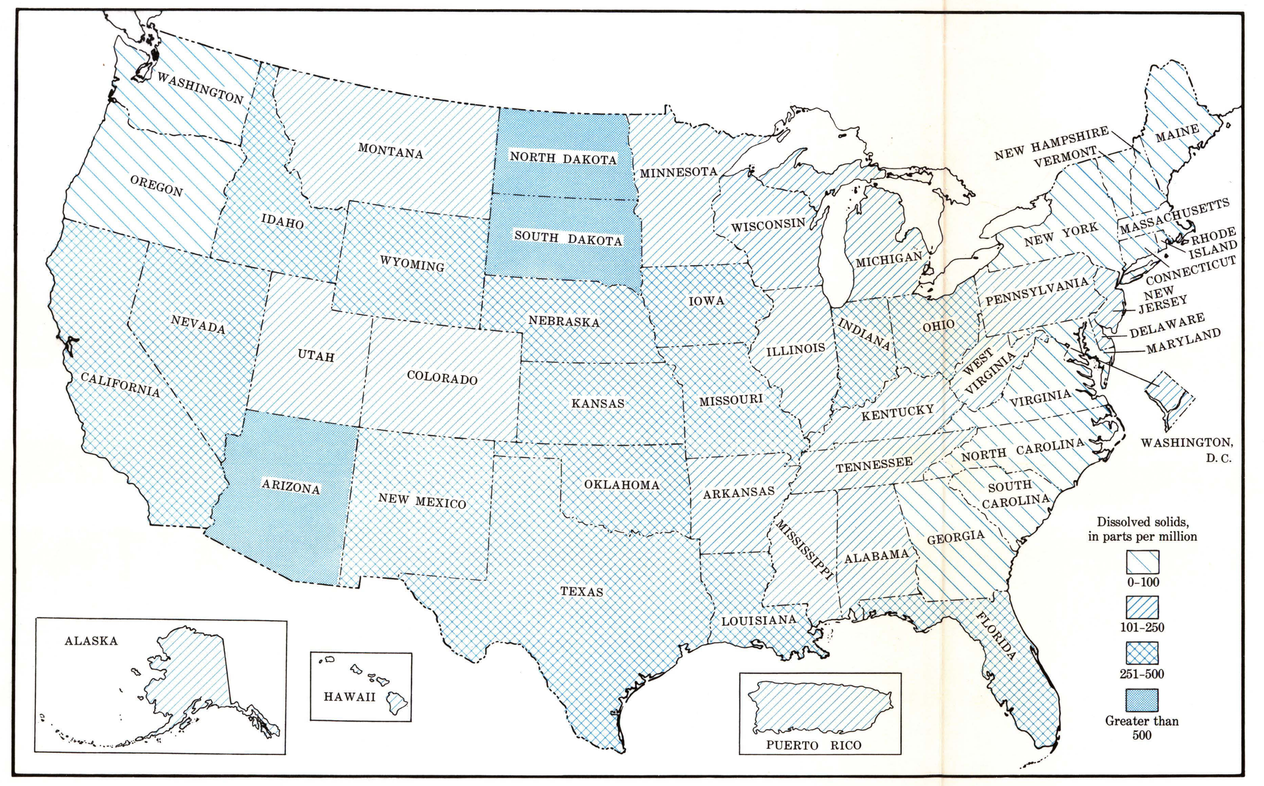
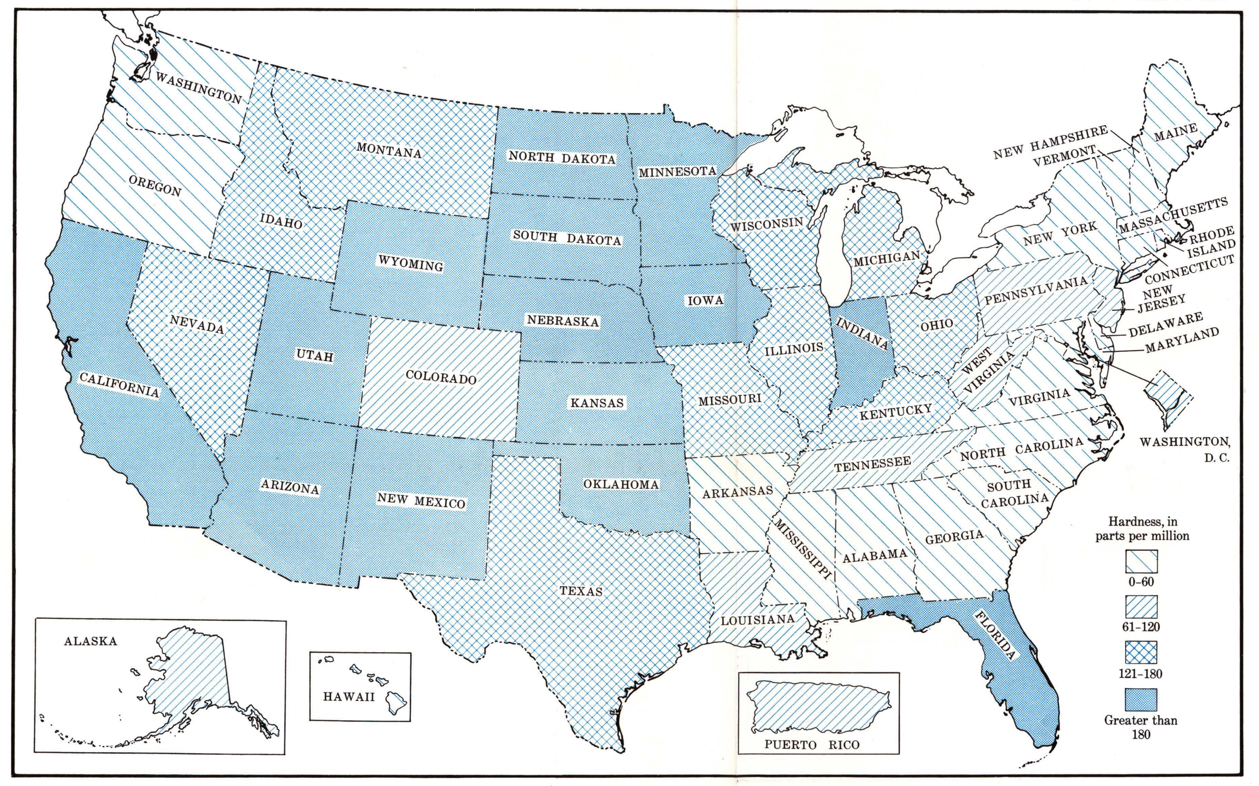
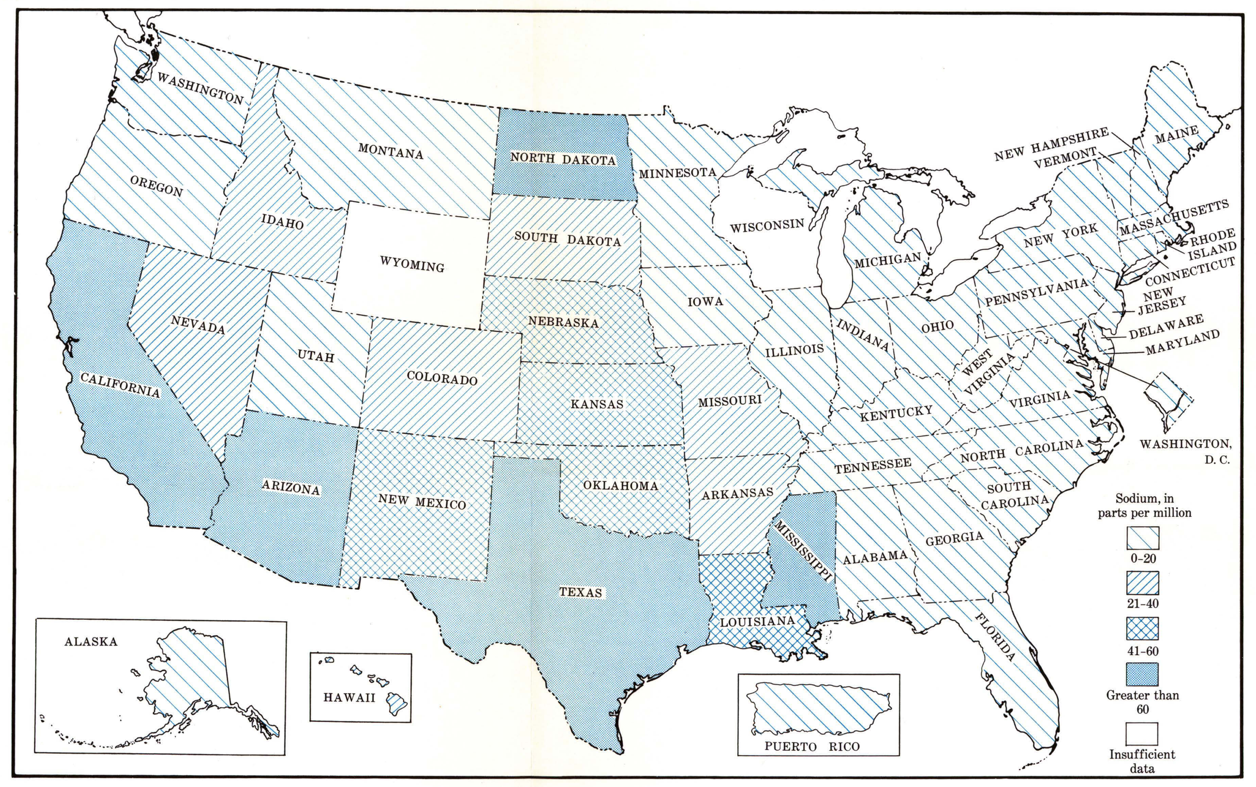
UNTREATED WATER SUPPLIES



