neponset (basin 19b), the Weymouth and Weir (basin 19c), the Charles (basin 20), Narragansett Bay and Mt. Hope Bay Shore (basin 26), and the Ten Mile (basin 27). Primary water-quality concerns in densely populated areas of the Commonwealth are contamination from highway deicing salts, septic and sewage systems, and industrial wastes. In the less densely populated areas, agricultural sources of contamination may be more important. Major agricultural areas (Massachusetts Department of Food and Agriculture, 1988) include basins in western Massachusetts, where dairy and maple-sugar production are important; the Connecticut Valley (basin 6), which also produces vegetables and some tobacco; basins in central Massachusetts, which produce vegetables; and southeastern Massachusetts, which produces cranberries (table 1). Primary water-quality concerns in these agricultural areas are contamination from animal wastes and from agricultural chemicals.

Geology

Bedrock geology in Massachusetts (fig. 3) can be characterized by four generalized zones. The Taconic-Berkshire zone in western Massachusetts contains limestone, dolostone, marble, quartzite, phyllite, schist, and gneiss. The Triassic lowland, located in the Connecticut Valley, contains conglomerate (arkose), sandstone, and shale. Most of the rest of the Commonwealth is underlain by igneous and metamorphic rocks. Cape Cod and the Islands are overlain by thick deposits of stratified glacial drift. Nearly all of the public-supply wells in Massachusetts tap shallow water-table aquifers in stratified glacial-drift deposits. Throughout most of the Commonwealth, the thickest drift deposits fill the valleys cut into the bedrock. Local bedrock geology (fig. 3) may be an important factor affecting the water quality in drift deposits because these drift deposits generally are derived from local bedrock and because water in the deposits may have circulated through the bedrock.

Climate

Massachusetts has a temperate climate and, according to the U.S. Department of Commerce (1968), the Commonwealth can be divided into three climatic zones. The Western division is in the western 25 percent of the Commonwealth; the Central division consists of about the central one-half of the Commonwealth; and the Coastal division consists of the remaining 25 percent of the Commonwealth located along the Atlantic Coast and on Cape Cod. Annual precipitation ranges from about 43 in. per year along the coast to about 45 in. per year in the western part of the Commonwealth. Precipitation is distributed fairly evenly throughout the year; however, year-to-year variation may be great.

Air-temperature fluctuations vary

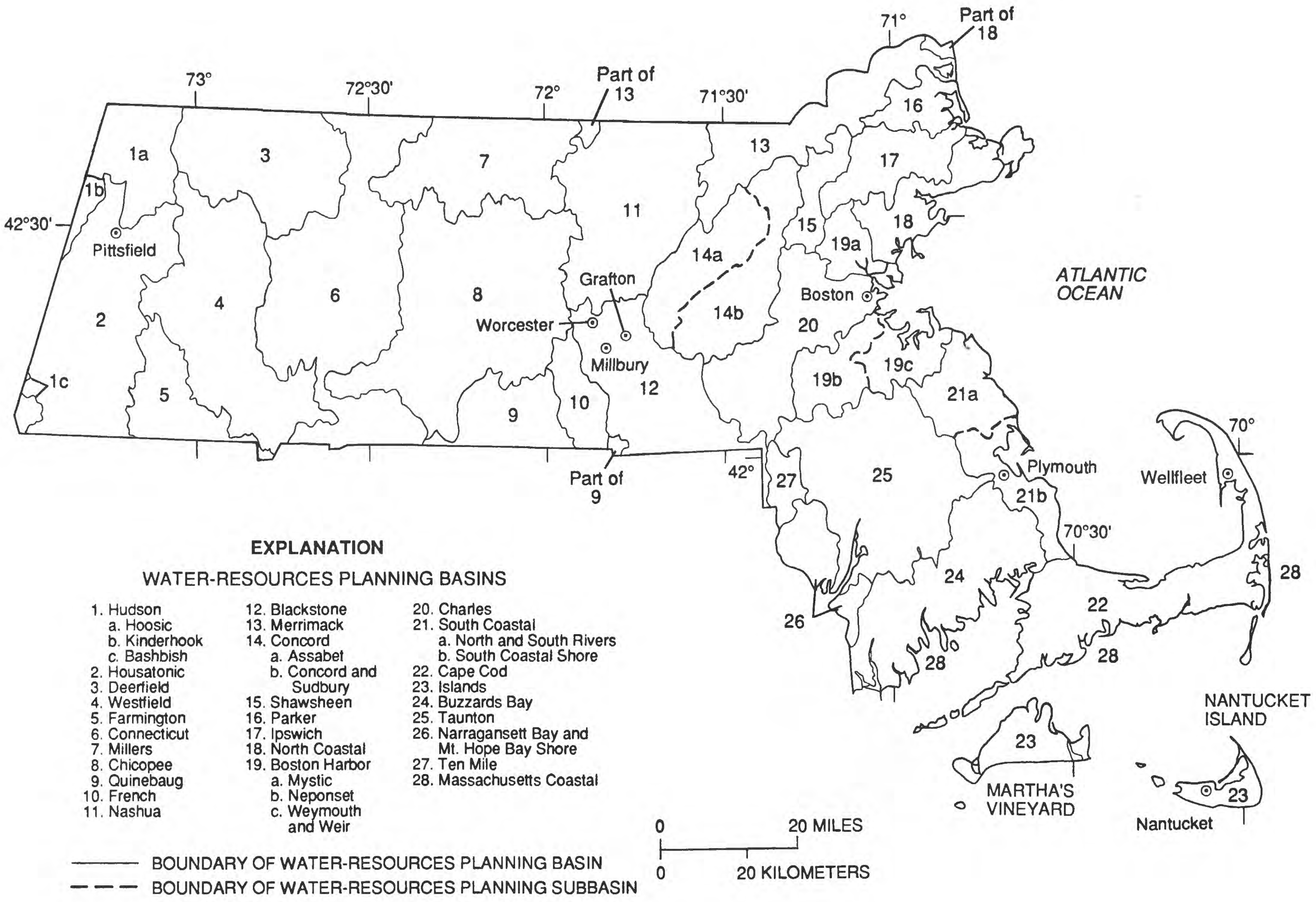

Figure 1. Location of Commonwealth water-resources planning basins.

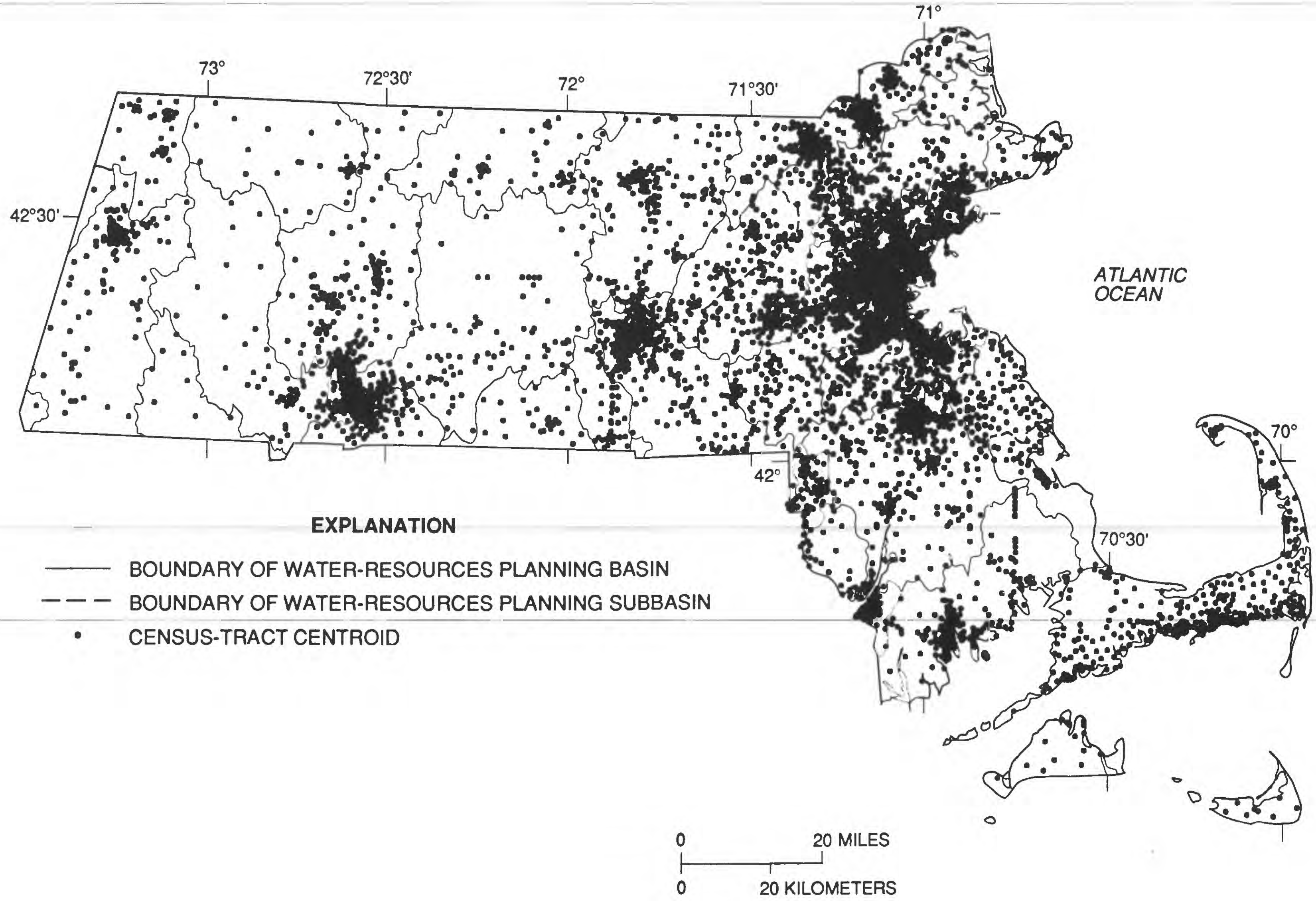

Figure 2. Location of census-track centroids as an indication of population distribution in Massachusetts. (Data from U.S. Bureau of the Census 1980 decennial files, adjusted to the 1985 U.S. Bureau of the Census data for county populations; each tract contains 1,000 people.)

Table 1. *Summary data for Massachusetts water-resources planning basins*

[Population data from Bureau of the Census 1980 decennial files, adjusted to the 1985 U.S. Bureau of the Census data for county populations; agricultural information from Massachusetts Department of Food and Agriculture, 1988]

Basin number (fig. 1)	Basin name	Basin size (square miles)	Population	Population density per square mile	Major agricultural products
01	Hudson	203.7	42,612	209	
01a	Hoosic	166.4	41,891	252	
01b	Kinderhook	21.9	630	29	
01c	Bashbish	15.5	91	6	
02	Housatonic	500.1	93,674	187	
03	Deerfield	346.6	31,856	92	Dairy, maple sugar
04	Westfield	516.6	88,729	172	Dairy, maple sugar
05	Farmington	155.7	3,891	25	
06	Connecticut	669.5	403,727	603	Tobacco, dairy, maple sugar, vegetables
07	Millers	310.4	51,921	167	Dairy, maple sugar
08	Chicopee	722.8	154,126	213	Dairy, maple sugar
09	Quinebaug	153.8	33,055	215	
10	French	94.7	42,570	450	
11	Nashua	445.7	183,721	412	
12	Blackstone	334.8	299,661	895	
13	Merrimack	278.8	326,553	1,171	Vegetables
14	Concord	399.6	339,963	851	
14a	Assabet	177.0	97,028	548	Vegetables
14b	Concord and Sudbury	222.6	242,935	1,092	Vegetables
15	Shawsheen	78.1	119,004	1,524	Vegetables
16	Parker	81.4	22,466	276	Vegetables
17	Ipswich	155.3	107,068	689	Vegetables
18	North Coastal	171.6	431,695	2,516	Vegetables
19	Boston Harbor	283.3	954,114	3,368	
19a	Mystic	76.1	475,231	6,246	
19b	Neponset	116.7	263,843	2,261	
19c	Weymouth & Weir	90.5	215,040	2,376	
20	Charles	319.2	987,738	3,095	
21	South Coastal	240.5	136,524	568	
21a	North & South Rivers	135.3	101,228	748	Cranberries
21b	South Coastal Shore	105.1	35,296	336	Cranberries
22	Cape Cod	394.8	155,119	393	Cranberries
23	Islands	159.9	15,610	98	Cranberries
24	Buzzards Bay	374.1	212,423	568	Cranberries, dairy
25	Taunton	529.8	393,818	743	Cranberries, vegetables
26	Narragansett Bay and Mt. Hope Bay	111.9	144,779	1,294	Vegetables
27	Ten Mile	48.6	56,494	1,162	Vegetables

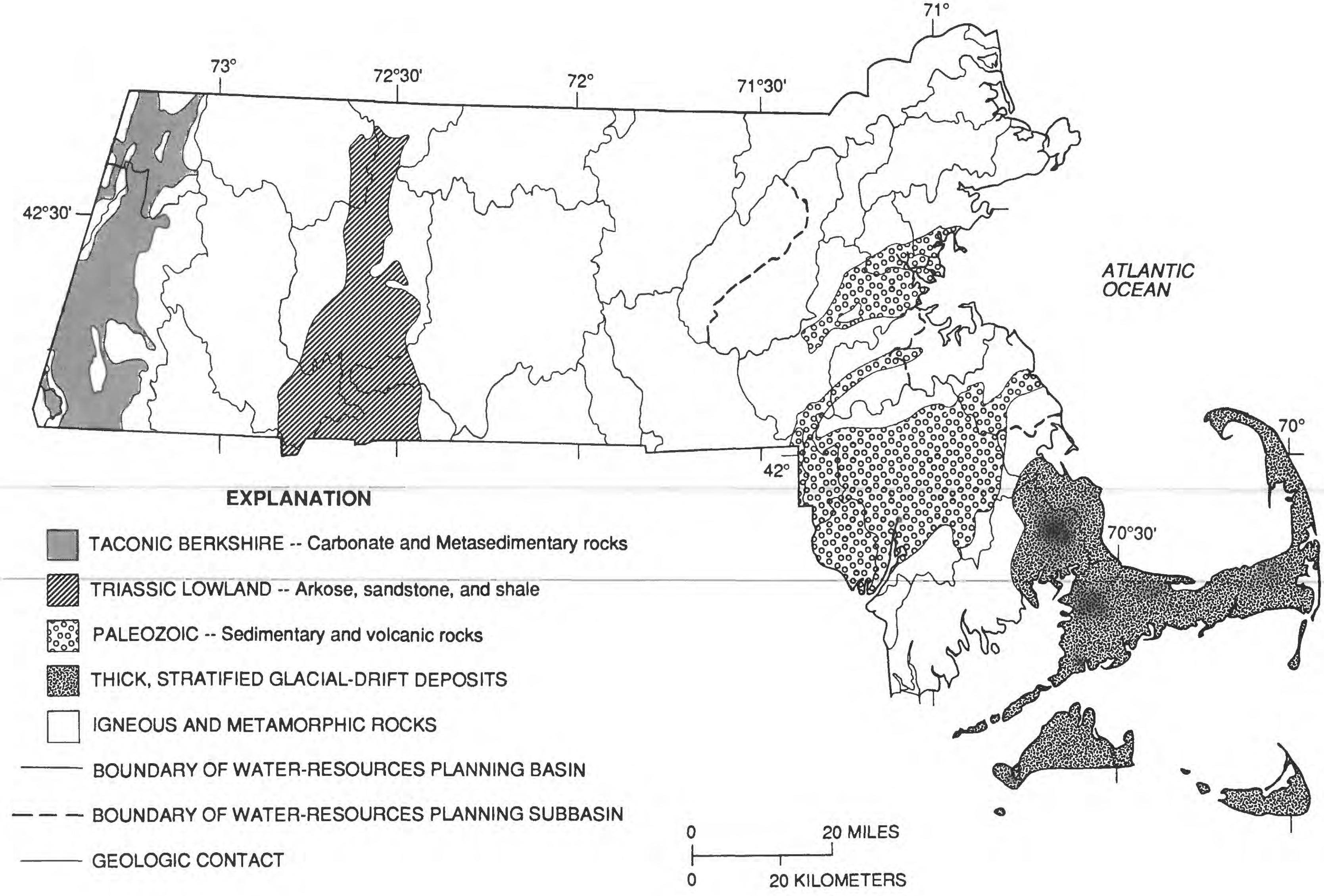

Figure 3. Generalized bedrock geology in Massachusetts.

considerably throughout the Commonwealth. For example, Boston and Nantucket have about 90 days per year where the minimum temperature is 32 °F or less (U.S. Department of Commerce, 1968), whereas Pittsfield, located in the western part of the Commonwealth, has about 160 days. In the summer, sea breezes help moderate temperatures along the coast; the temperature is 90 °F or greater, less than once every 2 years on Nantucket. As for the rest of the Commonwealth, the temperature is 90 °F or greater, twice a year in Pittsfield and six times a year in Worcester (fig. 1).

Previous Studies

Motts and Saines (1969) completed a preliminary study of the quality of ground water in Massachusetts using about 200 analyses from across the Commonwealth. They divided the Commonwealth into four hydrochemical zones on the basis of geology. The acidic hydrochemical zone 1 is common to most of the Commonwealth, corresponds to the regions underlain by igneous and metamorphic and Paleozoic sedimentary rocks (fig. 3), and includes Cape Cod (basin 22) and the Islands (basin 23). Ground water from hydrochemical zone 1 is characterized by pH values less than 7.0 and alkalinity concentrations less than about 50 mg/L as calcium carbonate (bicarbonate concentrations, less than 61 mg/L). Iron concentrations in ground water of zone 1 commonly exceed 0.3 mg/L, and manganese concentrations commonly exceed 0.05 mg/L. Alkaline hydrochemical zone 2 in western Massachusetts is underlain by carbonate rock (limestone, dolomite, and marble) and corresponds to the Taconic-Berkshire geologic zone (fig. 3). Ground water from zone 2 is characterized by pH values greater than 7.0. Concentrations of calcium, magnesium, and bicarbonate tend to be higher than in acidic zone 1, and concentrations of chloride, iron, and manganese tend to be lower. Hydrochemical zone 3, which also has alkaline ground water, corresponds to the Triassic lowland (fig. 3) underlain by arkosic conglomerate, sandstone, and shale. Ground water from this zone is characterized by pH values greater than 7.0 but smaller concentrations of calcium, magnesium, and bicarbonate than ground water from the Taconic-Berkshire zone. Hydrochemical zone 4, which includes the Parker (16) and Ipswich (17) basins also has alkaline ground water. Alkalinity is associated with amphibolite and carbonate and calc-silicate lenses within metamorphic rocks, basalts, and gabbros. Another factor that may contribute to the alkalinity in ground water is the reaction of the water with organic matter buried in marine sediments in the basin. The ground water from hydrochemical zone 4 is characterized by pH values greater than 7.0 and large concentrations of calcium, magnesium, and bicarbonate comparable to hydrochemical zone 3. Motts and Saines (1969) concluded aquifers in swampy areas and flood plains have water with concentrations of iron and manganese that exceed U.S. Environmental Protection Agency drinking-water regulations and pH values that are less than that in ground water from upland areas. By comparing their chloride data to analyses from the 1850's, Motts and Saines (1969) indicated a 4- to 10-fold increase in chloride concentrations in ground water across the Commonwealth from 1850-1966.

Persky (1986) found a strong positive correlation between nitrate concentrations and housing density on Cape Cod. Frimpter and Gay (1979) suggest that highway deicing salts, seawater flooding from storms, and saltwater intrusion caused by ground-water withdrawal are sources of sodium contamination of ground water on Cape Cod. Coastal aquifers are susceptible to seawater encroachment and contamination from surface sources. Frimpter (1988) completed a summary of Massachusetts ground-water quality and indicated that concentrations of iron and manganese exceed U.S. Environmental Protection Agency drinking-water regulations in some areas and that most ground water in the Commonwealth contains low concentrations of dissolved solids, is soft, acidic, and corrosive to pipes and plumbing.

Acknowledgments

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helped explain the data-collection and analysis procedures.

METHODS

Water-quality data from about 1,200 public-supply wells in Massachusetts were used in this study. The water-quality data base, compiled from archived laboratory sheets, consists of 8,300 inorganic analyses for concentrations of alkalinity, calcium, magnesium, sodium, potassium, chloride, sulfate, ammonia, nitrate, iron, and manganese, and for pH. Sample documentation data include town and well name, and sampling and (or) analysis date. The number of the Commonwealth water-resources planning basin was determined by overlaying a map of the town boundaries on a map of the basin boundaries. Where a town's boundaries lie within more than one planning basin, the basin assignment was made by overlaying a map of wells with known locations. This approach to making basin assignments was not exact because not all well locations were accurately known.

Data-Base Structure

The original data base consisted of about 14,000 analyses for the years 1965, 1970, and 1975-86. Analyses of water samples collected during aquifer tests and from test wells were deleted, leaving about 13,000 analyses. Analysis data were entered into the data base from copies of the original laboratory sheets. In addition, several hundred duplicate laboratory sheets, entered into the data base, were compared to evaluate data-entry errors. Few data-entry errors were found among the duplicate laboratory sheets. The data then were spot checked against the laboratory sheets for errors and corrected. Scatter plots of constituent data were used to help identify data-entry errors. Incorrect values were changed to the values on the laboratory sheets. If no substantial proof that a laboratory-sheet value was in error, even if the value looked suspicious, it was not changed. In addition to data-entry errors, some suspicious values may have originated from sampling and analytical problems. These suspicious values were not deleted because it is unlikely that all of the errors could be detected, and arbitrarily deleting them could have biased the data. One drawback to keeping these suspect values is that caution needs to be used in evaluating extreme values (maximums and minimums) because there is an increased chance that they may be in error.

Annual chemical data for 1975-86 were used in the analyses described in this report. Also, a number of wells had multiple yearly analyses, of which all but one were deleted. The deletion of multiple yearly analyses was accomplished using the assumption that the well's name was consistent for all of the samples collected throughout any given year. This is not necessarily correct because there could be typographic differences or different sample collectors could have assigned different names to the well. However, the assumption probably was adequate because there were few apparent multiple analyses observed during a final inspection of the data base. Where there were multiple analyses from a well for a given year, the analysis that was eventually saved in the final data base corresponds to the earliest day of the month sampled. This limits the bias that might have been introduced by selecting the first sample of the year.

Analysis Procedures and Limitations

Standard boxplots (figs. 4-14) were used to provide an overview of the concentration distributions within each of the 31 water-resources planning basins and subbasins. Boxplots are a useful method for comparing the statistical characteristics of several data sets (Dennis Helsel, U.S. Geological Survey, written commun., 1989) and are used here to compare the ground-water quality between basins. Median values, the centerline on the boxplots, give a fairly good idea of the overall ground-water quality within the basin. The length of the box, which is the distance between the 75th and 25th percentiles of the data, gives an indication of the variation in values. Relative skewness of the data is indicated by the difference in size between the box halves and the length of the "whisker" above and below the median line. The presence or absence of unusual values is indicated by plotting extreme values individually. "Outside" values, which are plotted as an asterisk (*), are present in less than 1 out of 100 values that are normally distributed. Values plotted as a circle (o) are present in less than 1 out of 10,000 values that are normally distributed. The term "typical range" (interquartile range) is used throughout this report to indicate where one-half of the values lie, between the 25th and 75th percentiles.

Correlation coefficients (Kendall's Tau-B) were calculated by using all of the well analyses in the basin to evaluate the relations of population density and time to selected chemical constituents and characteristics. Kendall's Tau-B is a nonparametric correlation that uses ranked data. Because population density is related to urbanization and industrialization, the correlations with population density show the relative importance of anthropogenic effects on ground-water quality. Correlations with time show time trends. Caution is needed in interpreting these coefficients because of anomalies in the data. For example, some wells in a town may have become contaminated by deicing salts after a new highway was built, and the wells taken out of service. If the wells were shut down after the contamination reached a critical level, the time trends might then indicate an improvement or no change in water quality within the basin when, in fact, the water quality may have deteriorated. The Kendall Tau-B coefficients, therefore, need to be used with caution to indicate areas that may need further detailed analysis. Conversely, these coefficients may not show trends that actually occur.