MAP A.— *Dissolved solids in untreated public water supplies of the United States and Puerto Rico, 1962.*
(Average weighted by population served)



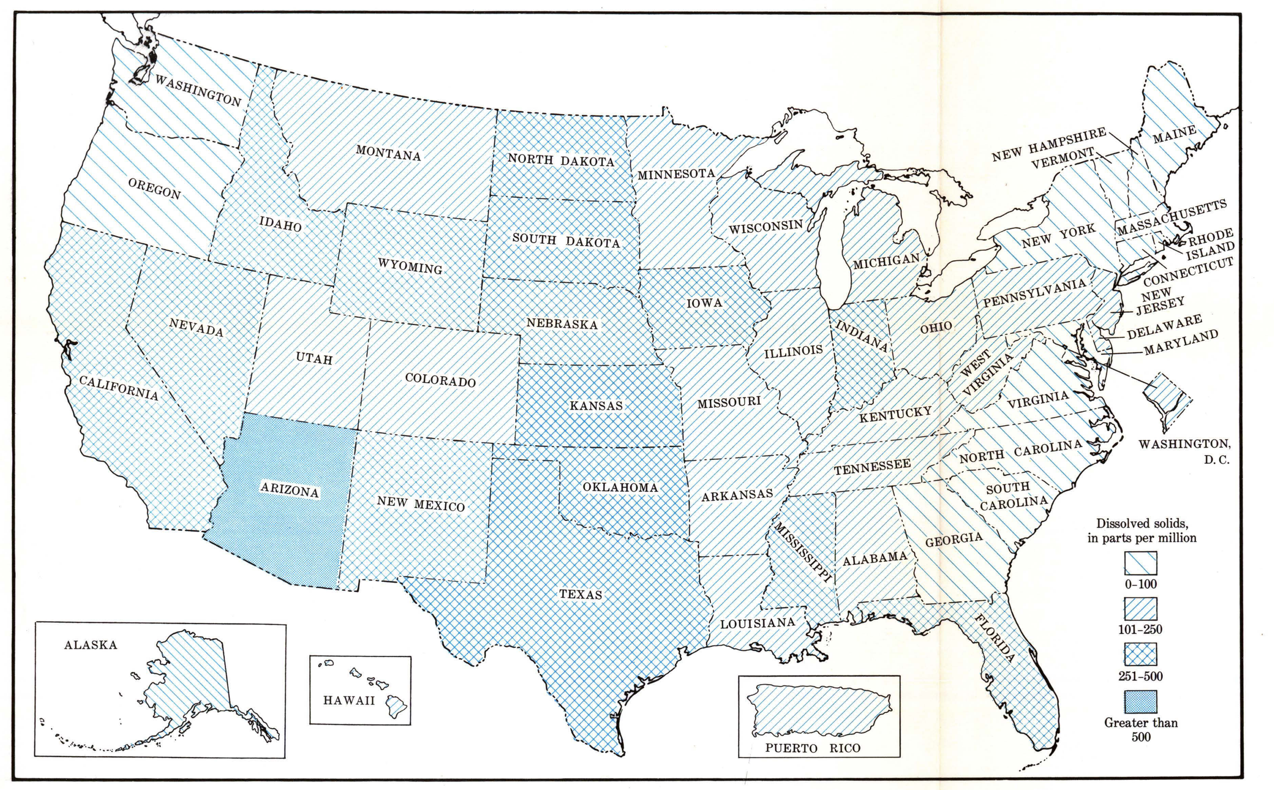
MAP B.— *Hardness of untreated public water supplies of the United States and Puerto Rico, 1962.*
(Average weighted by population served)



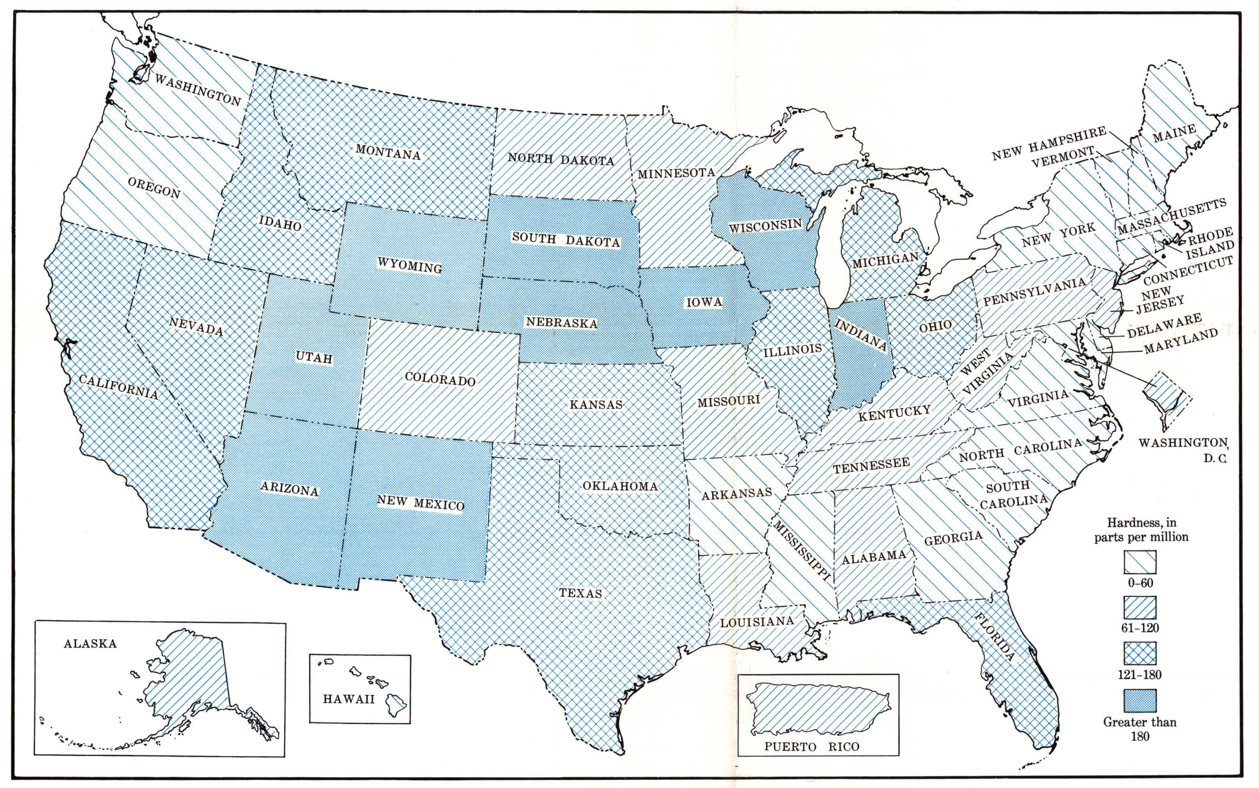
MAP C.— *Sodium in untreated public water supplies of the United States and Puerto Rico, 1962.*
(Average weighted by population served)

MAP D.— *Fluoride in untreated public water supplies of the United States and Puerto Rico, 1962.*
(Average weighted by population served)