WATER QUALITY

The characterization and analysis of ground-water chemistry in this report is based on annual chemical analyses of untreated well water from municipal supplies. The analyses include common inorganic mineral constituents and the properties of specific conductance and pH. The common cations calcium, magnesium, sodium, and potassium and the common anions bicarbonate, chloride, and sulfate were included in virtually every analysis. Nitrogen as nitrate and as ammonia, and the metals iron, manganese, and copper were also included in the analyses. Organic constituent analyses were limited to about one sample per well collected over a 5-year period. These analyses were interpreted for the occurrence of chloroform, which was detected at trace levels in about one-half of the wells.

Physical and Chemical Characteristics

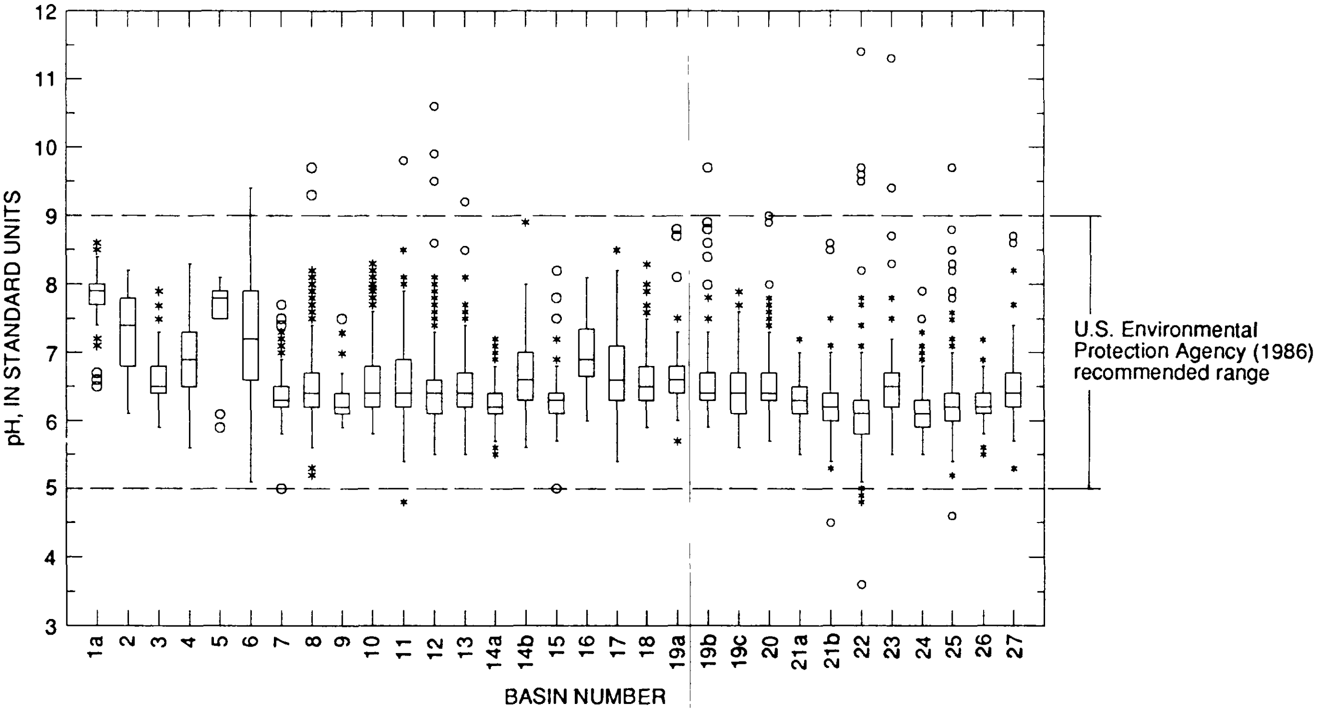
pH

The hydrogen-ion activity of water is measured by the pH. According to Hem (1985, p. 64), the pH of ground water in the United States typically ranges from 6.0 to 8.5 standard units. In carbonate-dominated aquifer systems and where the water is able to react with ultramafic rocks, the pH of the water becomes alkaline. In contrast, other factors, such as oxidation of dissolved ferrous iron, lower the pH. The U.S. Environmental Protection Agency (1986) recommends a pH range of 5.0 to 9.0 for domestic water supplies because, within that range, the pH can be adjusted easily by various treatment processes.

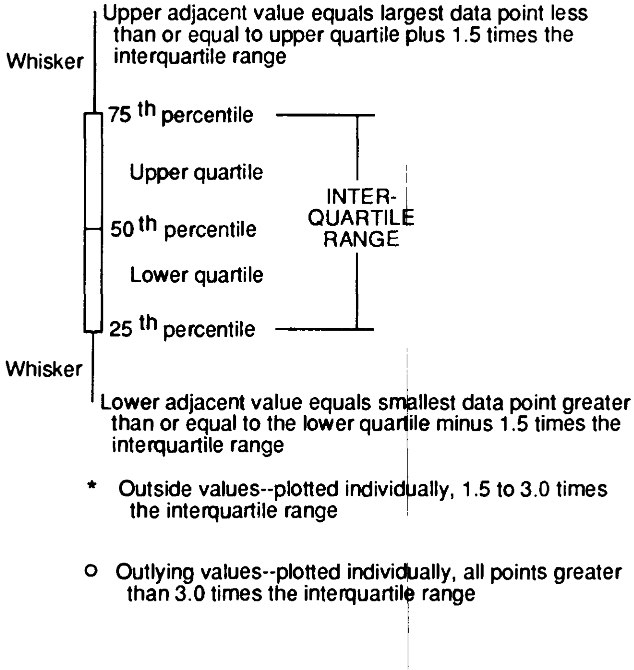
Boxplots of pH (fig. 4) indicate that the data do not follow a normal distribution because the data are skewed and there are a large number of extreme values. This distribution is typical of water-quality data in general. Most of the values fall within the U.S. Environmental Protection Agency's (1986) recommended range for pH and are typically slightly acidic, from about 6.3 to 6.6. However, nine of the 31 basins had water with pH values that exceeded the recommended maximum of 9.0; four had water with values that were less than the recommended minimum of 5.0, and three of these basins also had water with pH values greater than 9.0. Four basins had median pH values greater than 7.0 (Appendix 1, p. 44), the Hoosic (basin 1a), the Housatonic (basin 2), the Farmington (basin 5), and the Connecticut (basin 6); all of which are located in the western part of the Commonwealth (fig. 1). The two basins (Appendix 1, p. 44) with ground water with the lowest median pH value (6.1) are Cape Cod (basin 22) and Buzzards Bay (basin 24), both located on the Atlantic Coast.

Specific Conductance

Specific conductance is a measure of the ability of water to conduct electricity and is useful as an indicator of dissolved-solids concentration. In Massachusetts, the primary constituents of dissolved solids are the cations



EXPLANATION



Upper adjacent value equals largest data point less than or equal to upper quartile plus 1.5 times the interquartile range

Lower adjacent value equals smallest data point greater than or equal to the lower quartile minus 1.5 times the interquartile range

* Outside values--plotted individually, 1.5 to 3.0 times the interquartile range

○ Outlying values--plotted individually, all points greater than 3.0 times the interquartile range

Figure 4. Distribution of pH values in water from public-supply wells.

calcium, magnesium, sodium, and potassium, and the anions bicarbonate, chloride, and sulfate. Boxplots in figure 5 show the distribution of specific conductance in water from the 31 basins and subbasins. The typical range is from about 125 to 230 µS/cm. The largest observed specific-conductance values, with values as large as 1,000 to 1,500 µS/cm, are in water from the Chicopee (basin 8), the Blackstone (basin 12), and the Taunton (basin 25) planning basins. The largest (250-310 µS/cm) median values (Appendix 1, p. 43), however, are the Hoosic (basin 1a), the Parker (basin 16), the Ipswich (basin 17), and the Mystic (basin 19a) basins. The smallest median specific-conductance values (78 to 95 µS/cm) are in water from Cape Cod (basin 22), the Islands (basin 23), and Buzzards Bay (basin 24) located on the coast and in water from the Deerfield (basin 3) located in the western part of the Commonwealth.

Calcium

Calcium is a constituent of many igneous and metamorphic rocks, especially the silicates pyroxene and amphibole, plagioclase feldspar, and in other silicate minerals that are produced in metamorphism (Hem, 1985, p. 89). The calcium concentration in water that has been in contact with igneous or metamorphic rocks is generally small, however, because the solubility of silicate minerals is small and their weathering and decomposition is slow. Carbonate rocks, such as marble, limestone, and dolomite, dissolve readily, and therefore, the calcium concentration in water from carbonate-rock areas tends to be larger than in other areas. Other sources of calcium in Massachusetts ground water may include deicing salt mixtures used on roads during the winter.

Boxplots of calcium distribution (fig. 6) for water from the planning 31 basins and subbasins in Massachusetts show typical concentrations ranging from about 9.5 to 15.5 mg/L. The largest observed concentrations (100 to 115 mg/L) are in water from the Connecticut (basin 6), Blackstone (basin 12), Parker (basin 16), and Ipswich (basin 17), (Appendix 1, p. 46). The largest median concentrations (20 to 32 mg/L) are in the Hoosic (basin 1a), Concord and Sudbury (basin 14b), Parker (basin 16), and Ipswich (basin 17). The smallest median concentrations (2.3 to 4.6 mg/L) are in water from the South Coastal Shore (basin 21b), Cape Cod (basin 22), Islands (basin 23), and Buzzards Bay (basin 24); these basins are all contiguous on the Commonwealth's southeastern coast.

Magnesium

The principal sources of magnesium in ground water are ferromagnesian minerals, such as olivine, pyroxenes, amphiboles, and the dark-colored micas; altered-rock minerals, such as chlorite and serpentine; and carbonate rocks, such as dolomite and magnesite (Hem, 1985, p. 97). Carbonate rocks provide the most soluble source of magnesium. Figure 7 shows the distribution of magnesium in water from public-supply wells throughout Massachusetts. Typical concentrations range from about 2.2 to 3.9 mg/L. The largest concentrations (56 to 92 mg/L) are in water from the Westfield (basin 4), Chicopee (basin 8), Blackstone (basin 12), and Charles (basin 20) (Appendix 1, p. 47). The single largest concentration (92 mg/L) in water from the Westfield basin is anomalous because it is the only large concentration in water from a basin with otherwise small concentrations. The largest median concentrations (15 and 7.9 mg/L) are in water from the Hoosic (basin 1a) and Housatonic (basin 2) underlain by carbonate rocks, including dolomite in western Massachusetts. The smallest median concentrations are 1.4 mg/L in water from the Millers (basin 7) and 1.5 mg/L in water from the Islands (basin 23).

Sodium

Sodium is the most abundant member of the alkali-metal group of elements, and when dissolved, it tends to remain in solution (Hem, 1985, p. 100). Possible natural sources in Massachusetts include the weathering of plagioclose feldspar, the mixing with large sodium concentrations in ground water from marine sediments along the coast, and precipitation, among others. The primary sources for the larger observed sodium concentrations are deicing salts used on the roads during the winter and septic systems. Sodium is also a byproduct of water treatment; it is discharged by water softeners and reverse osmosis units and is a component of sodium

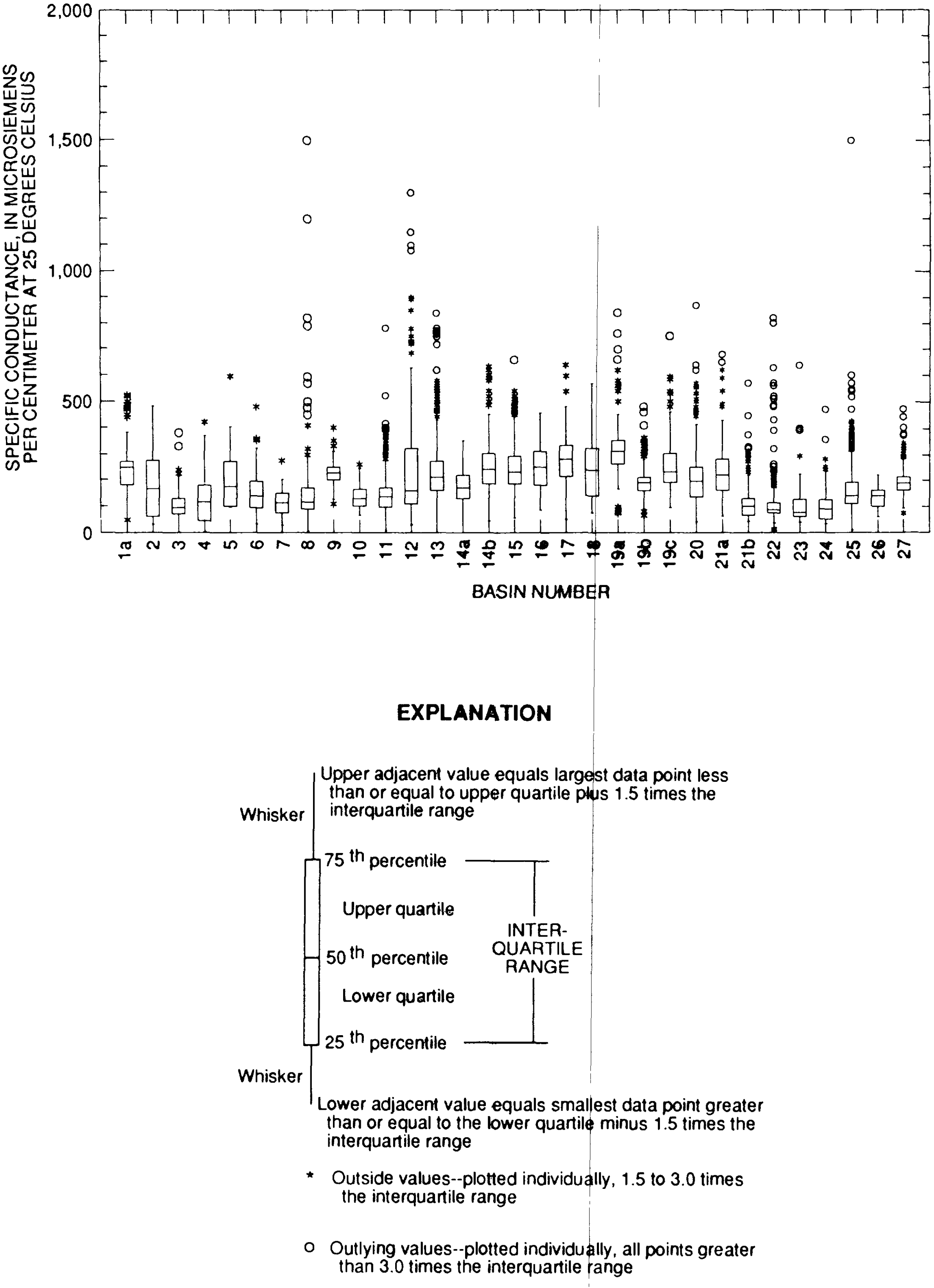


Figure 5. Distribution of specific-conductance values in water from public-supply wells.

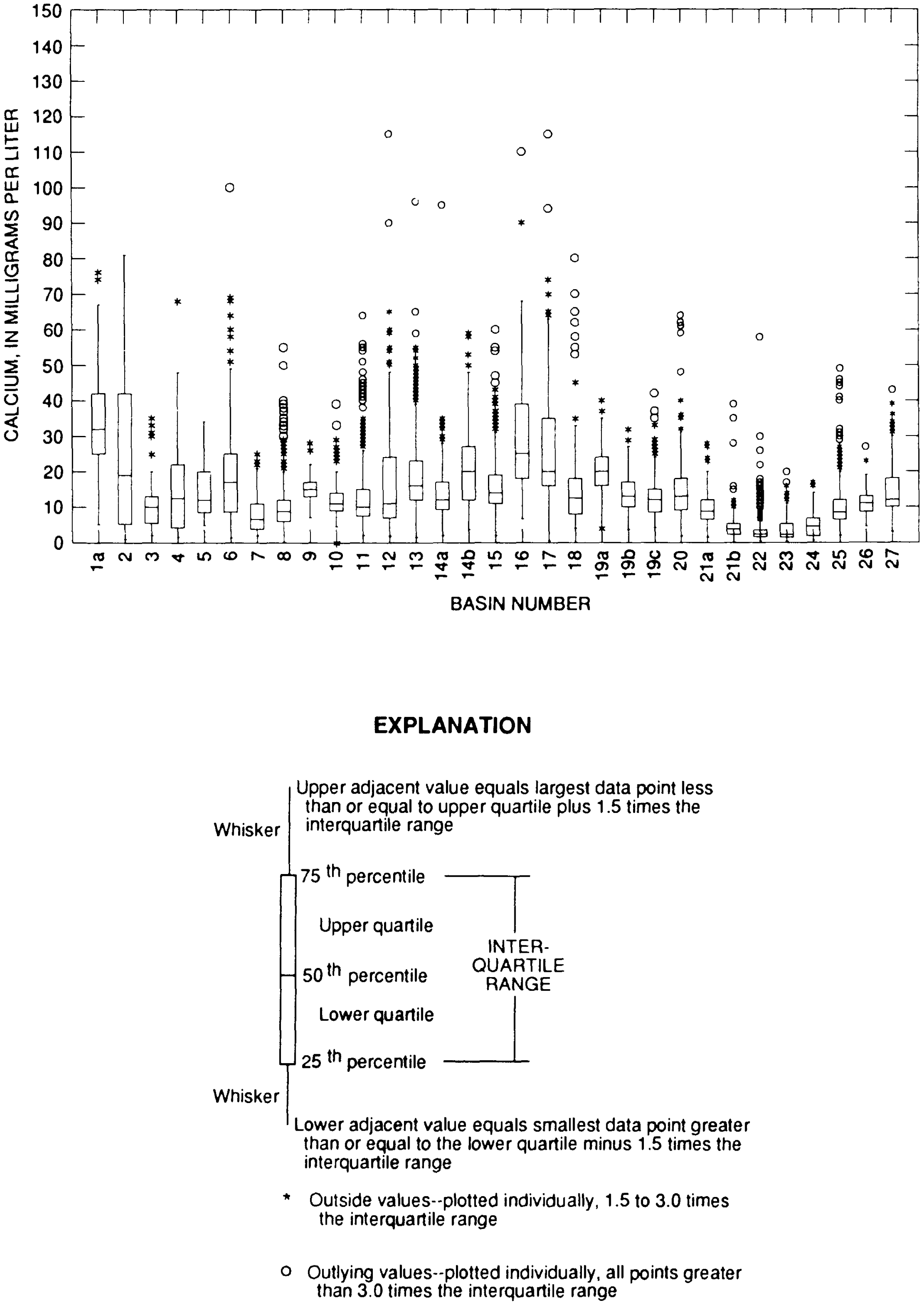


Figure 6. Distribution of calcium concentrations in water from public-supply wells.

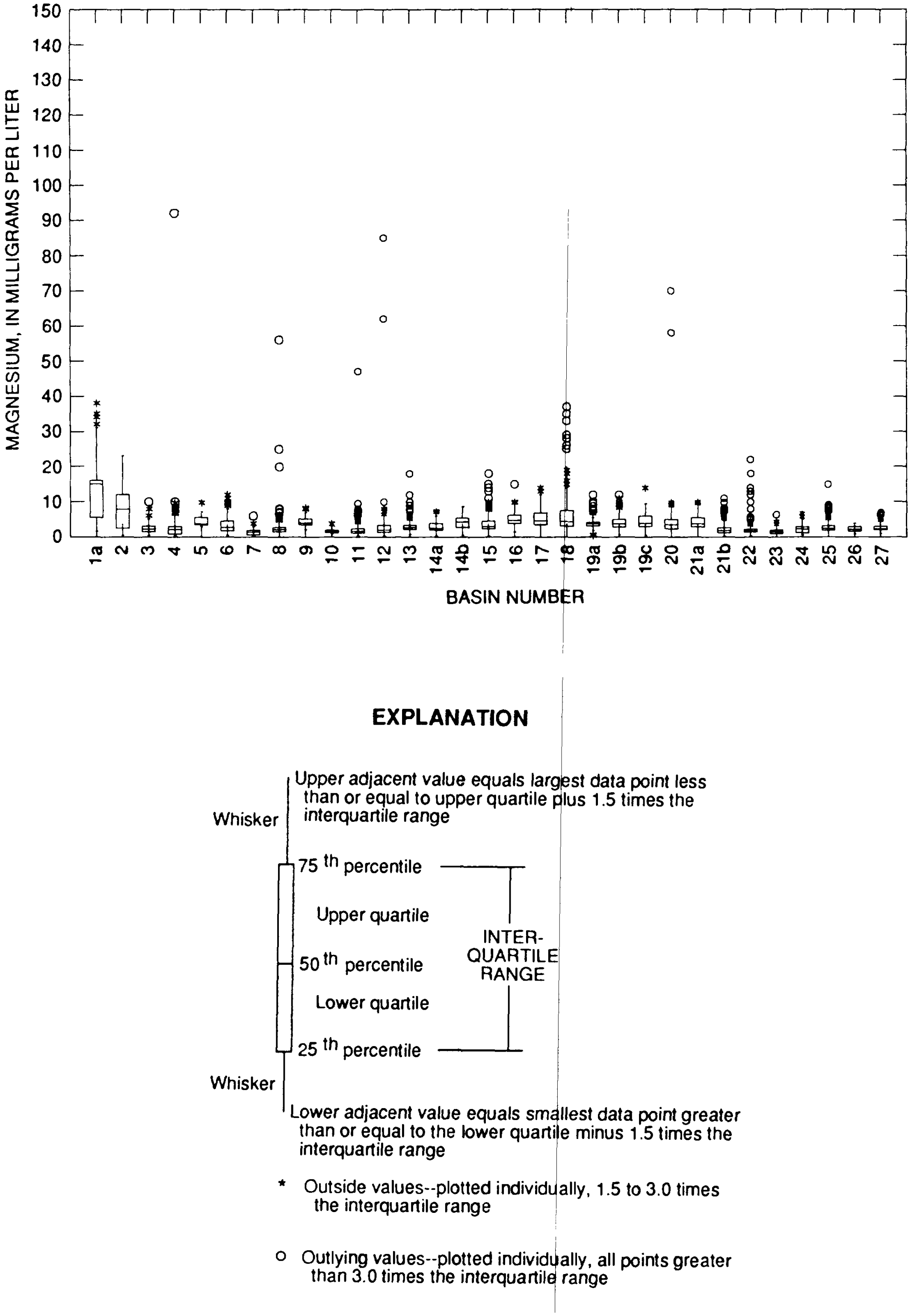


Figure 7. Distribution of magnesium concentrations in water from public-supply wells.

hydroxide, which is used to control pH and corrosiveness in water supplies. The Massachusetts Department of Environmental Protection requires that all water purveyors must notify their customers by mail if a 20-mg/L standard for sodium is reached. "This public notification allows the 'at risk' segment of the population to make necessary adjustments in their daily diets" (Special Legislative Commission on Water Supply, 1986, p. 110).

The distribution of sodium in water from public-supply wells for the 31 Massachusetts water-resources planning basins and subbasins is shown in figure 8. Typical concentrations range from about 9.4 to 18.3 mg/L. Except for the Hoosic (basin 1a), all of the basins have some analyses with concentrations that exceed 20 mg/L. The Taunton (basin 25) has one analysis as large as 750 mg/L (Appendix 1, p. 48); water from this well is no longer used for public supply. Eight other basins have outliers with concentrations exceeding 100 mg/L (120 to 200 mg/L)--Millers (basin 7), Chicopee (basin 8), Blackstone (basin 12), Merrimack (basin 13), Weymouth and Weir (basin 19c), Charles (basin 20), North and South Rivers (basin 21a), and Cape Cod (basin 22). Six basins have median concentrations greater than or equal to 20 mg/L (20 to 35 mg/L)--the Quinebaug (basin 9), Shawsheen (basin 15), Ipswich (basin 17), Weymouth and Weir (basin 19c), North and South Rivers (basin 21a). The smallest median concentrations of sodium (1.6 to 5.0 mg/L) are in water from the more rural western part of the Commonwealth in the Hoosic (basin 1a), Housatonic (basin 2), Deerfield (basin 3), Westfield (basin 4), and Connecticut (basin 6).