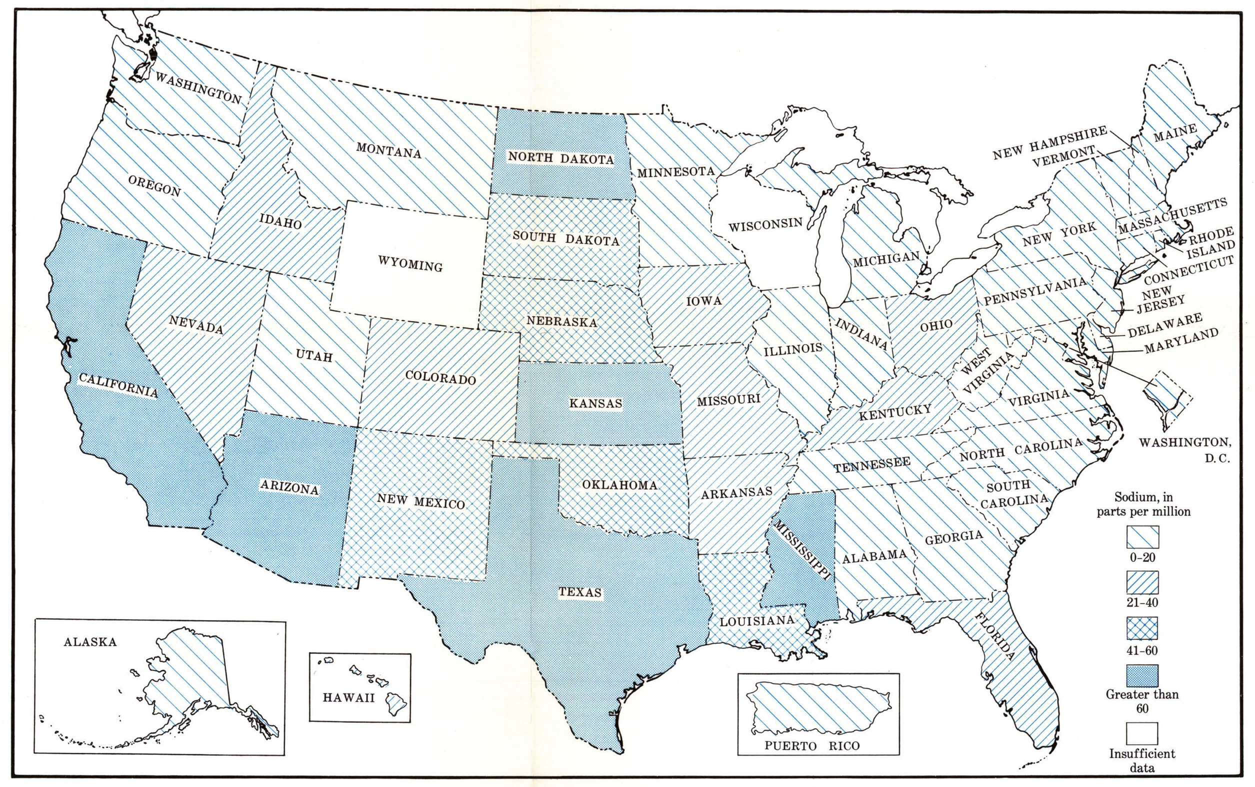
FINISHED WATER SUPPLIES



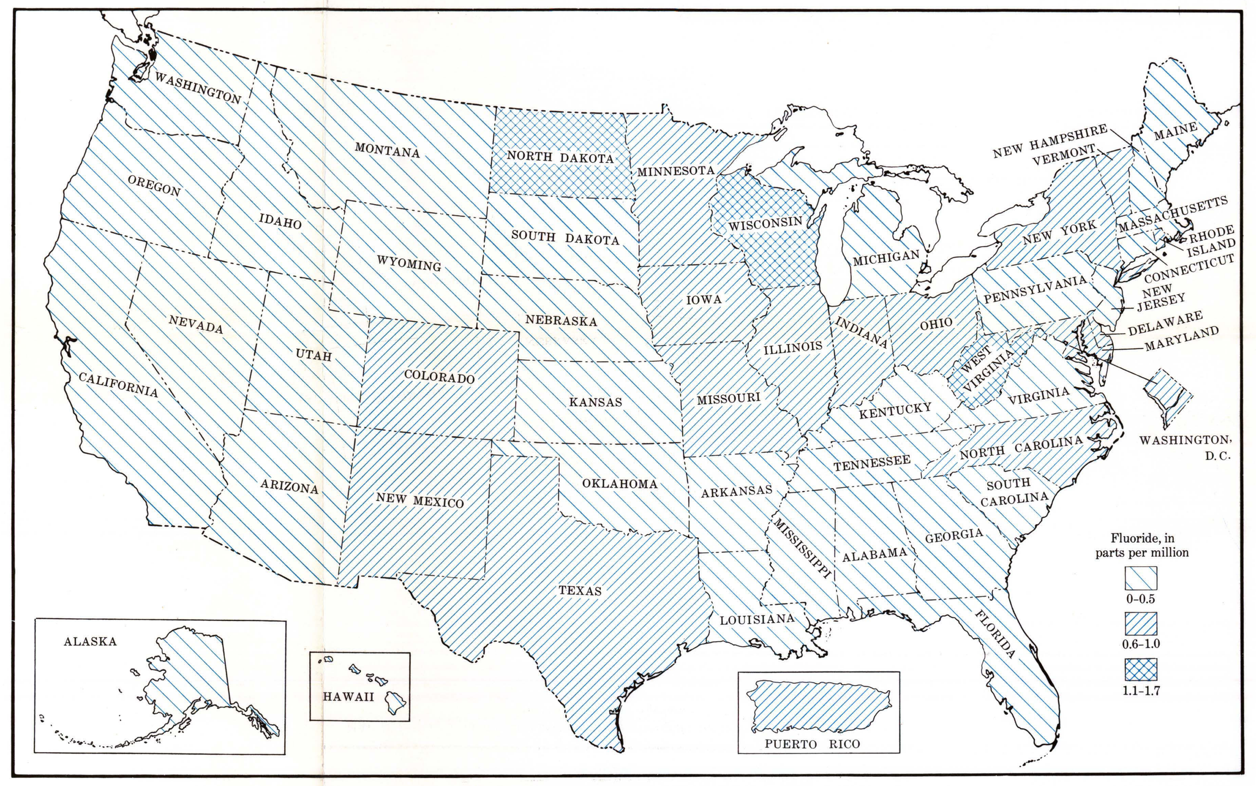
MAP E.— *Dissolved solids in finished public water supplies of the United States and Puerto Rico, 1962.*
(Average weighted by population served)



MAP F.— *Hardness of finished public water supplies of the United States and Puerto Rico, 1962.*
(Average weighted by population served)



MAP G.— *Sodium in finished public water supplies of the United States and Puerto Rico, 1962.*
(Average weighted by population served)



MAP H.— *Fluoride in finished public water supplies of the United States and Puerto Rico, 1962.*
(Average weighted by population served)

IMPORTANT ASPECTS OF THE WATER QUALITY IN PUBLIC WATER SUPPLIES

INTRODUCTION

Municipal water systems in the United States and Puerto Rico supply water for many commercial and industrial uses as well as for domestic uses. It is generally known that our water resources are unequally distributed throughout the country, but it is not quite so well understood that the quality of our water resources also is variable. This hydrologic investigations atlas shows, State by State, some of the chemical quality aspects of our public water supplies. This information can be used to evaluate the suitability of the public supplies for many uses—among them, manufacturing processes, food processing, cooling water, and domestic use.