Potassium

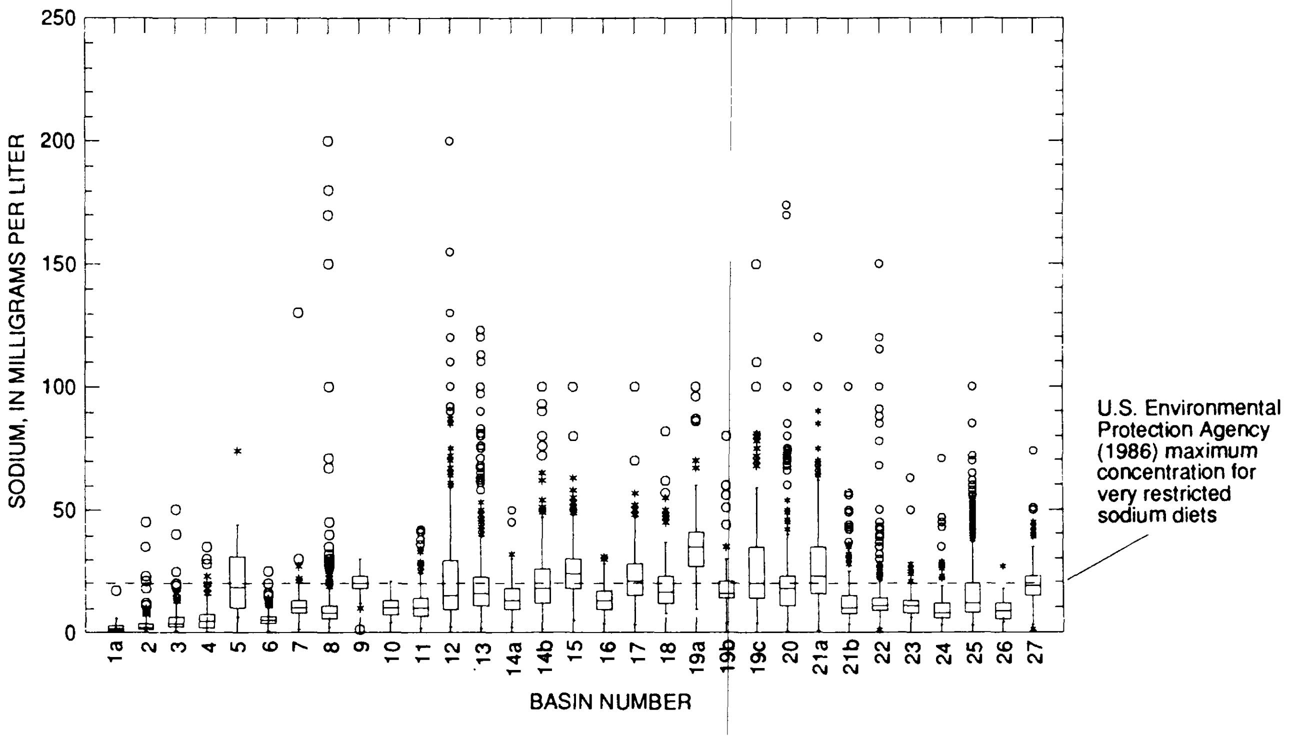
In most natural water (Hem, 1985, p. 104), potassium concentrations are much smaller than sodium concentrations. Potassium weathers and is released more slowly from silicate minerals than sodium and tends to be easily reincorporated into insoluble weathering products, such as clay minerals. Potassium is also a byproduct of water treatment where potassium hydroxide is used sometimes to increase the pH of acidic water. The distribution of potassium in water from Massachusetts public-supply wells is illustrated in figure 9. Concentrations are generally less than about 5 mg/L (from 0.9 to 2.0 mg/L), with some extreme outside values exceeding 10 mg/L. The Blackstone (basin 12) has water with the most concentrations exceeding 10 mg/L. The largest median concentration of 2.95 mg/L (Appendix 1, p. 49) is from water in the Mystic (basin 19a). The smallest median concentration of 0.6 mg/L is from water in the Westfield (basin 4).

Bicarbonate

Bicarbonate concentrations in water are calculated by dividing alkalinity by 0.8202 (Hem, 1985, p. 55, 57). Alkalinity is defined as the capacity of a solute to neutralize acid (Hem, 1985, p. 106-109) and is expressed as milligrams per liter of calcium carbonate. The primary sources for bicarbonate in ground water are dissolution of carbonate-rock minerals and biologic activity. The distribution of bicarbonate concentrations in ground water (fig. 10) varies throughout the 31 Commonwealth planning basins and subbasins. Typical concentrations range from about 20 to about 40 mg/L. Large median concentrations (Appendix 1, p. 50) are in water from the Hoosic (basin 1a) where the bicarbonate concentration is 152 mg/L (alkalinity is 125 mg/L as calcium carbonate); in water from the Housatonic (basin 2), 79 mg/L (alkalinity is 65 mg/L as calcium carbonate); and in water from the Parker (basin 16), 71 mg/L (alkalinity is 58.0 mg/L as calcium carbonate). The smallest median bicarbonate concentration is 8.5 mg/L (alkalinity is 7.0 mg/L as calcium carbonate) in water from Cape Cod (basin 22).

Chloride

Chloride is present in all natural water, but the concentrations are generally small (Hem, 1985, p. 118-119). The most important natural sources are associated with sedimentary rocks, marine sediments, and rainwater close to the ocean. Contamination from human sources may be a major source and include septic-system discharges and the use of deicing salts on the roads during the winter. The U.S Environmental Protection Agency (1986) recommends a maximum concentration of 250 mg/L in drinking water to prevent a salty taste. In the evaluation of chloride in Massachusetts ground water, Motts and Saines (1969) indicate that chloride concentrations in 1890 ranged



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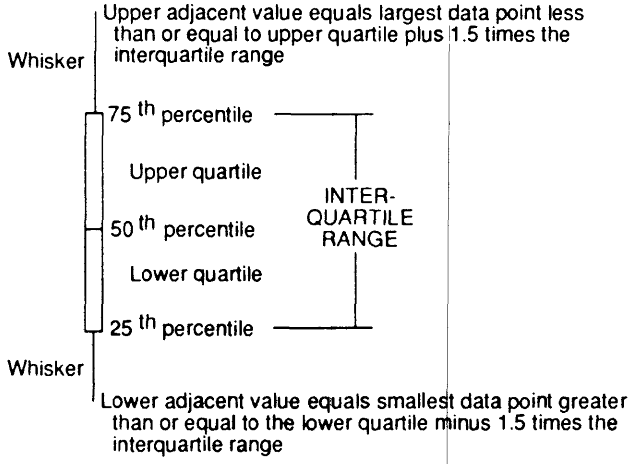


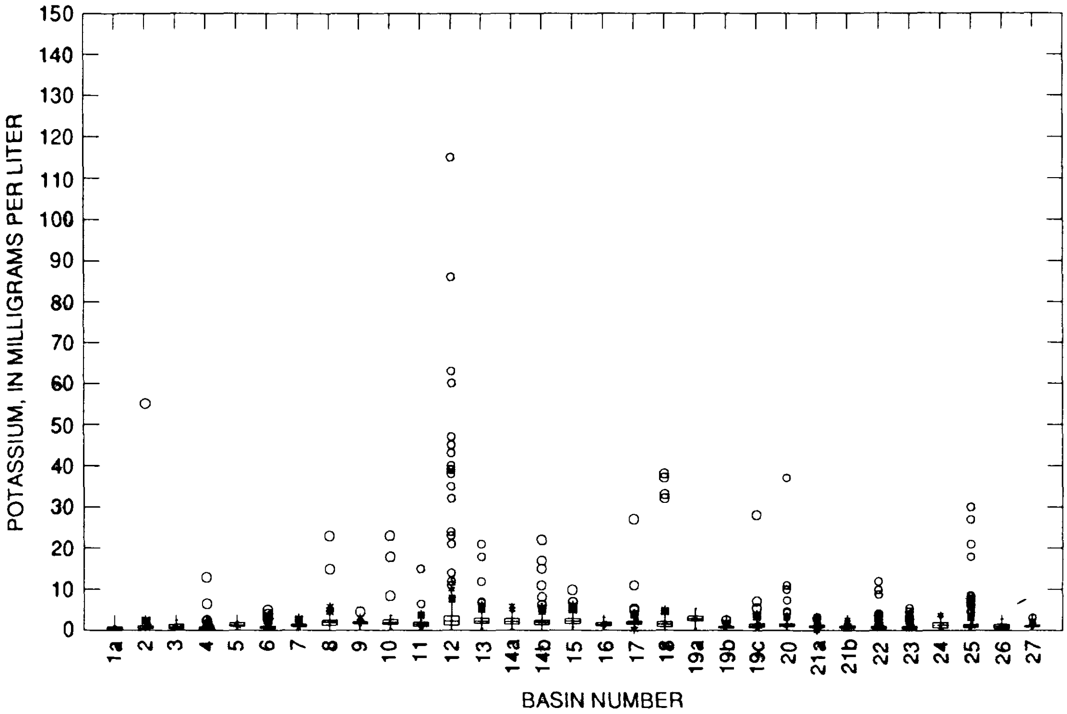
Upper adjacent value equals largest data point less than or equal to upper quartile plus 1.5 times the interquartile range

Lower adjacent value equals smallest data point greater than or equal to the lower quartile minus 1.5 times the interquartile range

* Outside values--plotted individually, 1.5 to 3.0 times the interquartile range

○ Outlying values--plotted individually, all points greater than 3.0 times the interquartile range

Figure 8. Distribution of sodium concentrations in water from public-supply wells.



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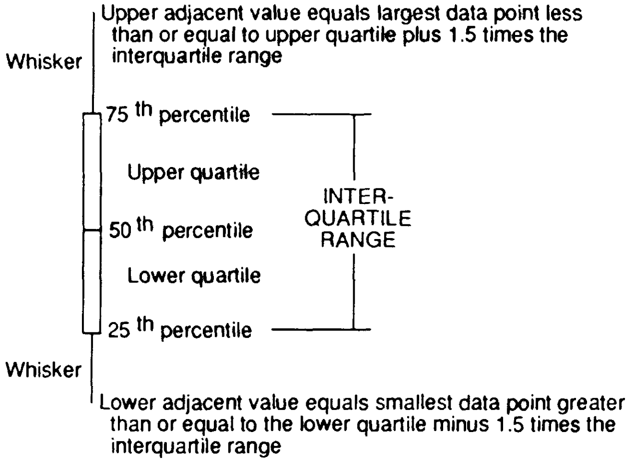
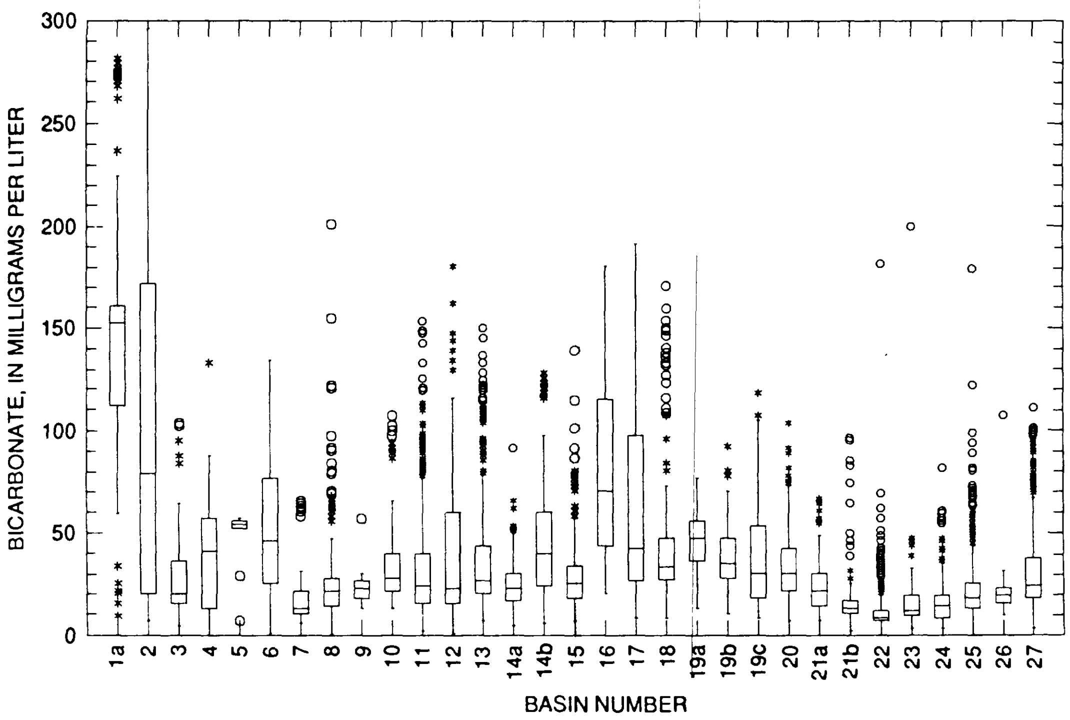


* Outside values--plotted individually, 1.5 to 3.0 times the interquartile range

○ Outlying values--plotted individually, all points greater than 3.0 times the interquartile range

Figure 9. Distribution of potassium concentrations in water from public-supply wells.



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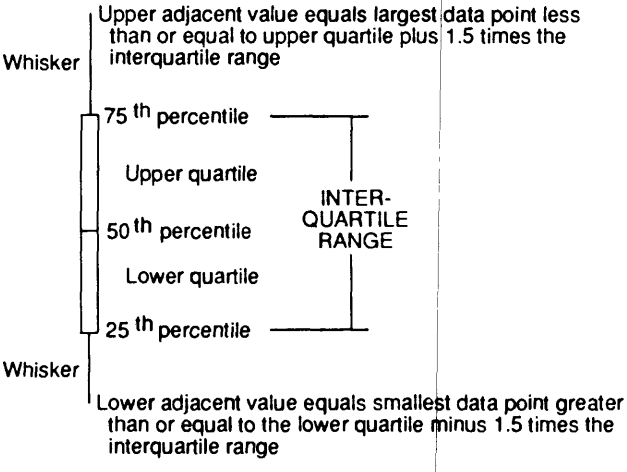


Upper adjacent value equals largest data point less than or equal to upper quartile plus 1.5 times the interquartile range

Lower adjacent value equals smallest data point greater than or equal to the lower quartile minus 1.5 times the interquartile range

* Outside values--plotted individually, 1.5 to 3.0 times the interquartile range

o Outlying values--plotted individually, all points greater than 3.0 times the interquartile range

Figure 10. Distribution of bicarbonate concentrations in water from public-supply wells.

from about 0.7 mg/L in western Massachusetts to about 5 mg/L in the eastern part of the Commonwealth. In water from the Cape Cod area, chloride concentrations were larger, and ranged from about 6 mg/L in Plymouth public-supply wells to about 24 mg/L in Provincetown public-supply wells (Motts and Saines, 1969, fig. 2). The east-to-west decrease in chloride concentrations was attributed by Motts and Saines to the diminishing effects of the ocean on precipitation and the presence of fewer minerals containing chloride in the western bedrock.

The U.S. Environmental Protection Agency 250-mg/L recommended maximum concentration was exceeded in only 10 out of 8,300 analyses (fig. 11)--two samples analyzed from the Chicopee (basin 8), five from the Blackstone (basin 12), one from the Neponset (basin 19b), one from the Weymouth and Weir (basin 19c), and one from Cape Cod (basin 22). Median concentrations are generally less than 50 mg/L, typically from about 3.0 to 33 mg/L. Only two basins have ground water containing median concentrations of 50 mg/L or greater (Appendix 1, p. 51)--the Quinebaug (basin 9), 50 mg/L, and the Mystic (basin 19a), 58.5 mg/L. The five smallest median concentrations are from western Massachusetts--the Hoosic (basin 1a), 2.0 mg/L; the Housatonic (basin 2), 3.0 mg/L; the Deerfield (basin 3), 6.0 mg/L; the Westfield (basin 4), 7.5 mg/L; and the Connecticut (basin 6), 8.0 mg/L.

Sulfate

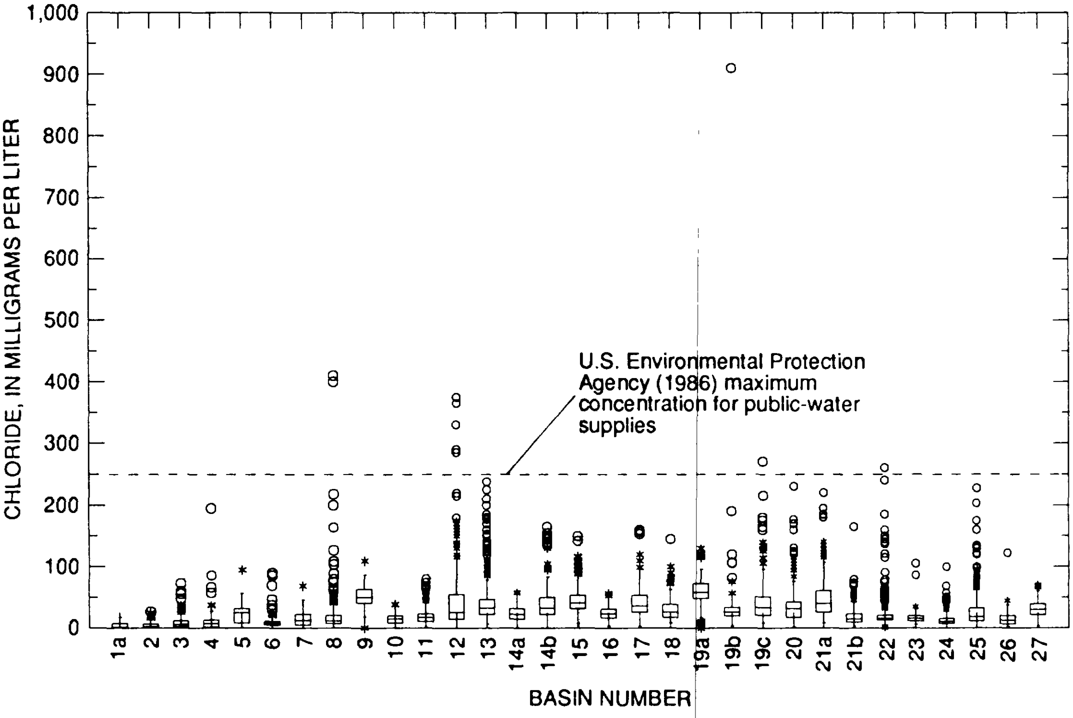
Natural sources of sulfate (Hem, 1985, p. 112-117) in water include the weathering of sulfur-bearing minerals, such as pyrite and gypsum, volcanic discharges to the atmosphere, and biologic and biochemical processes. Human sources include industrial discharges to both streams and the atmosphere and the combustion of fossil fuels, such as coal. The U.S. Environmental Protection Agency (1986) recommends a maximum concentration of 250 mg/L in drinking water to prevent laxative effects. In Massachusetts, the distribution of sulfate in water from public-supply wells is fairly uniform, with concentrations generally from about 10 to 20 mg/L (fig. 12). None of the concentrations exceeded the recommended maximum; however, ground water in four basins have sulfate concentrations greater than 150 mg/L--the Blackstone (basin 12), the Shawsheen (basin 15), the North Coastal (basin 18), and the Taunton (basin 25). The largest median concentrations (Appendix 1, p. 52) are 21 mg/L in the Mystic (basin 19a) and 23 mg/L in the Ipswich (basin 17). The smallest median concentrations are 5 mg/L in the Islands (basin 23) and 6 mg/L in the Farmington (basin 5) and Cape Cod (basin 22).

Nitrogen

Nitrogen is a relatively minor constituent in Massachusetts ground water. The two principal forms in which it is found are nitrate and ammonia (Hem, 1985, p. 124-126). Nitrate is transported readily in water and is stable under a variety of conditions, whereas ammonia is strongly adsorbed on mineral surfaces. Important ground-water sources include poor-quality surface-water infiltration through barnyards, sewage, septic systems, fertilized lawns, golf courses, and crop fields, and nitrogen oxides in the atmosphere resulting from the combustion of fossil fuel. Large concentrations of nitrate or ammonia may be indicative of contamination from agricultural activities and sewage or organic waste (Hem, 1985, p. 124).

Nitrate

The U.S. Environmental Protection Agency (1986) primary drinking-water regulation for nitrate is 10 mg/L as nitrogen (N) because larger concentrations may cause hemoglobin poisoning in infants. Nitrate (fig. 13) does not follow a normal distribution as suggested by the large number of outlying values. Most of the concentrations are less than 1 mg/L and range from about 0.3 to 0.7 mg/L. Only three basins have ground water with concentrations that exceed the 10-mg/L regulation; one analysis each from the Concord and Sudbury (basin 14b) and Shawsheen (basin 15), and three analyses from the Taunton (basin 25). As shown in Appendix 1 (p. 53), all of the analyses are less than 20 mg/L. The Neponset (basin 19b) is the only basin with a median concentration in water greater than 1.0 mg/L (1.2 mg/L). The smallest median concentrations are 0.05 mg/L in water from the Farmington (basin 5), and 0.1 mg/L in



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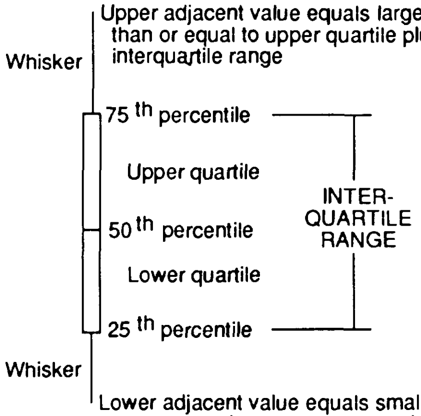


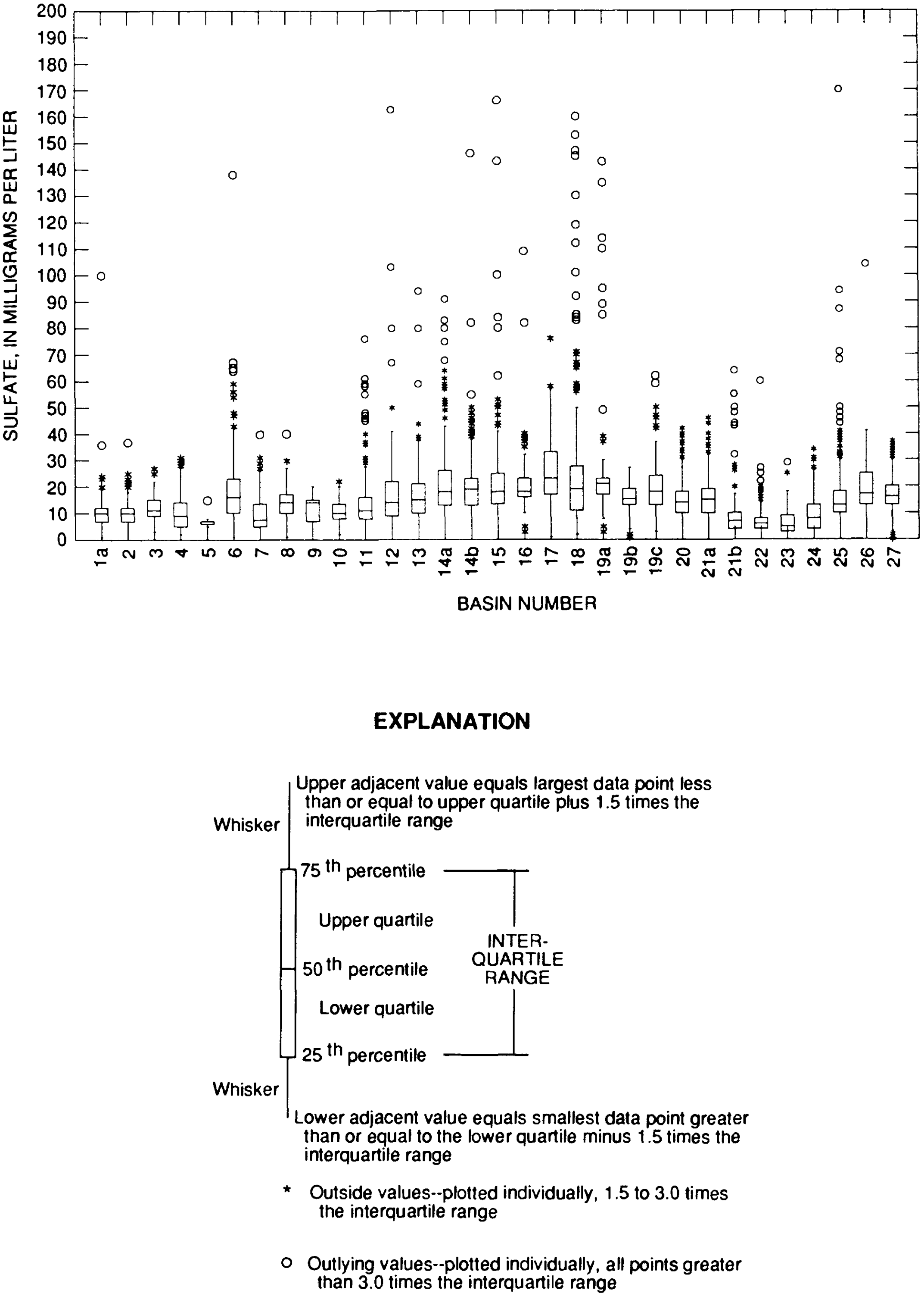
Upper adjacent value equals largest data point less than or equal to upper quartile plus 1.5 times the interquartile range

Lower adjacent value equals smallest data point greater than or equal to the lower quartile minus 1.5 times the interquartile range

* Outside values--plotted individually, 1.5 to 3.0 times the interquartile range

○ Outlying values--plotted individually, all points greater than 3.0 times the interquartile range

Figure 11. Distribution of chloride concentrations in water from public-supply wells.



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Lower adjacent value equals smallest data point greater than or equal to the lower quartile minus 1.5 times the interquartile range

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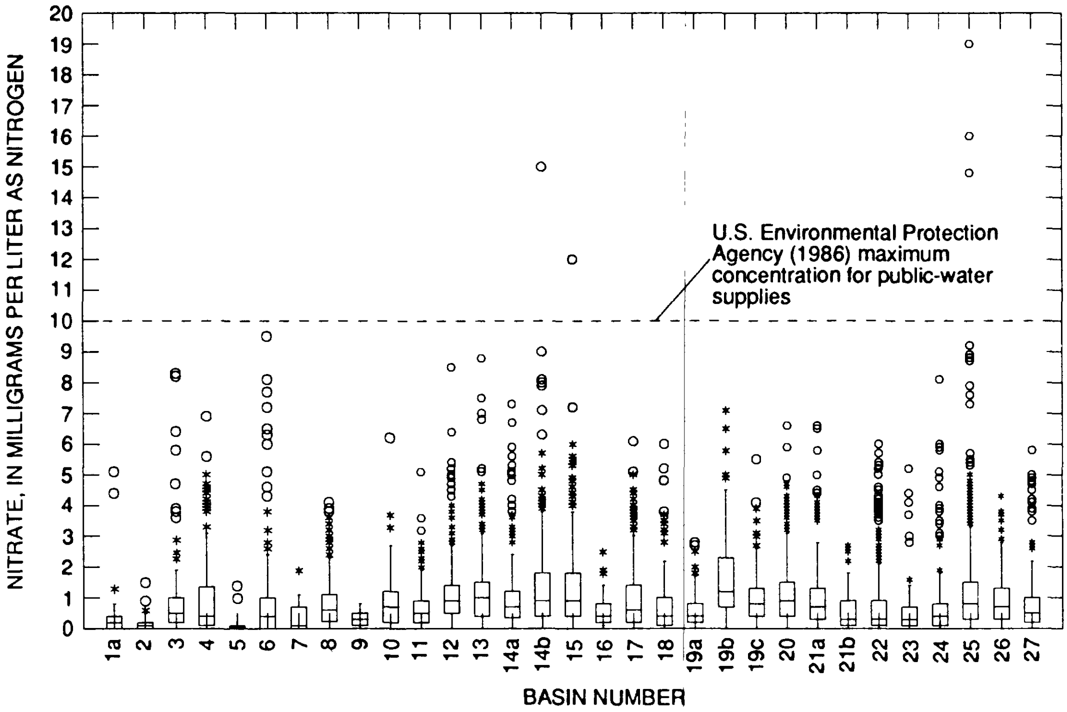
Figure 12. Distribution of sulfate concentrations in water from public-supply wells.



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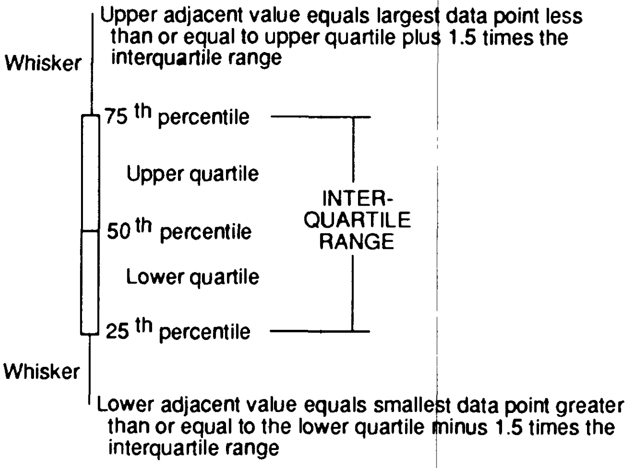


Upper adjacent value equals largest data point less than or equal to upper quartile plus 1.5 times the interquartile range

Lower adjacent value equals smallest data point greater than or equal to the lower quartile minus 1.5 times the interquartile range

* Outside values--plotted individually, 1.5 to 3.0 times the interquartile range

o Outlying values--plotted individually, all points greater than 3.0 times the interquartile range

Figure 13. Distribution of nitrate concentrations in water from public-supply wells.

water from the Housatonic (basin 2) and Millers (basin 7).

Ammonia

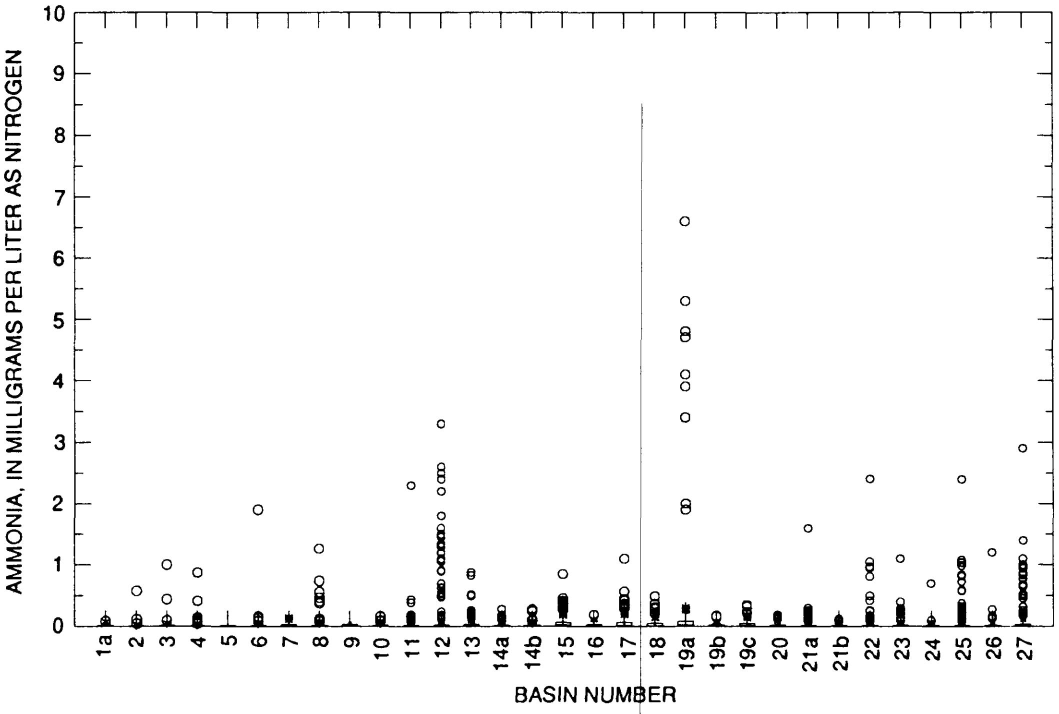
Boxplots for ammonia (fig. 14) are nearly impossible to construct because most of the concentrations are less than the detection limit (0.02 mg/L). Figure 14 does show the distribution of extreme values for the 31 Commonwealth planning basins and subbasins. Almost one-half of the basins have some analyses with concentrations of 1 mg/L or greater; two basins have several, the Blackstone (basin 12) and Mystic (basin 19a). All of the basins (Appendix 1, p. 55) have water with median concentrations less than 0.3 mg/L. The largest 75th-percentile concentrations, probably more indicative of problem areas, are 0.07 mg/L in water from the Shawsheen (basin 15) and Ipswich (basin 17) and 0.09 mg/L in water from the Mystic (basin 19a).

Iron

Although iron is the second most abundant metallic element in the Earth's crust, concentrations in water tend to be small because it is not generally soluble. A major cause of solution of iron in Massachusetts ground water is infiltration of surface water through reducing organic material, such as peat (Gay and Frimpter, 1985, p. 18-23). The U.S. Environmental Protection Agency (1986) secondary drinking-water regulation for iron is 0.3 mg/L in public-water supplies because it imparts a rusty metallic taste and forms precipitates that stain laundry and plumbing fixtures yellow to rusty brown. The use of boxplots to illustrate the distribution of metals is impractical here because most values are near or less than the detection limit (0.03 mg/L). The distribution of the 75th percentiles for iron concentrations in ground water from the 31 Commonwealth planning basins and subbasins is shown in figure 15. Two basins stand out among the others with 75th percentiles significantly larger than the 0.3-mg/L U.S. Environmental Protection Agency maximum concentration; the Quinebaug (basin 9) and Buzzards Bay (basin 24) have values exceeding 1 mg/L. The 75th-percentile concentration exceeds 0.3 mg/L in water from four other basins--the Shawsheen (basin 15), the Parker (basin 16), the Ipswich (basin 17), and the North Coastal (basin 18). Typical iron concentrations are from about 0.03 to 0.05 mg/L. The largest median concentration (Appendix 1, p. 57) of 2 mg/L is in water from the Quinebaug (basin 9). The smallest median concentrations, less than the detection limit, are in water from the Housatonic (basin 2) and Farmington (basin 5). Except for the Farmington (basin 5) and the Islands (basin 23), all of the basins have some analyses with iron concentrations exceeding 0.3 mg/L.

Manganese

The chemistry of manganese in water is similar to that of iron in that both metals participate in oxidation-reduction processes in weathering environments (Hem, 1985, p. 84-89). Manganese is a significant constituent of basalt, many olivines, and of pyroxenes and amphiboles. As with iron, concentrations in ground water are generally small. The major source for Massachusetts ground water is infiltration of surface water through anoxic organic material (Frimpter and Gay, 1979). Manganese is undesirable in water supplies largely because of taste and because it stains laundry and fixtures black or grey. The U.S. Environmental Protection Agency (1986) has established a maximum concentration of 0.05 mg/L for domestic supplies. Only water from six basins (fig. 16) have 75th-percentile concentrations less than 0.05 mg/L--the Hoosic (basin 1a), Housatonic (basin 2), Deerfield (basin 3), Westfield (basin 4), Farmington (basin 5), and Islands (basin 23). The 75th-percentile concentration for water from the Weymouth and Weir (basin 19c) is 1.1 mg/L (Appendix 1, p. 58), significantly larger than in the other basins. Typical concentrations range from about 0.01 to 0.1 mg/L. The largest median concentrations are 0.20 mg/L in water from the Shawsheen (basin 15) and Ipswich (basin 17) and 0.28 mg/L in water from the Weymouth and Weir (basin 19c). The smallest median concentrations are in ground water from western Massachusetts--less than the detection limit (0.02 mg/L) in water from the Hoosic (basin 1a), Housatonic (basin 2), Deerfield (basin 3), Westfield (basin 4), and Farmington (basin 5).



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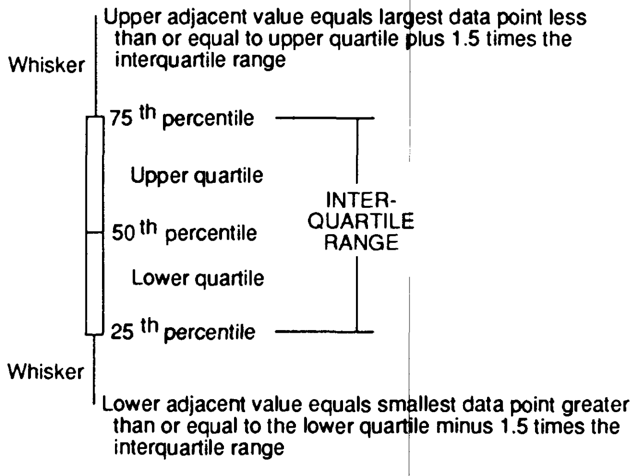

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○ Outlying values--plotted individually, all points greater than 3.0 times the interquartile range

Figure 14. Distribution of ammonia concentrations in water from public-supply wells.

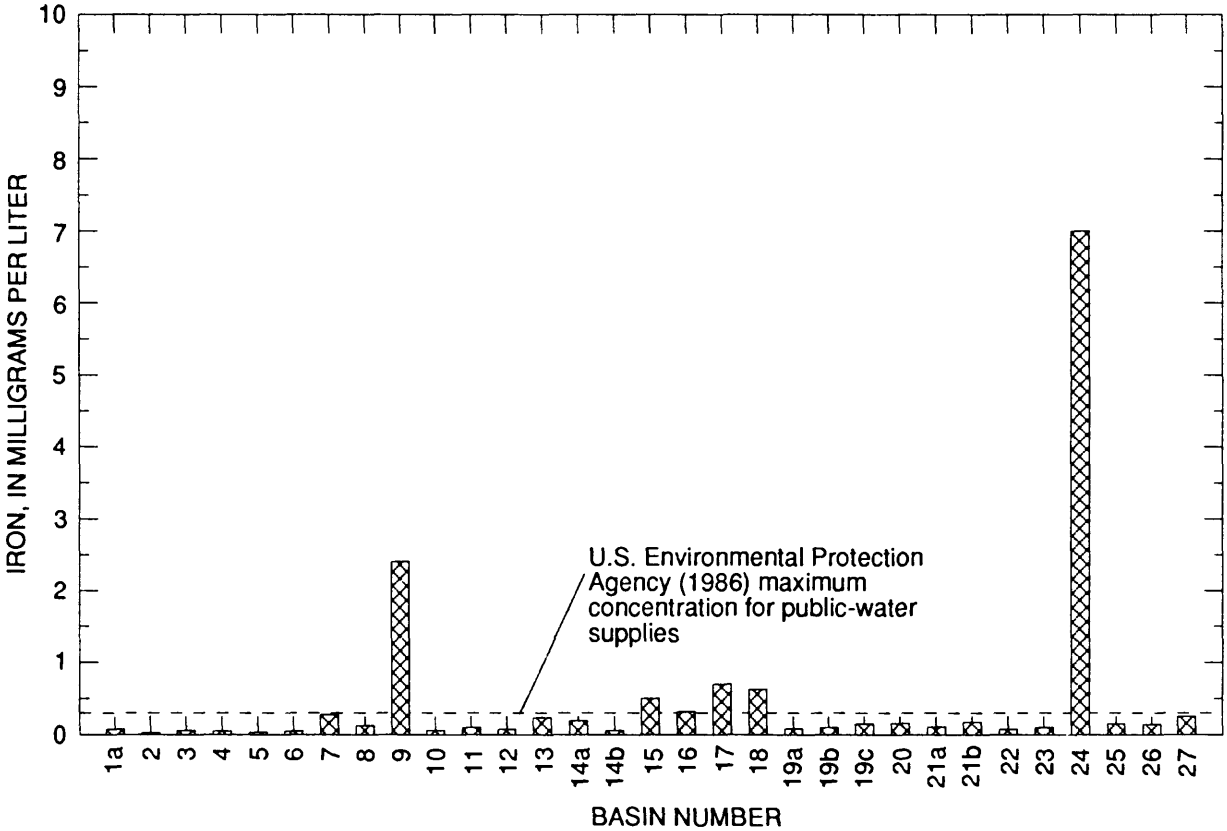

Figure 15. 75th-percentile concentrations for ironin water from public-supply wells.

Copper

Massachusetts ground water contains very little natural copper. Copper is used extensively for industrial and domestic purposes. Acidic water may dissolve copper from brass, bronze, and copper water pipes and pumps, and copper salts are sometimes added to ponds and water-supply reservoirs to limit algal growth (Hem, 1985, p. 141). The largest 75th-percentile concentrations of copper in ground water in Massachusetts (fig. 17 and Appendix 1, p. 56) are 0.215 mg/L in the Millers (basin 7) and 0.14 mg/L in the North Coastal (basin 18). Typical concentrations in Massachusetts public-supply wells are about 0.02 to 0.03 mg/L, which are larger than normal concentrations of less than 0.01 mg/L (Hem, 1985, p. 141). The largest median concentrations are 0.04 mg/L in water from the Assabet (basin 14a), Shawsheen (basin 15), and South Coastal Shore (basin 21b), and 0.05 mg/L in water from the North Coastal (basin 18). The smallest median concentrations are less than the detection limit (0.02 mg/L) in the Hoosic (basin 1a) and Housatonic (basin 2) and 0.01 mg/L in water from the Westfield (basin 4) and Connecticut (basin 6).

Factors Affecting Water Quality

Geologic

Geology affects inorganic water quality in Massachusetts by affecting pH, specific conductance, and concentrations of dissolved solids and major cations and anions. Major-ion data are presented graphically as a trilinear diagram in figure 18 to show the contribution of major cations and anions to the total ionic content of the water. Scales along the sides of the diagram indicate the percent concentration of each major ion, in milliequivalents per liter. Cations are shown in the left triangle, and anions are shown in the right triangle. The central diamond combines the cations with the anions. Small and large median concentrations

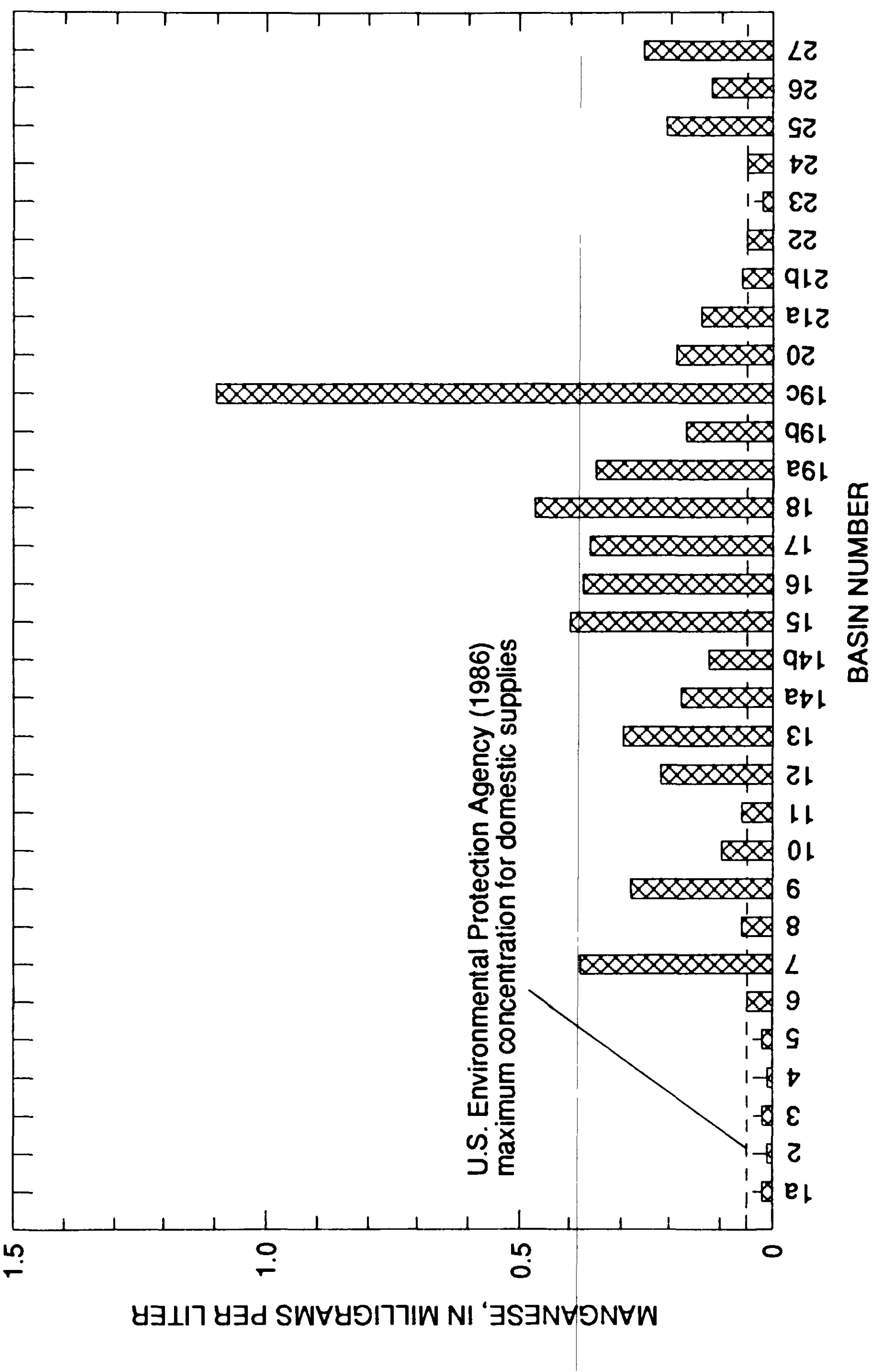

Figure 16. 75th-percentile concentrations for manganese in water from public-supply wells.

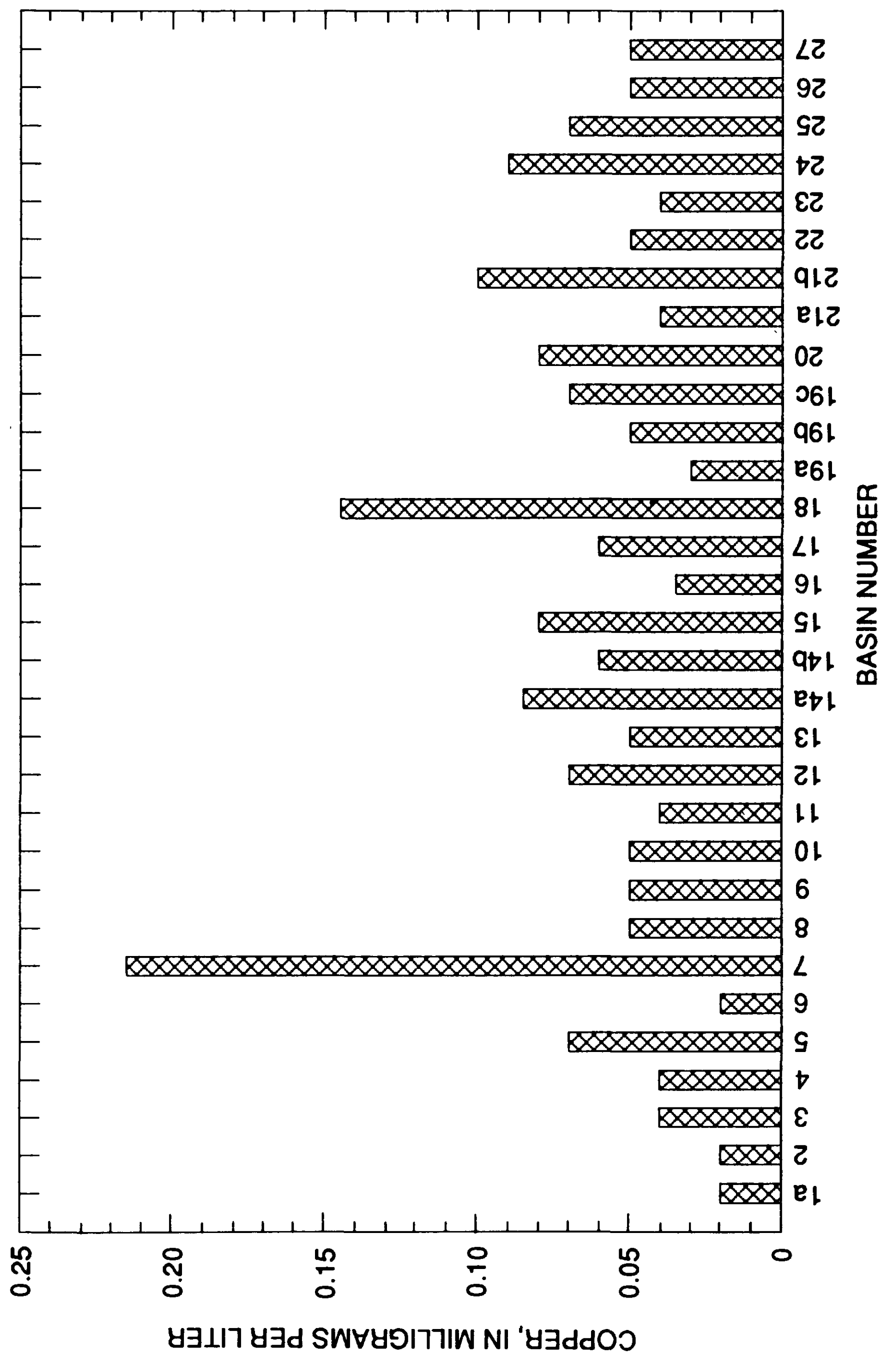

Figure 17. 75th-percentile concentrations for copper in water from public-supply wells.