The eight maps depict the dissolved-solids, sodium, and fluoride contents and the hardness of untreated and finished water supplies of 1,596 municipal water systems as of 1962. The information shown on the maps is discussed in the following text. Although maps of nitrate concentration were not prepared, the text discusses the sources and amounts of nitrate present in public supplies. Published and unpublished data used in this report were obtained from local, county, and State agencies, and also from the files of the district offices of the Water Resources Division, U. S. Geological Survey. Their cooperation is gratefully acknowledged. The published data are listed under "Selected References."

In the past 40 years many changes have taken place in our Nation's public water supplies which have affected the quality of water served. Among these changes one of the most important has been the search for better quality raw-water sources. Many cities were able to obtain new sources of supply and consequently the finished-water supplies were of better quality. This statement is strikingly illustrated by the State of Arkansas. In 1922, Arkansas' public water supplies had a Statewide average hardness of 149 ppm (parts per million); as a result of using better sources of water, finished-water hardness in 1932 was 106 ppm, by 1952 the hardness was down to 42 ppm and this hardness was maintained through 1962.

Another important change has been the improvement in municipal water-treatment practices. For example, in 1962, 28 of the 100 largest cities in the United States softened their water in contrast with 1922 when only 2 of these 100 cities softened their water (Durfor and Becker, 1964). However, not all cities changed their water sources or treatment practices and, consequently, in some areas the finished-water supply has changed little over the years as is shown by the State of Texas. In 1922, the Statewide average hardness of public water supplies in Texas was 136 ppm, in 1932 it was 135 ppm, in 1952 it was 132 ppm, and in 1962 it was 143 ppm. The hardness values of finished water (average weighted by population) for the United States and Puerto Rico over a 40-year period are shown in table 1.

The U. S. Geological Survey has been studying the quality of public water supplies for more than four decades. For 1922, Collins (1923) reported on 307 localities (36 percent of the Nation's total population); for 1932, Collins, Lamar, and Lohr (1934) reported on 670 localities (46 percent of the total population); and for 1952 Lohr and Love (1954) reported on 1,315 localities (58 percent of the total population). The present report surveyed 1,596 localities. Table 1 shows for each State, the District of Columbia, and Puerto Rico the number of municipal water systems included in this survey, the total population served, and the percentages of the State population and the urban population served by these systems. For the United States and Puerto Rico these figures represent a total of 103 million people or 81 percent of the urban population and about 57 percent of the total population.

The term "urban population" is used here as defined by the U. S. Bureau of Census (1963): "The urban population comprises all persons living in (a) places of 2,500 inhabitants or more incorporated as cities, boroughs, villages, and towns (except towns in New England, New York, and Wisconsin); (b) the densely settled urban fringe, whether incorporated or unincorporated, of urbanized areas; (c) towns in New England and townships in New Jersey and Pennsylvania which contain no incorporated municipalities as subdivisions and have either 25,000 inhabitants or more or a population of 2,500 to 25,000 and a density of 1,500 persons or more per square mile; (d) counties in States other than the New England States, New Jersey, and Pennsylvania that have no incorporated municipalities within their boundaries and have a density of 1,500 persons or more per square mile; and (e) unincorporated places of 2,500 inhabitants or more." In this investigation many water consumers living in "nonurban" areas received water from municipal water supplies. These nonurban consumers account for the fact that in some States the percentage of urban population served exceeds 100. For example, the District of Columbia water system furnishes water to several nonurban areas in nearby Maryland and Virginia and thus the percentage of urban population and State population given in table 1 is 144.

DISSOLVED SOLIDS

Map A depicts the dissolved-solids content of untreated water used for public supplies in the United States and Puerto Rico. No effort has been made to subdivide these data into ground-water or surface-water supplies. For each State the average dissolved-solids content has been weighted by the population served; this method gives an accurate picture of the dissolved-solids content of the water used by the majority of the population in that State. On map A and map E (dissolved-solids content in finished supplies) the dissolved solids are classified as follows: 0–100 ppm, 101–250 ppm, 251–500 ppm, and greater than 500 ppm.

Water boiled in a dish leaves a crust of salt composed principally of silica, calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, chloride, nitrate, and some water bound in the residue. Upon heating this residue, most of the water of crystallization is expelled and most bicarbonate is converted to carbonate. The residue dried at 180°C (called residue on evaporation) approximates the quantity of anhydrous chemicals in solution and is used as an indication of the dissolved-solids content of water.

The amount of dissolved solids in a stream is ever changing. Generally, the smallest amounts of dissolved solids are found near the headwaters and the largest amounts are found near the mouth. As an example, Minneapolis, Minn., draws water from the Mississippi River near its headwaters and its raw-water supply has only about half the amount of dissolved solids as does the raw-water supply of New Orleans, La., which draws water from the Mississippi near its mouth. The amount of dissolved solids in streams also varies with streamflow. Generally the minimum concentration of dissolved solids in streams occurs when streams are in flood; as the streamflow decreases, the concentration of dissolved solids in streams generally increases. A map showing the modal dissolved-solids contents of streams in the United States has been prepared by Rainwater (1962). Many cities impound stream water to provide for extended periods when water consumption exceeds streamflow. Water is diverted from streams into storage reservoirs (off-stream reservoirs) during periods of high streamflow when the dissolved-solids content of streams is at a minimum; the dissolved-solids content of water in these reservoirs is consistently lower than the average annual dissolved-solids content of the streams. Water collected in reservoirs located on streams (on-stream reservoirs) also is uniformly low in dissolved solids because the inflow flood water, which is low in dissolved solids, further reduces the dissolved-solids content of the water already in the reservoir.

The dissolved-solids content of ground water and the chemical composition of the dissolved solids depend largely on the rock formations of the area and generally do not vary greatly with time. Some rocks, such as granite, are nearly insoluble in water and have little influence upon the water in contact with them. Other rocks, such as limestone and dolomite, under certain conditions are highly soluble; water in contact with these rocks may dissolve large amounts of minerals.

Ground water is in contact with rocks for a longer time than is surface water and thus contains more dissolved minerals than adjacent surface water. Consequently, in a perennial stream the maximum dissolved-solids content occurs when the streamflow is low and is maintained by ground water.

Most municipalities treat the raw-water supply before serving the water to the consumer. Water may be chlorinated to make sure that the water is safe; the water may be filtered to remove suspended matter; the pH of water may be adjusted (usually with lime); the water may be aerated to remove iron and manganese; and the water may be softened by the addition of lime and soda ash or, in a few places, by cation exchange. Softening by lime and the removal of iron and manganese generally lower the dissolved-solids content; most other municipal water treatments slightly increase the dissolved-solids content.

Water containing more than 500 ppm of dissolved solids should not be used for drinking water if other less mineralized supplies are available according to drinking water standards promulgated by the U. S. Public Health Service. "Although waters of such quality are not generally desirable, it is recognized that a considerable number of supplies with dissolved solids in excess of the recommended limits are used without any obvious ill effects" (U. S. Public Health Service, 1962a). In many locations, efforts are made to obtain an adequate public water supply with small amounts of dissolved solids. However, a person accustomed to drinking water with a moderate amount of dissolved solids may complain about the "flat taste" of drinking water that has less than 100 ppm of dissolved solids.

Figure 1 shows the dissolved-solids content of water served to the millions of people in this survey. For example, 29 million people (28 percent) receive water containing 100 ppm or less, 72 million people (71 percent) receive water containing 250 ppm or less, and 89 million people (86 percent) receive water containing less than 500 ppm.

Public water supplies of the United States furnished 6,080 mgd (million gallons per day) of the 20,400 mgd used by industry in 1960 (MacKichan and Kammerer, 1961). Water is used in industry for three principal purposes: cooling, steam generation, and processing. About 95 percent of the water used in industry is for cooling; in cooling water the dissolved-solids content generally is of little consequence. A much smaller fraction of industrial water is used in the generation of steam. For boilers operating at pressures greater than 2,000 psi the water inside the boiler should contain less than 500 ppm of dissolved solids; at pressures of 300 psi or less the dissolved solids in the boiler water should be 3,500 ppm or less (Betz, 1962). Water used in processing comes into contact with the product being manufactured. The recommended limits of dissolved solids for process water are as varied as the industries that use water; some industries limit the dissolved solids in process water to less than 200 ppm, whereas other industries can use process water containing thousands of parts per million.

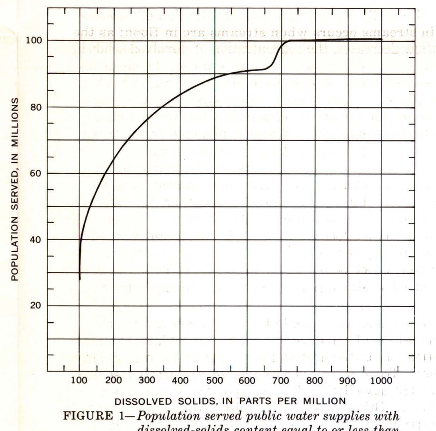


FIGURE 1—*Population served public water supplies with dissolved-solids content equal to or less than the amounts shown, 1962*

HARDNESS

Map B shows the average hardness for untreated public water supplies. For each State, the District of Columbia, and Puerto Rico the average hardness has been weighted by the population served. The hardness classification used here is:

Hardness range (in parts per million of calcium carbonate)	Hardness description
0–60	Soft.
61–120	Moderately hard.
121–180	Hard.
More than 180	Very Hard.

Hardness of water—caused principally by calcium and magnesium—is a measure of the amount of soap required to form a lather. Before a lather can form, part of the soap molecule must react with the calcium and magnesium in the water to form an insoluble curd. The smaller the amounts of calcium and magnesium, the easier soap suds are formed; conversely, the greater the amounts of calcium and magnesium, the more soap curds are formed and the more soap is consumed. Not many years ago the hardness of water was determined in the laboratory by the amount of soap solution needed to form suds. Today, hardness is calculated by determining the amount of calcium and magnesium in the water and expressing the results as the amounts of calcium carbonate chemically equal to the amount of calcium and magnesium in water. Aluminum, iron, manganese, and other heavy metals in water also consume soap, but the amount in which they are present in the water is generally small and their effect on hardness is insignificant.

Washing with hard water requires more soap than washing with soft water. Some people think that synthetic detergents are as effective in hard water as in soft water. However, most synthetic detergents contain about 30–50 percent sequestering ingredients that react with calcium and magnesium, the hardness components of water. A recent study indicated that three times the amount of synthetic detergents was required for water with a hardness of 400 ppm than for water with a hardness of 0 ppm (Aultman, 1957).

Hard water not only consumes excessive amounts of soap and detergent in homes and laundries, but also can be bothersome in industrial processing of foods and beverages, textile dyeing, and manufacturing of paper and synthetic rubber.

Many municipalities soften their water supply. The principal softening agents are lime and lime-soda ash, which convert the dissolved calcium and magnesium into bulky precipitates that settle out of the water as sludge. Also precipitated are iron, manganese, strontium, and possibly other trace elements. A few cities soften their water supply with a cation exchange system that replaces calcium and magnesium with nonhardness-causing sodium.

Water low in hardness usually has a low pH and thus can accelerate corrosion of metal surfaces, therefore some cities with "soft" water (hardness 0–60 ppm) add a small amount of lime to their water to raise the pH and thus slightly increase the hardness.

Map F, using the same classification as for untreated public water supplies, shows, by State, the hardness of finished water distributed by public systems. The population-weighted hardness values of finished water and the population served for each State, the District of Columbia, and Puerto Rico are given in table 1.