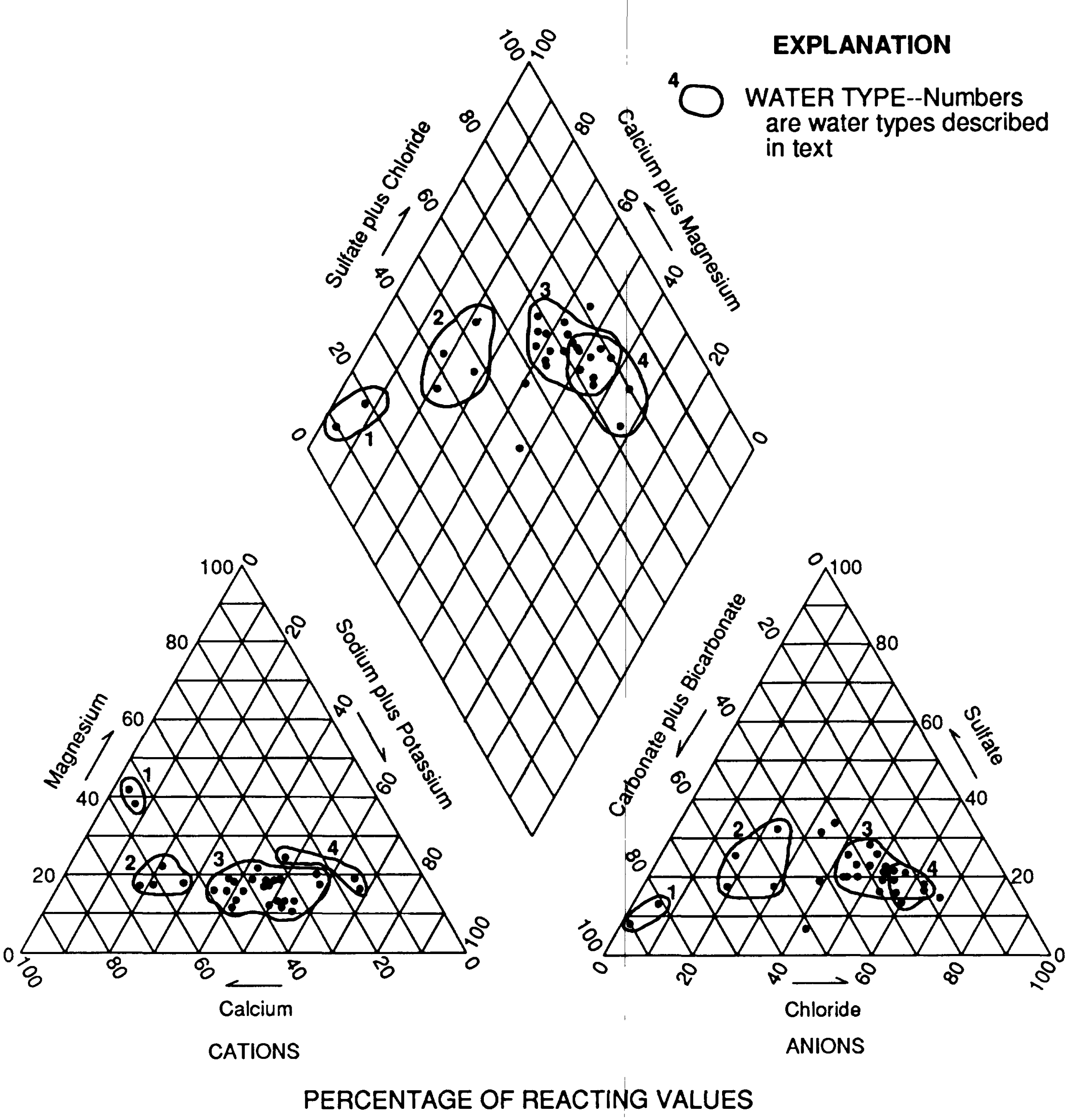

Figure 18. Distribution of median concentrations for major ions in water from public-supply wells (numbers are water-resources planning basin numbers shown in figure 1).

for the various constituents as discussed in this report are summarized in table 2. Water can be catagorized into four major types (fig. 19), based on ion ratios, pH, and specific conductance. The few isolated samples that do not plot with the groups may represent mixtures of the four water types. These four major water types compare and contrast with the hydrochemical zones of Motts and Saines (1969). The Hoosic (basin 1a) and Housatonic (basin 2) are water type 1 (calcium and magnesium bicarbonate type). They have very large ratios of calcium and magnesium to sodium, and bicarbonate to sulfate and chloride (fig. 18), as well as pH greater than 7.0 (table 2). These observations are consistent with Motts and Saines (1969) hydrochemical zone 2 and with the Taconic-Berkshire carbonate rocks shown in

Table 2. *Water-quality summary data for Massachusetts water-resources planning basins*

[Numbers in parentheses represent values which are considered small or large as discussed in the text. pH given in standard units; specific conductance in microsiemens per centimeter at 25 degrees Celsius; all other concentrations are given in milligrams per liter. +, indicates concentrations equals or exceeds first value; o, indicates concentration is less than or equal to the second value; no entry, indicates concentration is between first and second value]

Basin number (fig. 1)	pH, median (7.0, 6.1)	Specific conductance (250, 95)	Calcium, median (20, 4.6)	Magnesium, median (7.9, 1.5)	Sodium, median (20, 5)	Potassium, median (2.95, 0.6)	Bicarbonate, median (79,9)	Chloride, median (50, 8)	Sulfate, median (21, 6)	Nitrate nitrogen, median (1.2, 0.10)	Ammonia, 75th percentile (0.07)	Iron, 75th percentile (1.0, 0.03)	Manganese, median (0.20, 0.02)	Copper, median (0.04, 0.02)	Agricultural land use
01A	+	+	+	+	o		+	o					o	o	
02	+			+	o		+	o		o		o	o	o	
03		o			o			o					o	o	yes
04					o	o		o					o	o	yes
05	+								o	o			o	o	
06	+				o			o					o	o	yes
07				o						o					yes
08													o	o	yes
09					+			+				+			
10														o	
11													o	o	
12															
13														o	yes
14A														+	yes
14B			+											o	yes
15					+						+		+	+	yes
16		+	+											o	yes
17		+	+		+				+		+		+	o	yes
18														+	yes
19A		+	+		+	+		+	+		+			o	
19B										+				o	
19C					+								+	o	
20															
21A					+								o	o	yes
21B			o											+	yes
22	o	o	o				o		o				o		yes
23		o	o	o					o				o	o	yes
24	o	o	o									+	o		yes
25															yes
26															yes
27														o	yes

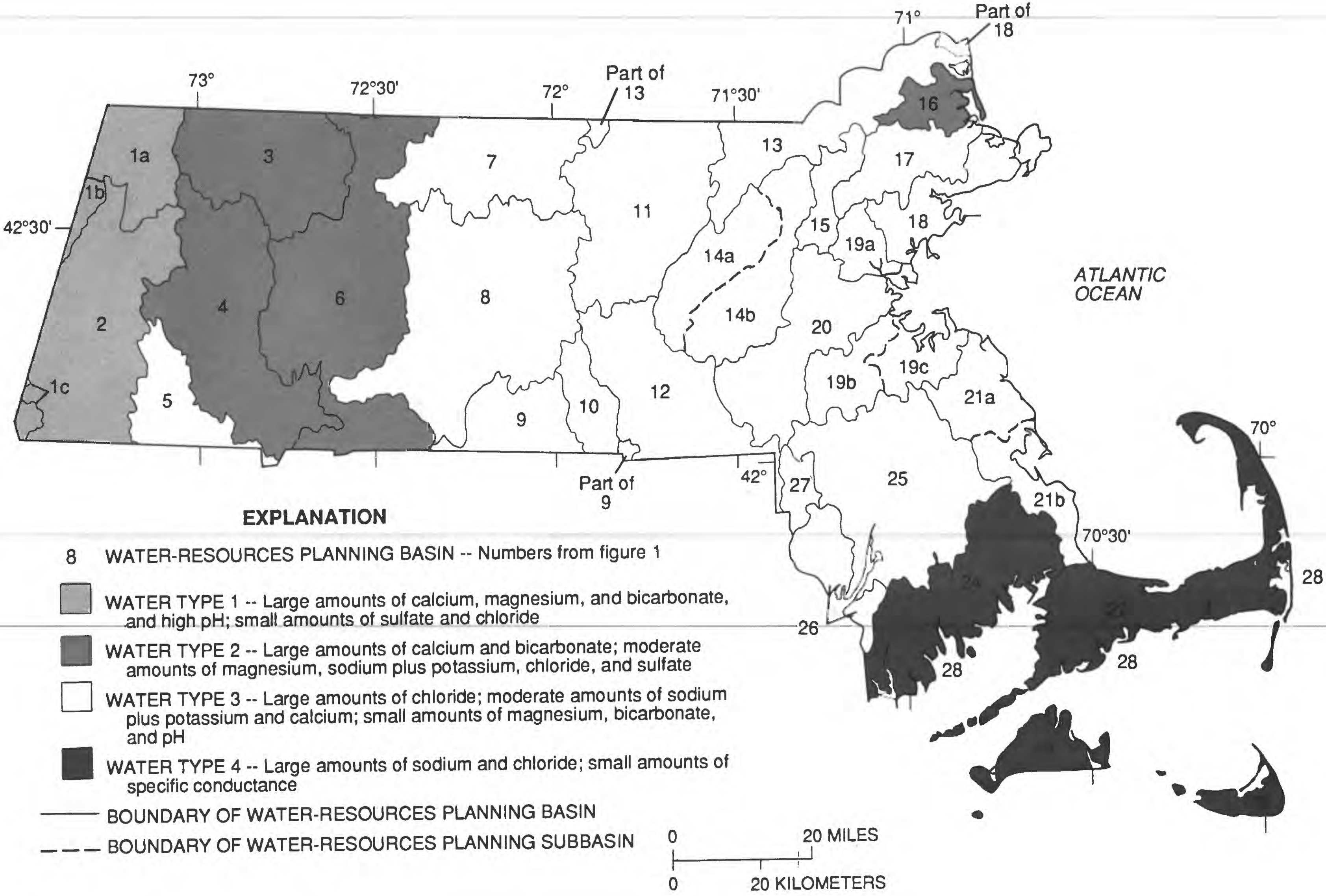

Figure 19. Water types in Massachusetts based on ion ratios, pH, and specific conductance.

figure 3.

Water type 2 is present in the Deerfield (basin 3), Westfield (basin 4), Connecticut (basin 6), and Parker (basin 16), where calcium and bicarbonate are the dominant ions--about 75 and 50 percent of total ions, respectively (fig. 18). The Triassic lowland in the Connecticut (basin 6) is overlain by Pleistocene sand and gravel and lake deposits composed of clay, silt, and fine-grained sand (Walker and Caswell, 1977). These Pleistocene sediments are largely derived from the underlying Triassic bedrock, which may contribute calcium and bicarbonate to the ground water (Motts and Saines, 1969, hydrochemical zone 2). Water from the Deerfield (basin 3) and Westfield (basin 4) reflects the effects of the Connecticut Valley sediments because most of the public-supply wells in these basins are in the Triassic lowland. Water from the Parker (basin 16) drains amphiobolite bedrock and reflects Motts and Saines (1969) alkaline hydrochemical zone 4. Water from the Ipswich (basin 17), however, does not appear to fit into the Motts and Saines alkaline hydrochemical zone 4.

Water type 3 is present in most of the basins underlain by igneous and metamorphic rock (Motts and Saines, 1969, hydrochemical zone 1) and has about equal concentrations of sodium plus potassium and calcium (water type 3), with smaller concentrations of magnesium and bicarbonate and larger concentrations of chloride than water types 1 or 2 (fig. 18). Water from the Chicopee (basin 8) and Narragansett Bay and Mt. Hope Bay Shore (basin 26) have slightly higher sulfate concentrations than other basins in water type 3 (fig. 18). Water from the Farmington (basin 5) has larger concentrations of bicarbonate at the expense of sulfate. The South Coastal area (basins 21a and 21b) has water with slightly larger sodium concentrations (table 2 and fig. 18). The minor variations in cation and anion ratios shown in figure 18 probably reflect the variation in local geology across the Commonwealth, which ranges from granitic rocks rich in sodium and potassium to gabbros and basalts rich in calcium, magnesium, and iron. There was no hydrochemical difference shown between the areas underlain by igneous and metamorphic rocks and the Paleozoic sediments (fig. 3). Larger concentrations of sulfate may indicate the presence of sulfide minerals; the increased sodium-to-cation ratio suggests ocean effects (Motts and Saines, 1969, p. 23-36), either from the atmosphere or from saltwater intrusion. Atmospherically derived sodium probably would cause smaller increases than saltwater intrusion.

Water type 4 is present in Cape Cod (basin 22) the Islands (basin 23), Buzzards Bay (basin 24), and is included in Motts and Saines' (1969) acidic hydrochemical zone 1. The pH values for ground water from Cape Cod and Buzzards Bay are the lowest in the Commonwealth. These three basins have water with the smallest specific-conductance values (table 2) in the Commonwealth, reflecting the smallest dissolved-solids concentrations. Sodium and chloride are the dominant ions in water from Cape Cod (basin 22) and the Islands (basin 23) (fig. 18). The median specific-conductance values (dissolved-solids concentrations) in water from Cape Cod (basin 22), the Islands (basin 23), and Buzzards Bay (basin 24) are among the smallest (about 100 µS/cm). Median chloride concentrations in water from public-supply wells (mostly from about 15 to 20 mg/L) range from 12 mg/L in water from Bourne public-supply wells, located in the western part of Cape Cod, to 91 mg/L in water from North Truro wells, which are located near the northern tip of Cape Cod and affected by saltwater intrusion. The Cape Cod area is underlain by thick, stratified-drift deposits composed primarily of quartz and feldspar sand containing virtually no carbonate and sulfate. The major source of dissolved solids is the ocean, which supplies sodium and chloride through atmospheric precipitation and in some places through saltwater intrusion. Buzzards Bay (basin 24) is slightly less exposed to the ocean than Cape Cod (basin 22) and the Islands (basin 23) and, therefore, receives less sodium and chloride.

Large iron and manganese concentrations present a major contamination problem to ground-water supplies in Massachusetts. Gay and Frimpter (1985) have attributed large iron and manganese concentrations to infiltration of surface water through organic streambed deposits, which creates reducing conditions that dissolve these metals from the aquifers. Motts and Saines (1969, p. 41-45) also suggest that iron and manganese concentrations in water increase with depth in aquifers with crystalline basement rocks (acidic hydrochemical zone 1). The area west of the Connecticut River basin (fig. 20) in Massachusetts has water with the smallest iron and manganese concentrations (table 2), which may be because the wells are generally screened in sediments derived from carbonate rock, which is a poorer source of iron and manganese than crystalline rock and alluvial plain deposits. The largest iron and manganese concentrations, whose 75th percentile exceeds U.S. Environmental Protection Agency (1986) secondary drinking-water regulations, are in water from the Quinebaug (basin 9), Shawsheen (basin 15), Ipswich (basin 17), and Buzzards Bay (basin 24) where the wells may be screened in marshy areas near the flood plains of rivers where surface water infiltrates through poorly oxygenated deposits.

Anthropogenic

Anthropogenic (human) factors that affect inorganic water quality are nearly ubiquitous and are illustrated by the nearly statewide increase in chloride concentrations, which result from the use of sodium chloride and calcium chloride on the roads during winter; and the nitrate and ammonia concentrations, which are caused by leaching from fertilizers and from septic systems (Hem, 1985, p. 125-126). The effects of highway deicing salts are characterized primarily by increased sodium and chloride concentrations in water from public-supply wells (fig. 21). The Quinebaug (basin 9) has ground water with the largest median chloride-anion ratio of any of the basins in Massachusetts (fig. 18) as well as large sodium and chloride concentrations (table 2), which suggests that deicing salts may present a problem in the basin. The Shawsheen (basin 15), Ipswich (basin 17), Mystic (basin 19a), Weymouth and Weir (basin 19c), and North and South Rivers (basin 21a) also have ground water with large sodium and chloride concentrations (table 2). Cape Cod (basin 22) and the Islands (basin 23) have water with large sodium-cation and chloride-anion ratios (fig. 18), but they also have water with small median specific conductance, which suggests that the chloride in these basins is due primarily to natural sources.

Other anthropogenic factors that affect inorganic water quality are more subtle and more difficult to distinguish individually than the use of highway deicing salts. The use of fertilizers may increase nitrate and ammonia concentrations in water from an agricultural basin. Two agricultural basins have large concentrations of nitrate or ammonia (table 2), and one basin has small nitrate concentrations. The two agricultural basins with large nitrate or ammonia concentrations (fig. 22), the Shawsheen (basin 15) and Ipswich (basin 17), are also urban and industrialized; therefore, an agricultural source cannot be assumed without additional investigation. All of the basins with large nitrate or ammonia concentrations, including the Mystic (basin 19a) and Neponset (basin 19b), are urban basins in the metropolitan Boston area. All the basins with small nitrate and ammonia concentrations are rural, suggesting that large median nitrate and ammonia concentrations are more related to urbanization than to agriculture for Massachusetts public-water supplies.

Nitrate concentrations in ground water have been related to housing density in 18 sample areas on Cape Cod (Persky, 1986). Nitrate contamination of ground water from septic systems is a major concern on Cape Cod, even though the basin now has one of the smallest median concentrations in the Commonwealth (table 2). Ground-water supplies generally are developed in protected areas away from potential sources of contamination; consequently, the use of public-supply wells to evaluate regional water quality may be biased. The results may indicate how good the water may be in the basin, but it may not indicate how poor the water may be. For example, many domestic wells in rural areas may have large nitrate concentrations. If these protected water supplies have degraded, however, then this degradation may be an indication of more severe problems elsewhere in the basin. Unfortunately, once they become contaminated and are closed down, they are no longer sampled.

Each of the inorganic water-quality constituents were compared to population density (table 1) by calculating Kendall Tau-B correlation coefficients. There were statistically significant correlations at the 0.01 confidence

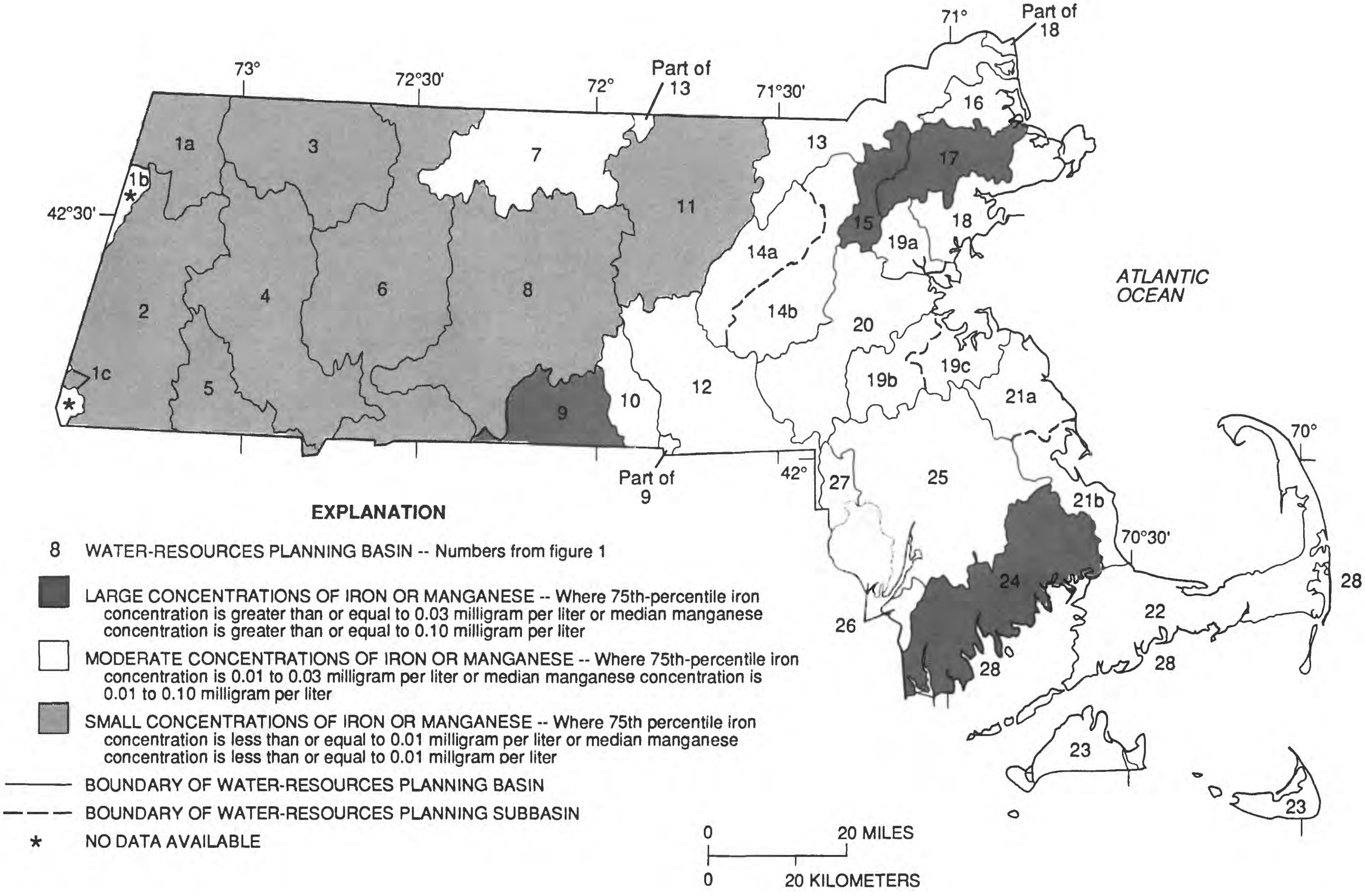

Figure 20. Basins with large or small 75th-percentile concentrations of iron or manganese.

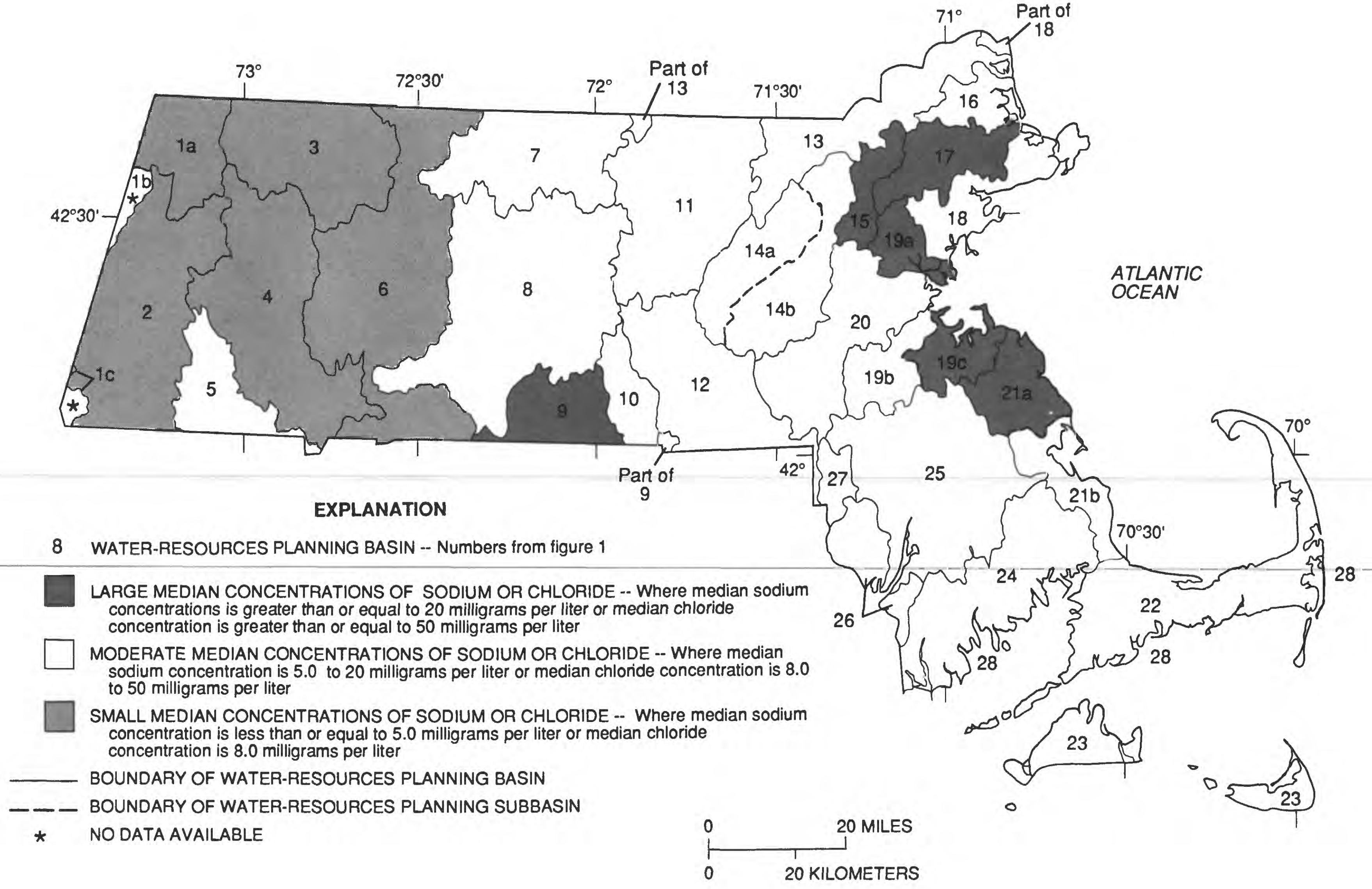

Figure 21. Basins with large or small median concentrations of sodium or chloride.

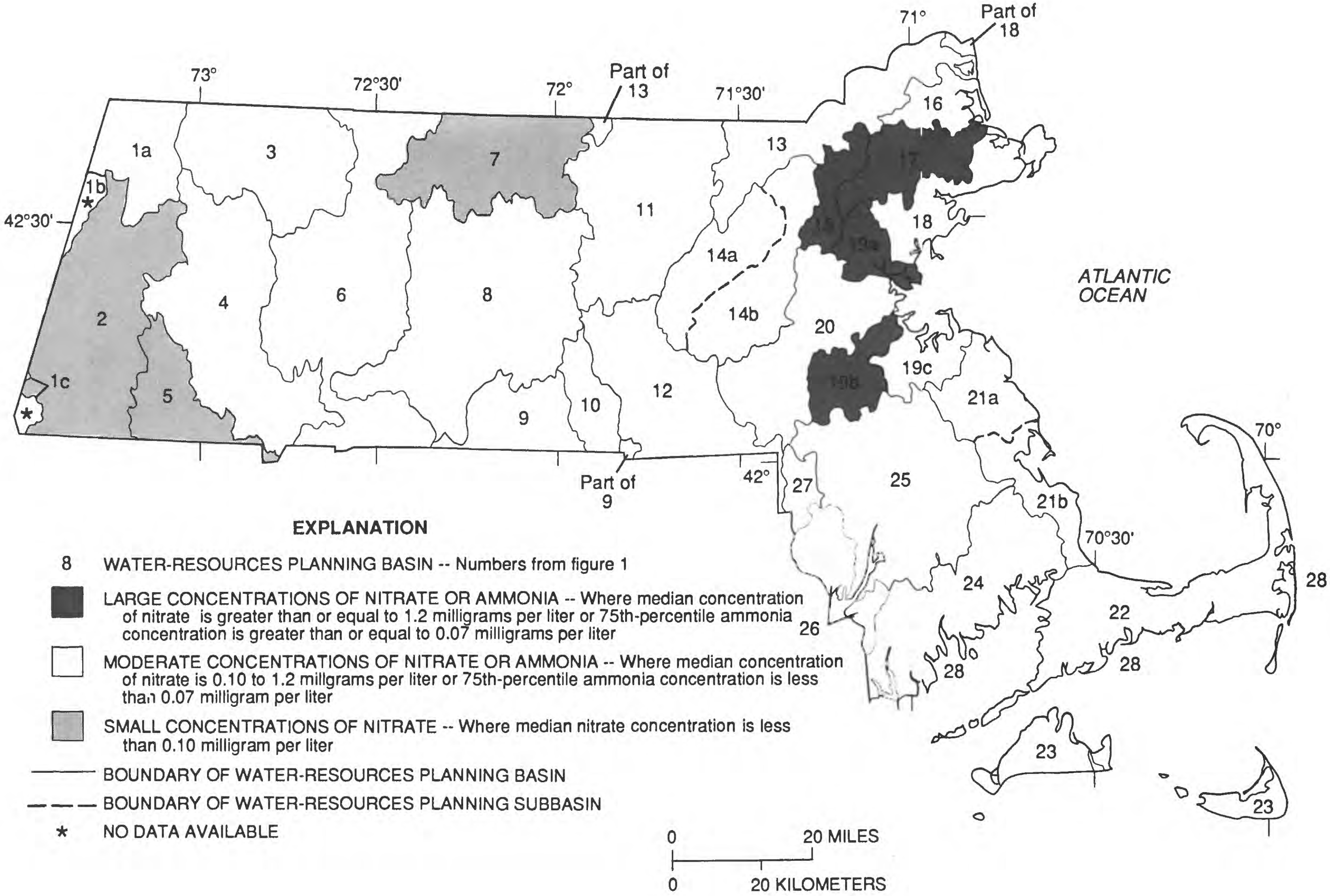

Figure 22. Basins with large or small median concentrations of nitrate or ammonia.

level for specific conductance and concentrations of sodium, chloride, sulfate, manganese, nitrate, and ammonia. With the exception of manganese, each of these constituents commonly are associated with urban and industrial sources, such as septic waste, deicing salt, industrial waste, and the burning of fossil fuels. Septic wastes and deicing salts are also found in nonindustrial rural areas as well; however, their effects appear to be directly related to population density. The manganese correlation may be caused by infiltration of poor-quality surface water through organic-compound-bearing sediments. Although constituent concentrations may not be at unacceptable levels now, further degradation of the water supply may cause problems in the future.

Effects of Water Treatment and Distribution Systems

The annual chemical analysis of water from public-supply wells is the only systematic sampling of ground-water quality in Massachusetts. To be representative of ground-water quality rather than of water supplied, the data used in this investigation were limited to samples collected at the wellhead. As described in the "Methods" section, analyses of water identified as having been collected from distribution systems or after treatment were deleted from the data base. Several observations of the final data base, however, reveal the effects of treatment on what was expected to be representative analyses of untreated ground water.

Analyses of the data-base samples showed the presence of copper, potassium, and chloroform in concentrations greater than normally found in ground water in Massachusetts, confirming the effects of water treatment and the distribution system on water quality. Identified copper mineralizations in Massachusetts have never been large enough for mining, and only a few veins containing chalcopyrite, a copper-sulfide ore, have been prospected. Samples of ground water analyzed by Frimpter and Gay (1979) from Cape Cod contained no copper concentrations within the detectable limits of the laboratory method of 0.05 µg/L. Copper, however, was detected in Cape Cod public supplies in concentrations as large as 13 mg/L (Appendix 1, p. 56). These large concentrations are attributed to copper and copper alloys in pump parts, the distribution system, and domestic plumbing.

Potassium commonly is not found in the ground water of Massachusetts in concentrations exceeding 5 mg/L (Frimpter, 1988). Under natural conditions, when the sodium concentration exceeds about 10 mg/L, the potassium concentration is generally one-tenth to one-half that of sodium (Hem, 1985, p. 105). However, concentrations in excess of 5 mg/L and in excess of sodium concentrations were found in the analyses used in this study. Potassium concentrations exceeded sodium concentrations in 10 analyses of public-supply water from the Blackstone (basin 12). Potassium hydroxide and sodium hydroxide are used to increase the pH of acidic water to reduce corrosion of pipes and fixtures in distribution systems and plumbing. Commonly, the hydroxides are added to the water supply immediately after the water is pumped from the well. Potassium hydroxide is preferred in those areas where the addition of sodium is undesired. The correlation of potassium and pH for the Blackstone (basin 12) shows a strong relation at potassium concentrations greater than 5 mg/L (fig. 23). Also, the towns of Grafton and Millbury, where these concentrations were observed, inject potassium hydroxide into wells to increase the pH of their water supplies and to prevent corrosion of their pumps.

Another possible source of potassium is fertilizer, but the element is strongly sorbed to clay in the soil, and concentrations in ground water generally do not become large even in agricultural areas. If fertilizer were the source of potassium, the large concentrations would be associated with the more soluble and persistent constituent nitrate. There is no indication of such a relation, and fertilizer is not indicated as a source of potassium in the public-supply-well data base. Although sodium hydroxide is used for pH control, there are so many other sources of sodium that the presence of large sodium concentrations is not diagnostic.

The close correlation between chloroform concentrations and chlorination (fig. 24) is another strong indicator that the samples represented in the public-supply-well data base

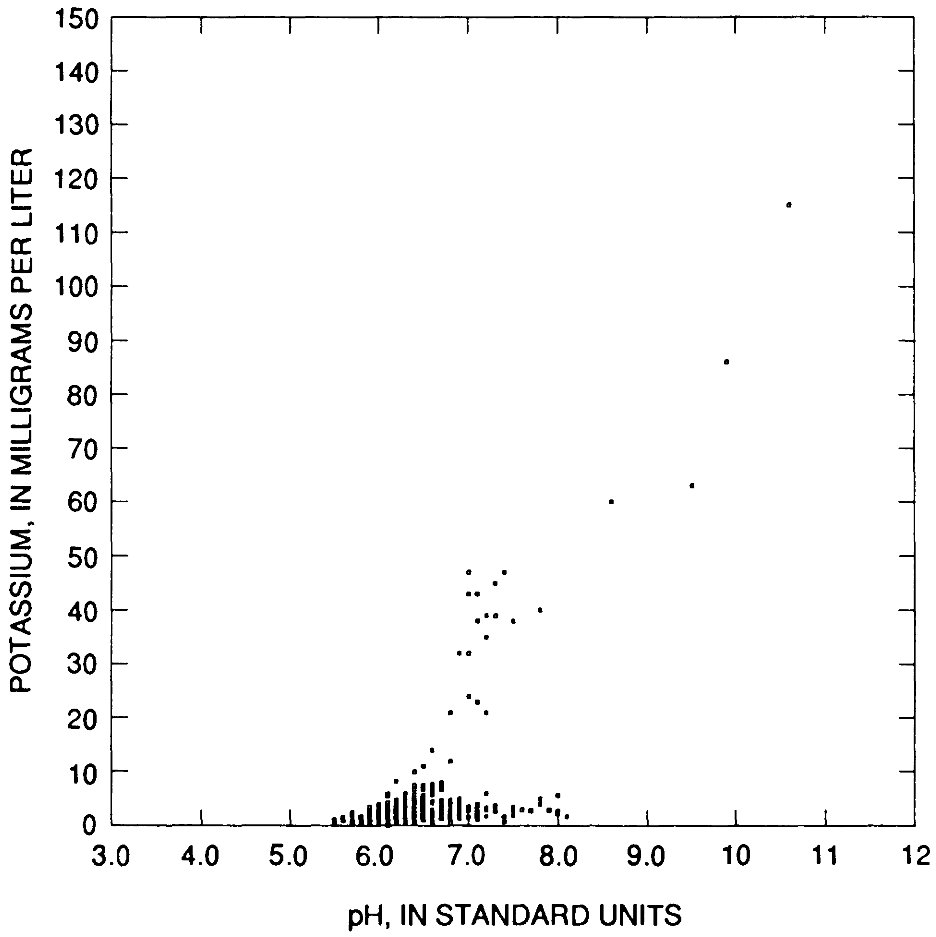

Figure 23. Relation of potassium concentration to pH in water from Blackstone water-resources planning basin.

may be affected by water treatment. Analyses for organic constituents collected during 1984-88 from ground-water and surface-water sources, treated and untreated, were used in this correlation analysis. Even though the samples were collected before treatment, they strongly correlate with the presence of chloroform and chlorination of the supply. There is, therefore, a strong possibility that chlorination of water supplies, including ground water, produces chloroform in the water. Whether the detected chloroform could be derived directly from chlorinated water in the water-supply system or from ground water recharged by septic systems at homes served by chlorinated water is unknown.

Other effects of water treatment and distribution systems may be more subtle or undetected in the available data. The presence of copper, potassium, and chloroform in water samples collected at the wellhead before treatment suggests flaws in the assumptions about the representativeness of the samples. Possibly, the samples were not collected in accordance with their labeling and are actually samples collected from the distribution system after treatment; however it is unlikely that a large number of samples could have been labeled so erroneously. Another possibility is that reverse flow within the distribution system could have allowed treated water from the system to flow backward toward and even into the well.

Generally, backflow is prevented by check

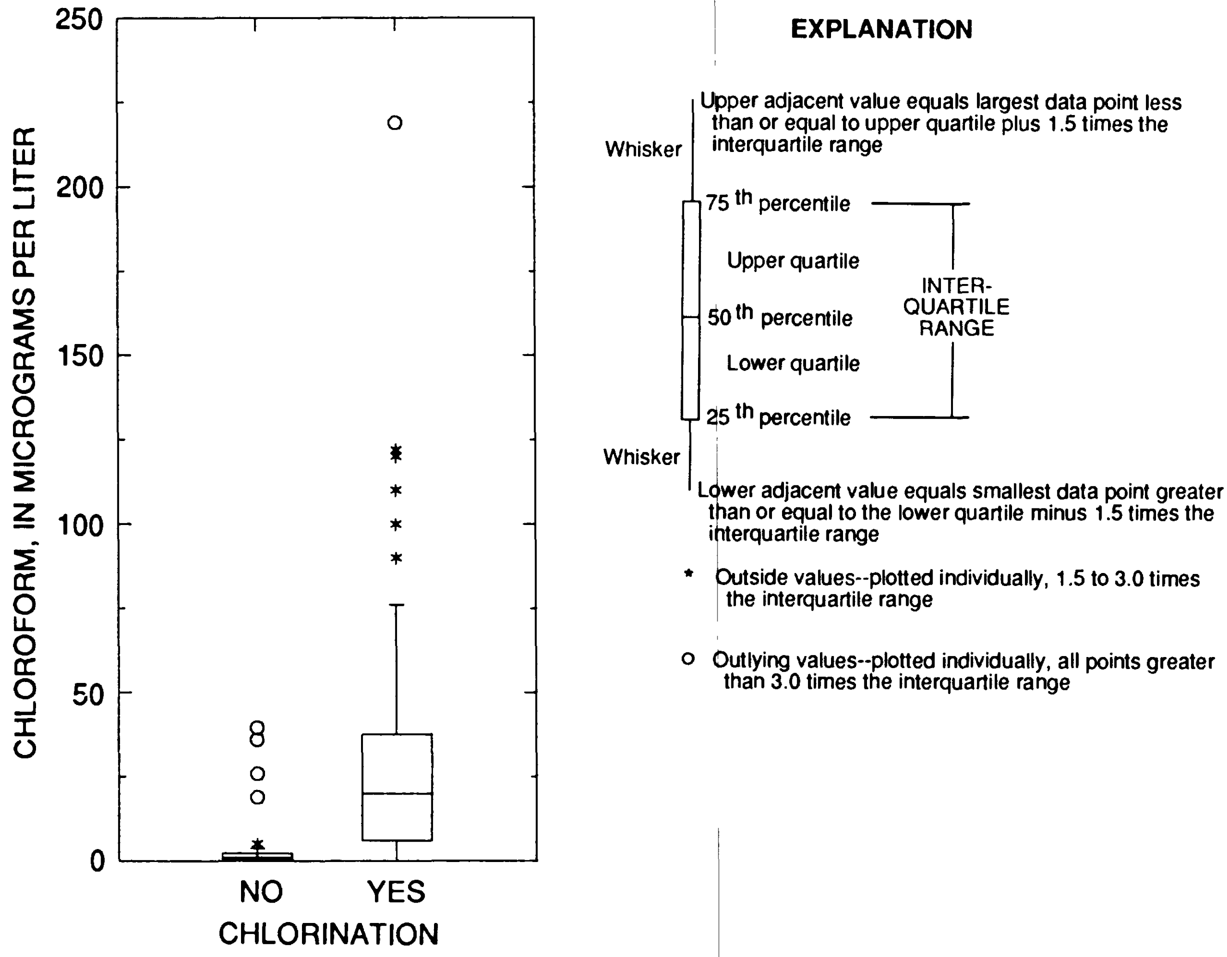

Figure 24. Relation of chloroform concentration to use of chlorination in public-water supplies..

valves, which allow water to flow into the system when the well is on but close and prevent flow from the system into the well when the pump is off. These are automatic, pressure-activated, mechanical valves that can leak. A small leak can allow backflow sufficient to account for constituent occurrences between the well and the treatment facility. Public-supply wells commonly are not pumped for periods of 12 hours or more. Where the treatment equipment is a few feet downstream of the point of sampling, a small check-value leak might be sufficient to cause the observed effect on water samples. One such reverse seepage was discovered in Wellfleet, on Cape Cod, where pH was 8.0 (about the same as in the distribution system) when initially sampled at the wellhead 1 minute after initiation of pumping but changed to 6.1 after the well was pumped for about 10 minutes (M.H. Frimpter, U.S. Geological Survey, oral commun., 1989). Because this phenomenon may be common, water samples intended to represent ground water prior to treatment might best be collected after sufficient pumping has flushed all backflow water into the distribution system.

Water-Quality Trends

The seasonal Kendall test (Hirsch and others, 1982) was used to detect time trends for selected constituents in each of the 31 basins and subbasins. Results, listed in table 3, are somewhat limited because the test was applied to median annual concentrations in water from each basin instead of from individual wells. This approach obscures local trends, but it does indicate general basin tendencies.

The level of statistical significance for the test (PROB) is the probability of error in rejecting the null hypothesis that no trend exists. Trends were assumed for probability levels equal to 0.10 or less. The trend slope (SLOPE) is an estimate of annual change in the constituent's value. The medians (MED) listed in table 3 are the medians of the median annual values used in the test and are not necessarily the median value for the basin. They are, however, generally in close agreement to the median value for the basin.

Four basins have ground water with negative trends in pH. Trends of 14 of the 27 remaining basins (about one-half) are negative, even though the trends are not statistically significant. No trend is apparent in 10 basins, and positive trends were noted in 3 basins. Overall, these observations suggest that pH is decreasing in Massachusetts ground water. The effects of acid rain have been a concern in Massachusetts during the past few years, and decreasing pH in ground water may be a consequence, particularly in sand aquifers that tend to be poorly buffered.

Changes in specific conductance indicate changes in dissolved-solids concentrations. In Massachusetts, these changes usually are associated with changes in bicarbonate, chloride, or sulfate concentrations. Specific conductance in ground water is increasing in eight basins. The French (basin 10) has water in which bicarbonate, chloride, and sulfate concentrations are increasing. The Nashua (basin 11) and Charles (basin 20) have water in which bicarbonate is increasing. The Taunton (basin 25) has water in which sulfate concentrations are increasing. The Chicopee (basin 8), Merrimack (basin 13), South Coastal Shore (basin 21b), and Ten Mile (basin 27) have water in which no significant trends in bicarbonate, chloride, or sulfate concentrations are apparent.

Specific conductance is decreasing in ground water from four basins. Bicarbonate and chloride concentrations are decreasing in the North and South Rivers (basin 21a). Chloride concentrations are decreasing in the Narragansett Bay and Mount Hope (basin 26). Trends in bicarbonate, chloride, or sulfate concentrations are not apparent in the Parker (basin 16) and Mystic (basin 19a).

Changes in bicarbonate, chloride, or sulfate concentrations are not reflected by changes in specific conductance in several basins. Bicarbonate concentrations are decreasing, and sulfate concentrations are increasing on Cape Cod (basin 22). Chloride concentrations are decreasing in water from the Westfield (basin 4). Sulfate concentrations are increasing in the Quinebaug (basin 9), Shawsheen (basin 15), Neponset (basin 19b), and Islands (basin 23).

Nitrate concentrations are decreasing in water from six basins--the Chicopee (basin 8), Quinebaug (basin 9), Shawsheen (basin 15), Parker (basin 16), Ipswich (basin 17), and Neponset (basin 19b). The Neponset (basin 19b) has water with the largest median nitrate concentration (1.20 mg/L) and the largest negative trend (0.10 mg/L per year). Nitrate concentrations are increasing in water from two basins--the French (basin 10) and Taunton (basin 25). Median nitrate concentrations are less than 1 mg/L, and the trend slopes are less than 0.05 mg/L per year in water from both basins.