SODIUM

Sodium is a metal found in most waters. It and potassium—another alkali metal—generally occur in much smaller concentrations than calcium and magnesium. In humid areas, sodium is present in many surface and ground waters in tens of parts per million or less; tidal streams and streams affected by high-sodium waste waters may contain more than 1,000 parts per million. In arid regions, streams and ground waters contain more sodium than they do in humid regions; and streams and ground waters receiving waste water from irrigation and drainage from sodium beds may contain several thousands parts per million of sodium. In some areas, for example in southern Louisiana and southeastern Texas, sodium in soils is exchanged with calcium and magnesium in ground water; as a result the ground water is enriched in sodium and the hardness of such water is low or nonexistent.

Map C shows the Statewide averages of sodium in untreated public water supplies. On this map and the map showing sodium in finished public water supplies (map G) the sodium content in water is grouped as follows: 0–20 ppm, 21–40 ppm, 41–60 ppm, and greater than 60 ppm. For two States data were insufficient to calculate reliable population-weighted averages. Municipal water-treatment practices can raise the sodium content of public supplies. Soda ash (sodium carbonate)—used to raise the pH and used in conjunction with lime to soften water—increases the sodium content of water. Cation exchange for the removal of calcium and magnesium (softening) also increases the sodium content of treated water. No common municipal water treatment lowers the sodium content of water. Demineralization and distillation remove dissolved minerals (including sodium) from water, but these techniques are not commonly used in municipal water treatment.

Sodium in domestic water supplies is of current interest in planning sodium-restricted diets. These diets may limit the daily intake to 500 milligrams or in some cases to 100 milligrams (National Academy of Sciences, 1954). In many areas, the sodium content is low enough to be ignored; however, in some public water supplies the sodium content must be considered in the design of low sodium diets. For example, water with a sodium concentration of 40 ppm contains 40 milligrams of sodium per liter (about 1 quart) of water, thus a daily consumption of 2.5 liters (about 2.5 quarts) of water would provide 100 milligrams of sodium; 2.5 liters of water containing 60 ppm of sodium would provide 150 milligrams of sodium. Consequently, before effective sodium-restrictive diets can be designed the sodium content of water must be known.

FLUORIDE

Fluoride is an element found dissolved in most natural waters as a result of dissolution of fluoride from minerals such as amphibole, apatite, and fluorite. Map D shows the population-weighted average of fluoride, by State, in untreated public water supplies. On this map the fluoride content is grouped as 0–0.5 ppm and 0.6–1.0 ppm. In most raw waters used for public supplies the fluoride concentrations are less than 1 ppm. However, in some local areas the fluoride concentration in untreated water for public supplies exceeds 5 ppm but the population involved does not affect State averages.

Interest in these small amounts of fluoride in water was engendered by their effect upon tooth enamel. For more than 60 years the staining on enamel of teeth has been under investigation. Before fluoride was proved to be the cause of mottled enamel it was reasoned that some trace element in water caused the dental defect (McNeil, 1957). It was subsequently proved that fluoride concentrations of about 0.6 to 1.7 ppm reduced the incidence of dental caries and that concentrations greater than 1.7 ppm also protected the teeth from cavities but caused an undesirable black stain (U.S. Public Health Service, 1962a). For further information on physiological effects of fluoride the reader is referred to a selection of papers on the subject printed by the U.S. Public Health Service (1962b).

As a result of the cavity-preventing property of fluoride in water many municipalities have artificially introduced small amounts of fluoride into water supplies. Fluoride is added as sodium fluoride, sodium silicofluoride, or fluosilicic acid. The amount of fluoride added to water depends upon the recommended optimum level and the amount present in the natural water. The following statement and table are from U. S. Public Health Service (1962a).

"When fluoride is naturally present in drinking water, the concentration should not average more than the appropriate upper limit shown in the table. Presence of fluoride in average concentrations greater than two times the optimum values in the table shall constitute grounds for rejection of the supply.

"Where fluoridation (supplementation of fluoride in drinking water) is practiced, the average fluoride concentration shall be kept within the upper and lower control limits shown in the table."

Annual average of maximum daily air temperatures[1]	Recommended control limits — Fluoride concentrations in mg/1 [ppm]		
	Lower	Optimum	Upper
50.0–53.7	0.9	1.2	1.7
53.8–58.3	.8	1.1	1.5
58.4–63.8	.8	1.0	1.3
63.9–70.6	.7	.9	1.2
70.7–79.2	.7	.8	1.0
79.3–90.5	.6	.7	.8

[1] Based on temperature data obtained for a minimum of five years

Between 1945 and 1962, the number of communities that added fluoride to water increased from 6 to more than 2,000. In 1962, about 51 million people in the United States and Puerto Rico were using fluoridated water supplies (American Water Works Association, 1964). In the 1,596 cities of this report more than 43 million people obtained water containing between 0.6 and 1.7 ppm of fluoride. Map H shows the population-weighted average fluoride for finished public water supplies. The classification used on the map is 0–0.5 ppm, 0.6–1.0 ppm, and 1.1–1.7 ppm.

New York City, which serves a population of more than 8 million people, decided in December 1963 to fluoridate its water supplies.

NITRATE

Small amounts of nitrate are found in most natural waters; generally the concentrations of nitrate in most streams and ground waters are less than 10 ppm. Nitrate concentrations above 10 ppm are generally the result of (a) decomposition of plant and animal matter in shallow surface waters, (b) pollution from industrial wastes containing oxidizable nitrogen, and (c) leaching of soils to which organic or inorganic fertilizers containing oxidizable nitrogen have been applied. Less than 5 percent of the raw and finished supplies in this survey contained more than 10 ppm. Most municipal water-treatment practices have little effect upon the nitrogen content.

As a result of illness—particularly in infants less than several months old—caused by the ingestion of water containing large amounts of nitrate, the Public Health Service recommends that the nitrate concentration of drinking water should not exceed 45 ppm. They further recommend that "in areas in which the nitrate content of water is known to be in excess of the listed concentration [45 ppm], the public should be warned of the potential dangers of using the water for infant feeding" (U. S. Public Health Service, 1962a).