SUMMARY AND CONCLUSIONS

The quality of public ground-water supplies in Massachusetts has become a major concern during the last few years. During 1978-81, 25 public-supply wells were removed from service because of contaminants. By 1985, about 100 wells had been closed because of ground-water contamination. Water-quality data on selected inorganic constituents and physical properties for public-supply wells across the Commonwealth were used to evaluate areal and temporal water-quality trends. The data consisted of 8,300 analyses, grouped by 31 Commonwealth water-resources planning basins and subbasins, for 1975-86. Statistical and graphical methods, such as boxplots and Kendall Tau-B correlations, were used to evaluate water-quality trends and relate them

Table 3. *Kendall Tau-B correlations relating time to selected constituents*

[Prob, probability of error in rejecting null hypothesis that no trend exists; Slope, trend slope used to estimate annual change in constituent value; Med, median of annual constituent values]

Basin number (fig 1)	pH			Specific conductance			Bicarbonate			Chloride			Sulfate			Nitrate as N		
	Prob	Slope	Med	Prob	Slope	Med	Prob	Slope	Med	Prob	Slope	Med	Prob	Slope	Med	Prob	Slope	Med
01a	0.89	0	7 90	0 15	3 24	248	0.30	1.22	154	0.72	0	1 5	0.89	0	10.0	0.83	0	0.20
02	1.00	0	7.35	.88	-1 64	180	.81	-2.31	82.3	56	0	2.0	.52	-.17	10 0	.62	0	10
03	.14	- 03	6 50	76	-1 00	100	.39	-.37	20 7	.81	0	5.0	81	0	11.0	.31	.02	.55
04	75	-.01	6.90	1.00	0	116	.81	.30	42 7	06	- 40	7.0	.81	0	9 0	.33	-.01	40
05	.20	-.05	7 80	37	-26.25	182	.54	-.61	53.7	.65	3 5	25 0	53	- 17	6 0	.87	0	0
06	.21	.05	7.25	1.00	0	146	.14	1.62	50.6	93	0	7.0	.64	- 14	15 5	30	.02	40
07	04	-.02	6.25	70	2 10	108	1 00	0	13.4	1 00	0	10 5	34	21	7 5	.80	0	.15
08	58	01	6 40	09	1.42	118	1.00	0	22.0	.37	18	12 5	19	25	13 8	.01	-.05	.60
09	.21	- 02	6.20	1 0	0	232	.16	-.61	20.7	.76	.88	57.5	02	1.00	14 0	.03	-.03	25
10	70	- 01	6.50	0	4 42	129	.07	.61	28.0	.08	.75	14.0	10	25	10.0	.09	03	60
11	.58	-.02	6.40	.08	1.89	138	.06	.46	25.6	1.00	0	18.0	.13	.12	12.0	.47	.01	.40
12	69	0	6.40	.81	-1.00	164	48	.61	22 6	1.00	17	26 0	38	17	13.0	.81	0	.85
13	47	0	6.40	.04	3.29	210	.77	0	26.8	.11	21	32.8	33	13	15 8	.89	0	95
14a	.66	0	6.30	.39	-.75	165	.34	.30	24.4	.53	.25	22.0	.26	.20	17 5	.27	-.02	.60
14b	.62	0	6.60	.58	1.67	245	.64	-.20	40.2	.81	.05	33 0	.80	0	18.0	.69	0	90
15	.10	-.02	6.30	.16	-2.67	230	.63	0	24.4	.11	-.57	41.0	.04	.50	18.0	07	-.04	.80
16	.64	-.02	6.80	.06	-5 00	260	.53	-.71	65 9	.64	-.22	23.0	.34	.29	18.0	.06	-.06	40
17	1.00	0	6.60	.39	-1 00	280	.70	46	43 9	.58	- 33	37.0	1.0	0	25.0	07	- 04	.60
18	15	- 02	6 45	1 00	1 00	240	18	-.61	33.5	.94	25	30.5	75	.20	20 0	.43	-.02	40
19a	1.00	0	6.55	06	-7.67	281	.75	.20	43.3	.14	-2 40	59.5	.27	-.50	22.0	.63	- 01	.30
19b	.27	.01	6.40	.64	.86	191	.53	-.30	35 4	.69	0	25.5	.04	.33	15 0	.10	-.10	1.20
19c	.18	+.02	6.35	.70	2.50	235	.88	-.20	26.8	.81	.25	36.0	87	0	17.0	.94	0	80
20	.80	0	6.40	.07	3.00	205	.08	61	29.3	.81	0	32.0	.30	.25	13.0	.11	- 01	.90
21a	.23	-.01	6.30	.04	-7.67	230	.06	-.30	22.0	.02	-2.00	42.0	.94	0	16.0	.34	- 02	.70
21b	.22	-.01	6.20	.01	2.62	98	.23	.20	13 4	1.00	0	15.0	.80	0	6.0	.81	0	30
22	.20	- 02	6.10	.21	.54	87	.09	-.13	8.54	.89	0	16.0	.05	.15	5.8	.14	.01	30
23	01	-.05	6.40	.53	.94	80	.11	-.30	12.2	1.00	0	14 0	.01	.33	5.0	.15	02	25
24	.11	-.02	6.10	.81	25	90	.52	-.12	15.9	.23	- 17	10.5	16	25	9 0	.37	-.01	35
25	.08	-.02	6.20	.05	2.39	141	.52	0	18.3	.44	.24	18.5	0	.50	13 8	0	02	80
26	.75	- 01	6.20	.04	-3.58	145	.26	.20	19.5	.03	-.56	13 0	18	.50	17.5	23	-.04	70
27	.75	0	6.40	04	4 17	188	.35	.44	24.4	.16	80	31.0	.81	0	15.5	.75	0	.50

to natural and anthropogenic factors.

In general, water from public-supply wells in Massachusetts is of good quality, well within U.S. Environmental Protection Agency regulations for drinking water, and suitable for human consumption. The water tends to be slightly acidic (with pH values of about 6.3 to 6.6 standard units), and poorly buffered (with bicarbonate concentrations of about 20 to 40 mg/L). Median chloride concentrations in water from the 31 Commonwealth planning basins and subbasins ranged from about 30 to 33 mg/L. Only two basins had water with median concentrations in excess of 50 mg/L. Median nitrate concentrations in water were generally small and ranged from about 0.3 to 0.7 mg/L. Three basins had isolated analyses with nitrate concentrations exceeding the U.S. Environmental Protection Agency primary drinking-water regulation of 10 mg/L. Large iron and manganese concentrations are a source of concern in Massachusetts. Typical iron concentrations in water were about 0.03 to 0.05 mg/L; however, all but two of the basins had isolated analyses with concentrations exceeding the U.S. Environmental Protection Agency secondary drinking-water regulation of 0.3 mg/L. Manganese concentrations in water were typically between 0.01 and 0.1 mg/L, and only five basins had water with 75th-percentile concentrations less than the U.S. Environmental Protection Agency secondary drinking-water regulation of 0.05 mg/L.

Water chemistry in Massachusetts is related primarily to geologic and anthropogenic factors. Four major water types can be defined on the basis of ion ratios, pH, and specific conductance. Water of calcium and magnesium bicarbonate type (water type 1) is found in the Hoosic and Housatonic basins of western Massachusetts, which is located in the Taconic-Berkshire geologic zone and underlain by carbonate rocks. These two basins have water with large ratios of calcium and magnesium to sodium, and bicarbonate to sulfate and chloride; and large pH values characteristic of water from carbonate rocks. The water in the Deerfield, Westfield, Connecticut, and Parker basins have water in which calcium and bicarbonate predominate (water type 2). Water in the Deerfield, Westfield, and Connecticut basins is affected by the Triassic lowland sediments. Water quality in the Parker basin may be the result of contact with amphibolite rock.

Most of Massachusetts is underlain by igneous and metamorphic rocks. Water from these rocks (water type 3) is characterized by about equal milliequivalent amounts of sodium plus potassium and calcium, with small concentrations of magnesium and bicarbonate and large concentrations of chloride. Slightly increased sulfate-anion ratios are present in water from the Chicopee basin and the Narragansett Bay and Mt. Hope Bay Shore. The South Coastal basin has water containing slightly elevated concentrations of sodium and chloride, possibly because of oceanic influences--either atmospheric deposition or saltwater intrusion.

Southeastern Massachusetts, including Cape Cod and the Islands, has water with the lowest specific conductance. However, the water (water type 4) has the largest sodium:cation and chloride:anion ratios, partly because of saltwater intrusion. Large iron and manganese concentrations in ground water are related to wells screened in acidic areas with reducing environments. The 75th-percentile concentrations of iron and manganese exceeded U.S. Environmental Protection Agency secondary drinking-water regulations (iron = 0.3 mg/L; manganese = 0.05 mg/L) in the Quinebaug, Shawsheen, Parker, Ipswich, North Coastal, and Buzzards Bay basins.

The use of deicing salts on roads during the winter affects ground-water quality. The basins that have water with the largest median sodium and chloride concentrations and, therefore, the most problems with deicing-salt contamination, are the Quinebaug, Shawsheen, Mystic, Weymouth and Weir, and North and South River basins. There is strong correlation between the chlorination of water supplies and the presence of chloroform.

Kendall Tau-B correlations with population density indicate significant correlations at the 0.01 level for specific conductance and concentrations of sodium, chloride, sulfate, manganese, nitrate, and ammonia. With the exception of manganese, each of these constituents commonly is associated with urban and industrial sources.

Seasonal Kendall test correlations with time show that pH may be decreasing over time in 4 of the 31 basins, suggesting a possible connection to acidic rain in those basins. Specific conductance (and, therefore, dissolved-solid concentrations) is increasing in water from eight of the basins, indicating a trend towards degradation of water quality in those basins. Specific conductance is decreasing in water from four other basins. Trends in specific conductance generally are reflected in changes in bicarbonate, chloride, and (or) sulfate concentrations. The use of public-water supplies to evaluate regional water quality may be biased because ground-water supplies are generally developed in protected areas away from potential sources of contamination. Also, when public-supply wells become contaminated, they are closed down and are no longer sampled.

Sulfate concentrations appear to be increasing in ground water from 10 basins and decreasing in water from only two, suggesting a possible link to industrial discharges or to deposition resulting from the use of fossil fuels. Although Cape Cod, the Islands (basin 23), and Taunton basins have water with relatively small nitrate concentrations, these concentrations are increasing and may be the result of increased septic-system discharges.

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Appendix 1.--Supplemental data

[<, indicates less than value given]

Specific conductance

Basin number (fig. 1)	Number of analyses	Minimum value (microsiemens per centimeter at 25 degrees Celsius)	25th-percentile value (microsiemens per centimeter at 25 degrees Celsius)	Median value (microsiemens per centimeter at 25 degrees Celsius)	75th-percentile value (microsiemens per centimeter at 25 degrees Celsius)	Maximum value (microsiemens per centimeter at 25 degrees Celsius)
01a	73	49	182	250	270	526
02	127	33	63	167	274	482
03	107	2.0	72	95	130	380
04	242	4.7	46	118	180	423
05	10	97	100	176	270	600
06	317	34	95	140	195	480
07	95	29	76	114	150	275
08	303	6.7	90	117	170	1,500
09	25	110	200	228	250	400
10	115	68	102	130	165	260
11	418	9.6	98	138	170	781
12	406	31	110	160	320	1,300
13	428	.1	160	210	270	840
14a	236	.2	130	170	219	350
14b	336	45	185	240	300	634
15	369	58	185	230	290	660
16	99	85	180	250	310	456
17	270	53	214	280	333	640
18	144	76	150	238	320	570
19a	94	74	260	310	350	840
19b	124	67	160	190	212	481
19c	165	96	190	230	300	751
20	639	43	137	195	250	870
21a	295	62	160	220	280	680
21b	237	44	68	100	130	570
22	1,043	11	75	87	114	820
23	166	41	63	78	128	640
24	217	36	53	90	126	470
25	793	10	110	140	190	1,500
26	119	60	100	140	160	220
27	255	74	160	187	210	470

Appendix 1.--Supplemental data--Continued

pH

Basin number (fig 1)	Number of analyses	Minimum value (standard units)	25th-percentile value (standard units)	Median percentile value (standard units)	75th percentile value (standard units)	Maximum value (standard units)
01a	73	6.5	7.7	7.9	8.0	8.6
02	129	6.1	6.8	7.4	7.8	8.2
03	109	5.9	6.4	6.5	6.8	7.9
04	244	5.6	6.5	6.9	7.3	8.3
05	10	5.9	7.5	7.8	7.9	8.1
06	321	5.1	6.6	7.2	7.9	9.4
07	95	5.0	6.2	6.3	6.5	7.7
08	304	5.2	6.2	6.4	6.7	9.7
09	25	5.9	6.1	6.2	6.4	7.5
10	115	5.8	6.2	6.4	6.8	8.3
11	416	4.8	6.2	6.4	6.9	9.8
12	408	5.5	6.1	6.4	6.6	10.6
13	432	5.5	6.2	6.4	6.7	9.2
14a	235	5.5	6.1	6.2	6.4	7.2
14b	336	5.6	6.3	6.6	7.0	8.9
15	371	5.0	6.1	6.3	6.4	8.2
16	99	6.0	6.6	6.9	7.4	8.1
17	270	5.4	6.3	6.6	7.1	8.5
18	114	5.9	6.3	6.5	6.8	8.3
19a	94	5.7	6.4	6.6	6.8	8.8
19b	124	3.9	6.3	6.4	6.7	9.7
19c	165	5.6	6.1	6.4	6.7	7.9
20	642	5.7	6.3	6.4	6.7	9.0
21a	301	5.5	6.1	6.3	6.5	7.2
21b	238	4.5	6.0	6.2	6.4	8.6
22	1,042	3.6	5.8	6.1	6.3	11.4
23	166	5.5	6.2	6.5	6.7	11.3
24	217	5.5	5.9	6.1	6.3	7.9
25	796	4.6	6.0	6.2	6.4	9.7
26	119	5.5	6.1	6.2	6.4	7.2
27	255	5.3	6.2	6.4	6.7	8.7

Appendix 1.--Supplemental data--Continued

Hardness as $CaCO_3$

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	20.0	103.0	135.0	167.0	346.0
02	129	5.0	23.0	77.0	154.0	262.0
03	109	10.0	26.0	35.0	44.0	99.0
04	244	6.0	15.5	42.0	71.0	280.0
05	10	24.0	36.0	48.5	71.0	126.0
06	321	10.0	31.0	52.0	82.0	295.0
07	95	7.0	13.0	23.0	33.5	80.0
08	304	1.0	22.0	32.0	44.0	280.0
09	25	31.0	46.0	53.0	65.0	107.0
10	114	16.0	29.0	33.0	45.0	105.0
11	418	7.0	25.0	33.5	47.0	186.0
12	408	7.0	24.0	36.0	75.5	374.0
13	432	8.0	41.0	51.0	71.5	267.0
14a	236	7.0	32.0	42.0	60.0	119.0
14b	336	12.0	42.0	69.0	90.0	180.0
15	370	12.0	37.0	48.0	67.0	224.0
16	99	18.0	61.0	84.0	123.0	315.0
17	269	2.0	54.0	73.0	116.0	331.0
18	144	17.0	37.0	52.0	87.5	274.0
19a	94	13.0	53.0	65.5	76.0	149.0
19b	124	12.0	39.0	47.5	62.5	114.0
19c	165	16.0	35.0	48.0	65.0	139.0
20	642	8.9	33.0	48.0	66.0	196.0
21a	301	8.0	29.0	38.0	54.0	101.0
21b	238	4.2	11.0	18.0	24.0	131.0
22	1,043	6.0	11.0	14.0	19.0	149.0
23	166	5.0	8.0	12.0	24.0	60.0
24	217	6.0	12.0	22.0	29.0	71.0
25	797	10.0	24.0	32.0	43.0	222.0
26	119	17.0	28.5	38.0	45.0	84.0
27	255	17.0	34.0	41.0	57.5	133.0

Appendix 1.--Supplemental data--Continued

Calcium

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	5.2	25.0	32.0	42.0	76.0
02	129	1.0	5.3	19.0	42.0	81.0
03	109	2.1	5.6	10.0	13.0	35.0
04	242	1.7	4.3	12.5	22.0	68.0
05	10	4.9	8.6	12.0	20.0	34.0
06	319	1.4	8.7	17.0	25.0	100.0
07	95	2.0	3.9	6.7	11.0	25.0
08	303	.2	6.1	8.8	12.0	55.0
09	25	7.0	13.0	15.0	17.0	28.0
10	115	0	9.0	11.0	14.0	39.0
11	418	2.1	7.5	10.0	15.0	64.0
12	408	1.9	7.0	11.0	24.0	115.0
13	432	1.5	12.0	16.0	23.0	96.0
14a	236	2.0	9.3	12.0	17.0	95.0
14b	336	3.7	12.0	20.0	27.0	59.0
15	370	2.0	11.0	14.0	19.0	60.0
16	99	6.7	18.0	25.0	39.0	110.0
17	269	.5	16.0	20.0	35.0	115.0
18	144	4.0	8.0	12.5	18.0	80.0
19a	94	3.9	16.0	20.0	24.0	40.0
19b	124	3.7	10.0	13.0	17.0	32.0
19c	165	4.2	8.6	12.0	15.0	42.0
20	642	1.9	9.2	13.0	18.0	64.0
21a	301	1.5	6.5	8.8	12.0	28.0
21b	238	.2	2.3	3.8	5.3	39.0
22	1,043	.5	1.7	2.4	3.6	58.0
23	166	.4	1.5	2.3	5.3	20.0
24	217	.7	1.9	4.6	6.8	17.0
25	797	2.0	6.5	8.5	12.0	49.0
26	119	4.6	8.7	11.0	13.0	27.0
27	255	3.0	10.0	12.0	18.0	43.0

Appendix 1.--Supplemental data--Continued

Magnesium

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	1.70	5.50	15.00	16.00	38.00
02	129	.50	2.50	7.90	12.00	23.00
03	109	.60	1.60	2.30	3.20	10.00
04	242	40	0.90	2.20	3.10	92.00
05	10	3.00	3.50	3.80	5.60	10.00
06	319	.50	1.80	2.80	4.60	12.00
07	95	.30	62	1.40	1.90	6.00
08	303	<.20	1.50	2.20	2.80	56.00
09	25	2.20	3.60	4.10	5.20	8.30
10	115	.90	1.30	1.70	2.10	3.80
11	418	.40	1.20	1.70	2.40	47.00
12	408	.40	1.40	2.00	3.40	85.00
13	432	.80	2.30	2.80	3.40	18.00
14a	236	40	2.00	2.50	3.95	7.50
14b	336	.50	2.80	4.25	5.40	8.70
15	370	34	2.40	3.10	4.50	18.00
16	99	1.60	3.95	4.80	6.25	15.00
17	269	<.20	3.50	4.70	6.90	14.00
18	144	<.20	3.15	4.40	7.55	37.00
19a	94	.52	3.20	3.75	4.20	12.00
19b	124	70	2.90	3.80	5.10	12.00
19c	165	.60	3.10	3.90	6.00	14.00
20	642	<.20	2.40	3.50	5.00	70.00
21a	301	<.20	2.90	3.80	5.50	10.00
21b	238	.30	1.30	1.90	2.70	11.00
22	1,043	.40	1.50	1.80	2.30	22.00
23	166	<.20	1.00	1.50	2.00	6.40
24	217	.70	1.30	2.30	2.90	6.70
25	797	<.20	1.90	2.40	3.20	15.00
26	119	.90	1.70	2.20	2.90	3.90
27	255	1.00	2.00	2.30	3.00	6.90

Appendix 1.--Supplemental data--Continued

Sodium

Basin number (fig 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	0.30	0.80	1.60	2.80	17.00
02	129	.50	1.40	2.00	3.70	45.00
03	109	.70	2.30	3.60	6.30	50.00
04	243	.20	2.00	4.70	7.30	35.00
05	10	6.30	10.00	18.50	31.00	74.00
06	319	.80	3.90	5.00	6.50	25.00
07	95	1.30	7.90	10.00	13.00	130.00
08	303	2.10	5.70	8.00	11.00	200.00
09	25	1.30	18.00	20.00	23.00	30.00
10	115	4.00	7.10	10.00	13.00	21.00
11	418	1.80	6.80	10.00	14.00	42.00
12	408	2.40	9.40	15.00	29.50	200.00
13	432	1.50	11.00	16.00	22.50	123.00
14a	236	2.10	9.45	13.00	18.00	50.00
14b	336	1.40	12.00	18.00	26.00	100.00
15	370	5.00	18.00	24.00	30.00	100.00
16	99	3.60	9.50	13.00	17.00	31.00
17	269	3.30	15.00	21.00	28.00	100.00
18	144	7.80	12.00	16.50	23.00	82.00
19a	94	9.40	27.00	35.00	41.00	100.00
19b	124	4.00	14.00	16.00	21.00	80.00
19c	165	3.80	14.00	20.00	35.00	150.00
20	642	.50	11.00	18.00	23.00	174.00
21a	301	.60	16.00	23.00	35.00	120.00
21b	238	3.50	7.80	10.00	15.00	100.00
22	1,043	1.00	9.10	11.00	14.00	150.00
23	166	6.20	8.00	11.00	13.00	63.00
24	217	3.20	6.00	8.10	12.00	71.00
25	797	3.00	8.30	12.00	20.00	750.00
26	119	4.20	5.60	8.80	12.00	27.00
27	255	1.50	15.00	19.00	23.00	74.00

Appendix 1.--Supplemental data--Continued

Potassium

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	<0.20	0.40	0.80	0.90	1.20
02	129	<.20	.60	1.00	1.20	55.00
03	109	.20	.60	.90	1.60	2.50
04	242	<.20	.45	.60	.90	13.00
05	10	.80	1.10	1.25	1.90	2.10
06	319	<.20	.50	.70	1.10	5.00
07	95	.40	.90	1.20	1.50	3.10
08	303	<.20	1.30	2.00	2.50	23.00
09	25	1.20	1.70	2.00	2.20	4.60
10	115	4.00	1.50	1.90	2.70	23.00
11	418	.40	1.10	1.50	2.00	15.00
12	408	<.20	1.30	2.30	3.60	115.00
13	432	.50	1.80	2.30	3.00	21.00
14a	236	.30	1.50	2.20	2.90	5.90
14b	336	<.20	1.40	2.00	2.60	22.00
15	370	.80	1.70	2.30	2.90	9.90
16	99	.70	1.20	1.50	2.00	3.20
17	269	.30	1.50	2.00	2.30	27.00
18	144	.10	.90	1.55	2.20	38.00
19a	94	.60	2.40	2.95	3.60	5.40
19b	124	.10	.70	.90	1.10	2.50
19c	165	.30	.80	1.20	1.70	28.00
20	642	<.20	1.00	1.30	1.70	37.00
21a	301	<.20	.80	1.00	1.30	3.30
21b	238	.20	.70	.90	1.20	2.70
22	1,043	<.20	.60	.80	1.00	12.00
23	166	<.20	.60	.70	1.00	5.50
24	217	.30	.70	1.30	1.90	3.90
25	797	<.20	.80	1.10	1.60	30.00
26	119	<.20	.60	1.00	1.55	2.80
27	255	.50	.90	1.00	1.30	3.10

Appendix 1.--Supplemental data--Continued

Alkalinity[1], total as $CaCO_3$

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	8.00	92.00	125.00	132.00	231.00
02	129	6.00	17.00	65.00	141.00	243.00
03	109	4.00	13.00	17.00	30.00	85.00
04	244	<2.00	11.00	34.00	47.00	109.00
05	10	6.00	43.00	44.50	46.00	47.00
06	321	<2.00	21.00	38.00	63.00	110.00
07	95	5.00	9.00	11.00	18.00	54.00
08	304	<2.00	12.00	18.00	23.00	165.00
09	25	11.00	15.00	19.00	22.00	47.00
10	115	11.00	18.00	23.00	33.00	88.00
11	418	2.00	13.00	20.00	33.00	126.00
12	408	2.00	13.00	19.00	49.50	148.00
13	432	6.00	17.00	22.00	36.00	123.00
14a	236	4.00	14.00	19.00	25.00	75.00
14b	336	5.00	20.00	33.00	49.50	105.00
15	371	6.00	15.00	21.00	28.00	114.00
16	99	17.00	36.00	58.00	94.50	148.00
17	270	7.00	22.00	35.00	80.00	157.00
18	144	7.00	22.50	27.50	39.00	140.00
19a	94	11.00	30.00	39.00	46.00	63.00
19b	124	9.00	23.00	29.00	39.00	76.00
19c	165	7.00	15.00	25.00	44.00	97.00
20	641	6.00	18.00	25.00	35.00	85.00
21a	301	6.00	12.00	18.00	25.00	55.00
21b	237	2.00	9.00	11.00	14.00	79.00
22	1,039	<2.00	6.00	7.00	10.00	149.00
23	166	3.00	8.00	10.00	16.00	164.00
24	217	3.00	7.00	12.00	16.00	67.00
25	797	<2.00	11.00	15.00	21.00	147.00
26	119	8.00	13.00	16.00	19.00	88.00
27	255	3.00	15.00	20.00	31.00	91.00

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[1] For bicarbonate, divide alkalinity by 0.8202.

Appendix 1.--Supplemental data--Continued

Chloride

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	<2.0	<2.0	2.0	8.0	18.0
02	129	<2.0	<2.0	3.0	7.0	27.0
03	109	<2.0	3.0	6.0	12.0	73.0
04	244	<2.0	2.0	7.5	14.0	195.0
05	10	<2.0	9.0	25.0	32.0	95.0
06	319	<2.0	5.0	8.0	11.0	90.0
07	95	<2.0	5.0	13.0	23.0	69.0
08	304	<2.0	8.0	12.0	21.0	410.0
09	25	<2.0	41.0	50.0	64.0	110.0
10	115	<2.0	9.0	15.0	20.5	39.0
11	418	2.0	11.0	18.0	24.0	81.0
12	408	<2.0	15.0	26.0	55.0	375.0
13	432	7.0	23.0	33.0	47.0	238.0
14a	236	<2.0	15.0	23.0	32.0	59.0
14b	336	<2.0	23.0	33.0	50.0	165.0
15	371	8.0	32.0	41.0	54.0	150.0
16	96	4.0	17.0	23.5	31.0	57.0
17	270	3.0	26.0	36.0	54.0	160.0
18	144	9.0	18.0	26.0	39.0	145.0
19a	94	<2.0	49.0	58.5	73.0	130.0
19b	124	4.0	20.0	26.0	34.0	910.0
19c	164	9.0	21.0	34.0	51.5	270.0
20	642	2.0	18.0	32.0	43.0	230.0
21a	301	9.0	26.0	40.0	61.0	220.0
21b	238	4.0	10.0	15.0	24.0	165.0
22	1,043	<2.0	14.0	16.0	21.0	260.0
23	166	6.0	12.0	16.0	20.0	105.0
24	217	<2.0	8.0	11.0	16.0	100.0
25	797	<2.0	12.0	19.0	33.0	227.0
26	119	3.0	7.0	13.0	20.0	122.0
27	255	4.0	22.0	30.0	39.5	71.0

Appendix 1.--Supplemental data--Continued

Sulfate

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	72	<2.0	7.0	10.0	12.0	100.0
02	129	<2.0	7.0	10.0	12.0	37.0
03	106	3.0	9.0	11.0	15.0	27.0
04	238	2.0	5.0	9.0	14.0	31.0
05	10	5.0	6.0	6.0	7.0	15.0
06	319	<2.0	10.3	16.0	23.0	138.0
07	95	<2.0	5.0	7.5	13.5	40.0
08	303	<2.0	10.0	14.0	17.0	40.0
09	25	<2.0	7.0	14.0	15.0	20.0
10	115	2.0	8.0	10.0	13.5	22.0
11	415	<2.0	8.0	11.0	16.0	76.0
12	408	<2.0	9.0	14.0	22.0	162.5
13	429	<2.0	10.0	15.0	21.0	94.0
14a	236	<2.0	13.0	18.0	26.0	91.0
14b	334	<2.0	13.0	19.0	23.0	146.0
15	371	<2.0	13.5	18.0	25.0	166.0
16	99	3.0	16.0	18.0	23.0	109.0
17	269	<2.0	17.0	23.0	33.0	76.0
18	144	2.0	11.0	19.0	27.5	160.0
19a	94	3.0	17.0	21.0	23.0	143.0
19b	124	<2.0	13.0	15.2	19.0	27.0
19c	165	3.0	13.0	18.0	24.0	62.0
20	642	<2.0	10.0	14.0	18.0	42.0
21a	301	<2.0	10.0	15.0	19.0	46.0
21b	238	<2.0	4.0	7.0	10.0	64.0
22	1,042	<2.0	4.0	6.0	8.0	60.0
23	166	<2.0	3.0	5.0	9.0	29.0
24	213	<2.0	4.0	8.0	13.0	34.0
25	793	<2.0	10.0	13.0	18.0	170.0
26	119	<2.0	13.0	17.0	25.0	104.0
27	255	<2.0	13.0	16.0	20.0	37.0

Appendix 1.--Supplemental data--Continued

Nitrate

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	<0.10	<0.10	0 20	0.40	5.10
02	129	<.10	<0.10	.10	.20	1.50
03	109	<.10	.20	.50	1.00	8.30
04	244	<.10	.10	.40	1.35	6.90
05	10	<.10	<.10	<.10	.10	1.40
06	321	<.10	<.10	.40	1 00	9.50
07	94	<.10	<.10	.10	.70	1.90
08	303	<.10	.24	.60	1.10	4.10
09	25	<.10	.10	.30	.50	.80
10	115	<.10	.20	.70	1.20	6.20
11	418	<.10	.20	.50	.90	5.10
12	405	<.10	.50	.90	1.40	8.50
13	430	<.10	.40	1.00	1.50	8.80
14a	235	<.10	.35	70	1.20	7.30
14b	335	<.10	.40	.90	1.80	15.00
15	370	<.10	.40	.90	1.80	12.00
16	99	<.10	.20	.40	.80	2.50
17	270	<.10	.20	60	1.40	6.10
18	144	<.10	.10	.40	1.00	6.00
19a	94	<.10	.20	.40	.80	2.80
19b	123	<.10	.70	1 20	2.30	7 10
19c	165	<.10	.40	80	1.30	5.50
20	640	<.10	.40	90	1.50	6.60
21a	300	<.10	.30	.70	1.30	6.60
21b	238	<.10	.10	.30	.90	2.70
22	1,042	<.10	.10	.30	.90	6.00
23	164	<.10	.10	.30	.70	5.20
24	215	<.10	.10	40	.80	8.10
25	794	<.10	.30	.80	1.50	19.00
26	119	<.10	.30	.70	1.30	4.30
27	255	<.10	.20	.50	1 00	5.80

Appendix 1.--Supplemental data--Continued

Nitrite

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	<0.0002	<0.0002	<0.0002	0.002	0.0060
02	129	<.0002	<.0002	<.0002	.0010	.0030
03	109	<.0002	<.0002	<.0002	.0010	.0170
04	244	<.0002	<.0002	<.0002	.0010	.0120
05	10	<.0002	<.0002	<.0002	.0020	.0020
06	321	<.0002	<.0002	<.0002	.0010	.1020
07	95	<.0002	<.0002	.0010	.0020	.0110
08	304	<.0002	<.0002	<.0002	.0010	.0170
09	25	<.0002	<.0002	.0020	.0040	.0110
10	114	<.0002	<.0002	<.0002	.0010	.0260
11	418	<.0002	<.0002	<.0002	.0010	.0330
12	408	<.0002	<.0002	<.0002	.0010	.3050
13	432	<.0002	<.0002	<.0002	.0020	.0140
14a	236	<.0002	<.0002	<.0002	.0010	.0160
14b	336	<.0002	<.0002	<.0002	.0020	.2400
15	371	<.0002	<.0002	.0010	.0030	.0540
16	99	<.0002	<.0002	.0010	.0020	.0190
17	270	<.0002	<.0002	.0010	.0050	.3100
18	144	<.0002	<.0002	.0010	.0020	.0380
19a	94	<.0002	<.0002	<.0002	.0020	.0660
19b	124	<.0002	<.0002	<.0002	.0010	.0170
19c	165	<.0002	<.0002	.0010	.0020	.0600
20	642	<.0002	<.0002	<.0002	.0010	.0970
21a	301	<.0002	<.0002	<.0002	.0010	.0390
21b	238	<.0002	<.0002	<.0002	.0010	.0160
22	1,043	<.0002	<.0002	<.0002	.0010	.0260
23	166	<.0002	<.0002	<.0002	.0010	.0080
24	214	<.0002	<.0002	<.0002	.0010	.0500
25	797	<.0002	<.0002	<.0002	.0010	.1930
26	119	<.0002	<.0002	<.0002	.0020	.0050
27	255	<.0002	<.0002	<.0002	.0020	.2660

Appendix 1.--Supplemental data--Continued

Ammonia

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	<0.02	<0.02	<0.02	0.02	0.09
02	129	<.02	<.02	<.02	<.02	.58
03	109	<.02	<.02	<.02	.02	1.00
04	244	<.02	<.02	<.02	<.02	.88
05	10	<.02	<.02	<.02	.02	.02
06	321	<.02	<.02	<.02	.02	1.90
07	95	<.02	<.02	.02	.04	.16
08	304	<.02	<.02	<.02	.02	1.27
09	25	<.02	.02	.02	.04	.07
10	115	<.02	<.02	<.02	.02	.16
11	418	<.02	<.02	<.02	.02	2.30
12	407	<.02	<.02	<.02	.03	3.30
13	432	<.02	<.02	<.02	.04	.88
14a	236	<.02	<.02	<.02	.02	.28
14b	336	<.02	<.02	<.02	.02	.28
15	371	<.02	.02	.03	.07	.85
16	99	<.02	<.02	<.02	.04	.19
17	270	<.02	<.02	.02	.07	1.10
18	144	<.02	<.02	<.02	.05	.49
19a	94	<.02	.02	.03	.09	6.60
19b	124	<.02	<.02	<.02	.02	.17
19c	165	<.02	<.02	.02	.05	.35
20	641	<.02	<.02	<.02	.03	.19
21a	301	<.02	<.02	<.02	.02	1.60
21b	238	<.02	<.02	<.02	.02	.12
22	1,043	<.02	<.02	<.02	.02	2.40
23	166	<.02	<.02	<.02	.02	1.10
24	217	<.02	<.02	<.02	.02	.70
25	796	<.02	<.02	<.02	.02	2.40
26	119	<.02	<.02	<.02	.02	1.20
27	255	<.02	<.02	<.02	.04	2.90

Appendix 1.--Supplemental data--Continued

Copper

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	<0 02	<0 02	<0.02	0.02	0.25
02	129	< 02	< 02	<.02	.02	.67
03	109	< 02	< 02	.02	.04	2.60
04	242	< 02	< 02	< 02	.04	2.00
05	10	<.02	< 02	.02	07	.27
06	319	< 02	< 02	<.02	.02	3.00
07	95	<.02	< 02	03	.22	7.40
08	302	<.02	< 02	.02	.05	8.10
09	25	< 02	.02	.03	.05	.20
10	115	< 02	< 02	.02	.05	.45
11	418	<.02	< 02	.02	.04	1.50
12	406	< 02	< 02	.03	.07	5.00
13	432	<.02	<.02	02	.05	4.50
14a	236	<.02	02	.04	.08	5.20
14b	336	< 02	< 02	.02	06	10.00
15	370	< 02	< 02	.04	08	4 30
16	99	< 02	< 02	02	04	83
17	267	< 02	< 02	.02	.06	2.10
18	143	< 02	.03	.05	.14	8.00
19a	94	< 02	< 02	.02	.03	11
19b	124	<.02	<.02	.02	.05	2.50
19c	165	<.02	<.02	.02	.07	1.40
20	641	<.02	<.02	.03	.08	15.00
21a	301	<.02	< 02	.02	.04	6.50
21b	238	< 02	02	.04	.10	6.20
22	1,043	< 02	< 02	.03	.05	13.00
23	166	< 02	< 02	.02	.04	1.20
24	217	<.02	<.02	.03	.09	9.50
25	797	<.02	<.02	03	.07	30.00
26	119	<.02	<.02	.03	.05	1.90
27	255	<.02	<.02	02	.05	5.50

Appendix 1.--Supplemental data--Continued

Iron

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	<0.03	<0.03	0 03	0.08	1 00
02	129	< 03	<.03	< 03	03	.73
03	109	<.03	< 03	.03	.06	7 20
04	244	<.03	<.03	<.03	.06	7.80
05	10	<.03	<.03	<.03	.04	06
06	321	<.03	<.03	< 03	.05	1 70
07	95	<.03	< 03	<.03	.28	.84
08	304	<.03	< 03	.04	.12	10.00
09	25	<.03	.54	2 00	2 40	3 30
10	115	<.03	<.03	03	.06	1 90
11	418	<.03	<.03	03	10	14 00
12	408	<.03	<.03	03	08	12 00
13	432	< 03	<.03	06	.24	3 80
14a	236	< 03	< 03	06	.20	11 00
14b	336	< 03	< 03	< 03	06	5 50
15	370	<.03	.30	.10	.50	10.00
16	99	<.03	<.03	.06	.32	3.50
17	269	<.03	<.03	15	.70	15.00
18	144	<.03	<.03	04	62	15.00
19a	94	<.03	<.03	03	09	2.80
19b	124	< 03	< 03	<.03	.10	1.60
19c	165	<.03	< 03	05	15	5.00
20	642	< 03	<.03	04	.16	7.00
21a	301	< 03	<.03	03	.11	12 00
21b	238	<.03	<.03	05	.18	30 00
22	1,043	<.03	<.03	03	.08	70 00
23	166	<.03	<.03	.03	.10	.20
24	217	<.03	< 03	05	7.0	5.40
25	797	<.03	<.03	04	.15	8.20
26	119	<.03	<.03	.05	.14	3.80
27	255	< 03	< 03	.04	.25	9 70

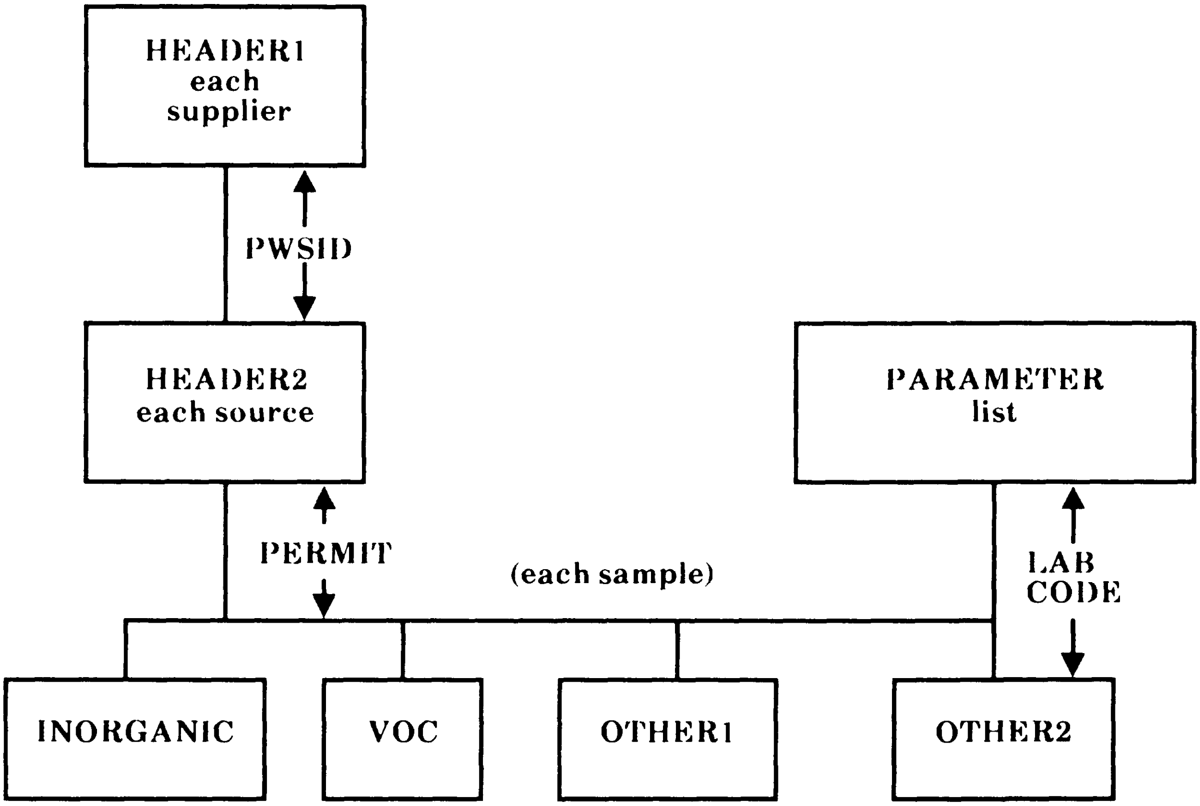
Appendix 1.--Supplemental data--Continued

Manganese

Basin number (fig. 1)	Number of analyses	Minimum concentration (milligrams per liter)	25th-percentile concentration (milligrams per liter)	Median concentration (milligrams per liter)	75th-percentile concentration (milligrams per liter)	Maximum concentration (milligrams per liter)
01a	73	<0.02	<0.02	<0 02	0.02	0.15
02	129	<.02	<.02	< 02	<.02	.20
03	109	< 02	< 02	<.02	.02	.75
04	244	<.02	< 02	< 02	<.02	17
05	10	< 02	< 02	< 02	02	.03
06	321	< 02	<.02	< 02	.05	.65
07	95	< 02	<.02	10	.38	1.40
08	304	<.02	< 02	< 02	.06	1.40
09	25	<.02	11	19	28	.50
10	114	<.02	< 02	04	.10	.32
11	418	<.02	< 02	< 02	.06	2.50
12	408	< 02	< 02	03	22	34 00
13	432	< 02	.02	09	30	2 60
14a	236	< 02	< 02	08	.18	81
14b	336	<.02	< 02	.03	.12	1.10
15	370	< 02	.08	20	40	5 00
16	99	< 02	.02	15	38	13.00
17	269	<.02	.05	.20	.36	2.20
18	143	<.02	02	15	.47	1 20
19a	94	< 02	.06	18	35	1 10
19b	124	<.02	< 02	.03	.17	.95
19c	165	<.02	03	.28	1.10	3.00
20	642	<.02	<.02	03	.19	2 40
21a	301	< 02	<.02	02	.14	1.80
21b	237	<.02	<.02	03	.06	.93
22	1,043	<.02	<.02	.02	.05	1.60
23	166	<.02	<.02	.02	.02	.61
24	217	<.02	<.02	.02	.05	.70
25	797	<.02	.02	.06	.21	3.60
26	119	<.02	.02	07	.12	1 30
27	255	<.02	< 02	08	.26	10.00

Appendix 2.--Sample data-base structure

FLOW CHART OF WATER-QUALITY DATA-BASE STRUCTURE



Appendix 2.--Sample data-base structure--Continued

HEADER1

FIELD	FIELD DESCRIPTION	FIELD NAME	TYPE	WIDTH
1.	WATER SUPPLIER	SUPPLIER	CHAR	30
2.	PUBLIC WATER SUPPLY ID NUMBER	PWSID	CHAR	7
3.	WATER USE ID NUMBER	WUID	CHAR	4
4.	WATER SUPPLY REGION	REGION	CHAR	1
5.	CONTACT PERSON	CONTACT	CHAR	25
6.	ADDRESS LINE 1	ADDRESS1	CHAR	30
7.	ADDRESS LINE 2	ADDRESS2	CHAR	30
8.	TOWN NAME	TOWN	CHAR	20
9.	STATE NAME	STATE	CHAR	2
10.	ZIP CODE	ZIP	CHAR	10

HEADER2

FIELD	FIELD DESCRIPTION	FIELD NAME	TYPE	WIDTH
1.	PUBLIC WATER SUPPLIER ID NUMBER	PWSID	CHAR	7
2.	SITE NAME	SITE-NAME	CHAR	30
3.	USGS SITE ID	SITEID	CHAR	15
4.	LATITUDE	LAT	CHAR	6
5.	LONGITUDE	LONG	CHAR	7
6.	LOCAL ID NUMBER	LOCNUM	CHAR	8
7.	DEQE MAP NUMBER	MAPNUM	CHAR	10
8.	STATE PERMIT NUMBER	PERMIT	CHAR	7
9.	STATE BASIN CODE	BASIN	CHAR	3
10.	USGS HYDROLOGIC UNIT CODE	HUC	CHAR	8
11.	USGS QUAD MAP	QUAD	CHAR	12
12.	SITE TYPE (WELL, SPRING)	SITE-TYPE	CHAR	2
13.	SUBCLASS (WATER SUPPLY)	SUBCLASS	CHAR	2

PARAMETER

FIELD	FIELD DESCRIPTION	FIELD NAME	TYPE	WIDTH
1.	LAB CODE	CODE	CHAR	5
2.	PARAMETER NAME	NAME	CHAR	30
3.	REPORTING UNITS	UNITS	CHAR	10
4.	DETECTION LIMIT	DLIMIT	CHAR	9.2
5.	METHOD NOTES	METHOD	CHAR	50

Appendix 2.--Sample data-base structure--Continued

INORGANIC

FIELD	FIELD DESCRIPTION	FIELD NAME	TYPE	WIDTH
1.	STATE PERMIT NUMBER	PERMIT	CHAR	7
2.	COLLECTOR'S NAME	COLLECTOR	CHAR	10
3.	SAMPLE NUMBER	S-NUMBER	CHAR	7
4.	SAMPLE DATE	S-DATE	DATE	(8)?
5.	TURBIDITY (NTU)	P00076	NUMB	4.0
6.	- - - NOTE - - -	N00076	CHAR	2
7.	SEDIMENT	P80154	NUMB	8.0
8.	- - - NOTE - - -	N80154	CHAR	2
9.	COLOR	P00080	NUMB	4.0
10.	- - - NOTE - - -	N00080	CHAR	2
11.	ODOR	P00085	NUMB	4.0
12.	- - - NOTE - - -	N00085	CHAR	2
13.	pH	P00400	NUMB	5.1
14.	- - - NOTE - - -	N00400	CHAR	2
15.	ALKALINITY (TOTAL)	P00410	NUMB	6.1
16.	- - - NOTE - - -	N00410	CHAR	2
17.	HARDNESS (TOTAL $CaCO_3$)	P00900	NUMB	5.1
18.	- - - NOTE - - -	N00900	CHAR	2
19.	CALCIUM (DIS)	P00915	NUMB	5.1
20.	- - - NOTE - - -	N00915	CHAR	2
21.	MAGNESIUM (DIS)	P00925	NUMB	5.1
22.	- - - NOTE - - -	N00925	CHAR	2
23.	SODIUM (DIS)	P00930	NUMB	5.1
24.	- - - NOTE - - -	N00930	CHAR	2
25.	POTASSIUM (DIS)	P00935	NUMB	5.1
26.	- - - NOTE - - -	N00935	CHAR	2
27.	IRON (DIS)	P01046	NUMB	7.2
28.	- - - NOTE - - -	N01046	CHAR	2
29.	MANGANESE (DIS)	P01056	NUMB	7.2
30.	- - - NOTE - - -	N01056	CHAR	2
31.	SULFATE (DIS)	P00945	NUMB	5.1
32.	- - - NOTE - - -	N00945	CHAR	2
33.	CHLORIDE (DIS)	P00940	NUMB	5.1
34.	- - - NOTE - - -	N00940	CHAR	2
35.	SPECIFIC CONDUCTANCE	P00095	NUMB	8.1
36.	- - - NOTE - - -	N00095	CHAR	2
37.	AMMONIA-NITROGEN (DIS)	P00610	NUMB	7.2

Appendix 2.--Sample data-base structure--Continued

INORGANIC-- Continued

FIELD	FIELD DESCRIPTION	FIELD NAME	TYPE	WIDTH
38.	- - - NOTE - - -	N00620	CHAR	2
39.	NITRATE-NITROGEN (DIS)	P00620	NUMB	7.2
40.	- - - NOTE - - -	N00620	CHAR	2
41.	NITRITE-NITROGEN (DIS)	P00615	NUMB	8.3
42.	- - - NOTE - - -	N00615	CHAR	2
43.	COPPER (DIS)	P01040	NUMB	7.2
44.	- - - NOTE - - -	N01040	CHAR	2
45.	BICARBONATE (TOTAL) CALC	P00440	NUMB	6.1
46.	- - - NOTE - - -	N00440	CHAR	2

Appendix 2.--Sample data-base structure--Continued

VOC

FIELD	FIELD DESCRIPTION	FIELD NAME	TYPE	WIDTH
1.	STATE PERMIT NUMBER	PERMIT	CHAR	7
2.	COLLECTOR'S NAME	COLLECTOR	CHAR	1
3.	SAMPLE NUMBER	S-NUMBER	CHAR	0
4.	SAMPLE DATE	S-DATE	DATE	(8)?
5.	METHYLENE CHLORIDE (DIS)	P34424	NUMB	9.2
6.	- - - NOTE - - -	N34424	CHAR	2
7.	1,1 DICHLOROETHYLENE (DIS)	P34502	NUMB	9.2
8.	- - - NOTE - - -	N34502	CHAR	2
9.	1,1 DICHLOROETHANE (DIS)	P34497	NUMB	9.2
10.	- - - NOTE - - -	N34497	CHAR	2
11.	1,2 TRANSDICHLOROETHYLENE (DIS)	P34547	NUMB	9.2
12.	- - - NOTE - - -	N34547	CHAR	2
13.	CHLOROFORM	P34316	NUMB	9.2
14.	- - - NOTE - - -	N34316	CHAR	2
15.	1,2 DICHLOROETHANE (DIS)	P34532	NUMB	9.2
16.	- - - NOTE - - -	N34532	CHAR	2
17.	1,1,1 TRICHLOROETHANE (DIS)	P34507	NUMB	9.2
18.	- - - NOTE - - -	N34507	CHAR	2
19.	CARBON TETRACHLORIDE (DIS)	P34297	NUMB	9.2
20.	- - - NOTE - - -	N34297	CHAR	2
21.	BROMODICHLOROMETHANE (DIS)	P34328	NUMB	9.2
22.	- - - NOTE - - -	N34328	CHAR	2
23.	TRICHLOROETHYLENE (DIS)	P34485	NUMB	9.2
24.	- - - NOTE - - -	N34485	CHAR	2
25.	DIBROMOCHLOROMETHANE (DIS)	P34307	NUMB	9.2
26.	- - - NOTE - - -	N34307	CHAR	2
27.	BROMOFORM (DIS)	P34288	NUMB	9.2
28.	- - - NOTE - - -	N34288	CHAR	2
29.	TETRACHLOROETHYLENE (DIS)	P34476	NUMB	9.2
30.	- - - NOTE - - -	N34476	CHAR	2
31.	1,2 DICHLOROPROPANTE (DIS)	P34542	NUMB	9.2
32.	- - - NOTE - - -	N34542	CHAR	2

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