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TABLE 1.—*Hardness values (population weighted) of finished water and the population served by the public water systems of the United States and Puerto Rico, 1922, 1932, 1952, 1954, and 1962*

	Hardness of water, in parts per million (average weighted by population served)					Population served							Number of municipal systems included in 1962 survey (total —1,596)
										1962			
											Percentage of State—		
	1922 (307 cities)	1932 (670 cities)	1952 (1,315 cities)	1954	1962 (1,596 cities)	1922 (thousands)	1932 (thousands)	1952 (thousands)	1954 (thousands)	Thousands	Urban population	Total population	
Alabama	53	52	55	---	65	283	608	1,149	---	1,302	72.5	39.9	21
Alaska	---	---	---	63	67	---	---	---	53	73	84.9	32.3	13
Arizona	221	207	216	---	249	49	106	438	---	867	89.3	66.6	17
Arkansas	149	106	42	---	42	94	221	542	---	511	66.8	28.6	26
California	172	133	118	---	161	1,800	3,408	9,907	---	14,694	108.2	93.4	54
Colorado	144	122	107	---	100	330	418	754	---	1,273	98.4	72.6	41
Connecticut	25	24	29	---	35	826	1,144	1,504	---	745	37.5	29.4	11
Delaware	51	53	60	---	35	114	123	172	---	178	60.7	39.9	4
District of Columbia	80	90	96	---	117	438	503	803	---	1,100	144	144	1
Florida	296	148	123	---	141	204	573	1,480	---	1,736	47.1	44.2	50
Georgia	27	41	41	---	41	421	666	1,531	---	2,123	97.4	53.8	29
Hawaii	---	---	---	51	57	---	---	---	328	352	72.7	55.6	8
Idaho	91	85	119	---	152	36	66	226	---	261	82.3	39.1	16
Illinois	156	148	156	---	163	3,435	4,759	5,450	---	6,080	74.7	60.3	52
Indiana	264	243	237	---	235	873	1,321	1,881	---	2,567	88.2	55.1	99
Iowa	298	277	212	---	228	412	664	1,021	---	1,114	76.1	40.4	32
Kansas	316	274	176	---	152	223	500	803	---	1,154	86.8	53.0	28
Kentucky	90	105	102	---	118	387	606	963	---	1,099	81.2	36.2	20
Louisiana	54	62	68	---	71	431	620	1,203	---	1,497	72.6	46.0	17
Maine	18	15	20	---	25	127	251	411	---	348	70.0	35.9	10
Maryland	53	53	48	---	57	792	970	1,711	---	1,830	81.2	59.0	10
Massachusetts	14	21	23	---	21	2,668	3,120	3,644	---	3,522	81.8	68.4	24
Michigan	134	137	115	---	129	1,722	2,772	3,869	---	4,969	86.6	63.5	77
Minnesota	158	173	114	---	120	714	997	1,294	---	1,480	69.8	43.3	24
Mississippi	14	36	39	---	33	46	219	522	---	390	47.5	17.9	10
Missouri	148	134	106	---	110	1,245	1,713	2,256	---	2,770	96.2	64.1	43
Montana	91	98	120	---	146	66	124	244	---	335	99.1	49.6	15
Nebraska	239	213	247	---	191	247	346	511	---	638	83.2	45.2	15
Nevada	74	143	135	---	171	16	34	96	---	186	92.5	65.2	10
New Hampshire	9.7	19	28	---	28	107	218	277	---	120	33.9	20.0	6
New Jersey	48	71	75	---	101	1,983	2,796	3,874	---	4,305	80.1	71.0	30
New Mexico	126	205	237	---	214	22	63	272	---	567	90.7	59.6	22
New York	47	55	52	---	42	7,576	9,606	11,782	---	10,374	72.4	61.8	37
North Carolina	22	28	34	---	37	157	527	1,251	---	2,014	111.8	44.2	109
North Dakota	141	185	170	---	111	36	81	153	---	212	95.1	33.5	9
Ohio	153	160	150	---	131	2,767	3,671	4,851	---	6,309	88.6	65.0	117
Oklahoma	400	156	125	---	153	194	554	896	---	948	64.7	40.7	17
Oregon	9.6	13	17	---	14	276	396	758	---	800	72.7	45.2	14
Pennsylvania	69	83	86	---	82	3,556	5,329	6,707	---	6,110	75.4	54.0	38
Puerto Rico	---	---	---	127	83	---	---	---	780	1,114	107.2	47.4	12
Rhode Island	12	27	32	---	51	475	615	714	---	749	100.8	87.1	7
South Carolina	31	22	18	---	22	105	224	740	---	1,054	107.4	44.2	106
South Dakota	503	395	299	---	253	40	92	181	---	255	95.5	37.4	20
Tennessee	57	65	70	---	76	416	704	1,333	---	1,600	85.8	44.9	24
Texas	136	135	132	---	143	841	1,590	3,861	---	6,026	83.8	62.9	146
Utah	158	171	191	---	188	151	210	373	---	485	72.7	54.4	12
Vermont	39	63	53	---	57	38	69	124	---	108	72.0	27.7	6
Virginia	45	56	65	---	58	489	660	1,559	---	1,500	68.0	37.8	26
Washington	41	41	44	---	45	570	782	1,337	---	1,438	74.0	50.4	14
West Virginia	76	93	88	---	118	174	366	649	---	738	103.8	39.6	20
Wisconsin	145	163	167	---	187	760	1,229	1,614	---	695	27.4	17.6	18
Wyoming	119	154	171	---	189	25	62	135	---	149	79.2	45.2	9
Average hardness:													
United States	99	102	97	---	111	---	---	---	---	---	---	---	---
Puerto Rico	---	---	---	127	83	---	---	---	---	---	---	---	---
Total population served:													
United States	---	---	---	---	---	38,757	56,696	87,826	---	101,750	---	---	---
Puerto Rico	---	---	---	---	---	---	---	---	780	1,114	---	---	---

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CHEMICAL QUALITY OF PUBLIC WATER SUPPLIES OF THE UNITED STATES AND PUERTO RICO, 1962

SHOWN AS STATEWIDE AVERAGES, MAINLY IN GRAPHIC AND TABULAR FORM

By
Charles N. Durfor and Edith Becker

1964

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