1988

Hard Water : Occurrence, Health Effects, and Consumer Drinking Practices in Brookings and Sioux Falls, South Dakota

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HARD WATER: OCCURRENCE; HEALTH EFFECTS; AND CONSUMER DRINKING PRACTICES IN BROOKINGS AND SIOUX FALLS, SOUTH DAKOTA

By
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A thesis submitted in partial fulfillment
of the requirements for the degree
Master of Science
Major in Civil Engineering
South Dakota State University

1988

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ACKNOWLEDGEMENTS

The author is deeply indebted to Dr. Dwayne A. Rollag for his earnest assistance and knowledgeable advice.

Appreciation is extended to the responsible City officials of Brookings and Sioux Falls for allowing access to water department records and for their valuable assistance.

Recognition is also made to Dr. Robert Lacher of the Mathematics Department and Dr. Linda Baer of the Sociology Department at South Dakota State University for their advice in data collection and analysis.

And last but not least, a special thanks to Mrs. Cheryl Havrevold for typing the final draft of this thesis.

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INTRODUCTION

Background

Many benefits of hard water for drinking have been suggested in the literature. Investigations carried out the last 30 years have consistently demonstrated a negative association between water hardness and cardiovascular diseases (CVD). Calcium and magnesium, the principal causes of hardness in water, have often been identified as critical in the prevention of heart diseases. Also, it is claimed that trace amounts of certain minerals in water help insure proper human nutrition. On the other hand, sodium-rich soft water constitutes a potential health hazard, especially for those on sodium-restricted diets.

Recently, the importance of dietary calcium in the prevention of osteoporosis has been widely publicized in the popular press. Books dealing with this bone disease have identified calcium as the cornerstone of any osteoporosis prevention program. It is often noted that many people do not meet the recommended daily requirements of calcium.

One of the primary causes of hardness in water is calcium. Consequently, drinking hard water contributes calcium to the diet. The significance of this source of calcium is not well-established. In certain regions of the United States, calcium in drinking water may be substantial. Likewise, hard water can also be regarded as a potentially significant source of magnesium.

In light of the probable benefits of drinking hard water, it would be anticipated that wherever hard water is available, dwellings would be plumbed to provide this water to the drinking tap. However, casual surveys in certain South Dakota communities had revealed that the plumbing is arranged in some dwellings so that drinking water available at the tap has been subjected to on-site softening. As a result, the water consumer has not only been deprived of the benefits of drinking hard water, but also subjected to the health hazards of drinking high-sodium water from ion-exchange softeners. The primary objective of this research was to determine the extent to which water softeners in residential homes are plumbed in such a manner that only soft water is available for drinking, thus depriving consumers of an important source of calcium and magnesium.

Objectives

The objectives of the research were:

1. To identify regions of the United States where hard water supplies are available and those with soft water supplies.
2. To review the literature on the relation between hardness of water and CVD and establish the current views on this subject.

3. To establish the current most suitable daily calcium requirement for good health and prevention of osteoporosis based on age and gender as established by the medical and scientific community.
4. To determine the extent to which drinking water currently contributes to the daily calcium and magnesium requirement.
5. To determine the extent to which dwellings in two cities in South Dakota have been plumbed to provide water for drinking that has been softened by on-site, ion-exchange units where hard water could have been provided instead.

By meeting the objectives outlined in this research, information regarding the many health benefits of drinking hard water and the hazards of drinking soft water could be enumerated. Also, the extent to which consumers drink on-site softened water when hard water is available will be estimated. If this practice appears extensive, this information could be used to publicize the need for changes in plumbing codes and procedures to ensure full advantage is taken of the health benefits of drinking hard water.

LITERATURE REVIEW

Introduction

The purpose of this literature review is to enumerate the health benefits of drinking hard water and any health hazards of drinking soft water. Other topics that are covered include the chemistry of water hardness, location of hard and soft water regions in the U.S., sodium levels in public water supplies, and the current drinking water standards that are being used, both locally and internationally.

The main topics addressed in this review concern the health effects of water hardness and the contribution of drinking water to mineral nutrition. Within these areas of studies, greater attention will be paid to the relationship between water hardness and CVD and the contribution of calcium in drinking water towards the prevention of osteoporosis.

Many investigations and studies have been conducted on the relationship between incidences of CVD and the hardness or softness of drinking water. Because these investigations spanned a period of three decades and were spread over several continents, a voluminous amount of literature on the subject has accumulated. One of the objectives of this review will be to summarize the studies that have been done and establish the current views on this subject.

Recently, a generous amount of publicity regarding the role of calcium in the prevention of osteoporosis has been generated in the mass media. A second major objective of this review will be to establish the current most suitable daily calcium requirement for good health and prevention of osteoporosis based on age and gender, and to determine the extent to which drinking water currently contributes to the daily calcium requirement.

Chemistry of Water Hardness

Definition of Hardness

Several definitions for hardness are in common use.

1) "The hardness of water is that property attributable to the presence of alkaline earths". (1)
2) "Hardness is a characteristic of water generally accepted to represent the total concentration of calcium and magnesium ions". (2)
3) "Hard waters are generally considered to be those waters that require considerable amounts of soaps to produce a foam or lather and that also produce scale in hot-water pipes, heaters, boilers, and other units in which the temperature of water is increased materially". (3)

Water hardness is caused by dissolved polyvalent metallic ions. Such ions react with soap to form precipitates and with certain anions present in the water to form scale. Calcium and magnesium are the principal hardness-causing ions present in natural waters. Strontium and barium are present in very low concentrations, whereas iron, manganese, and aluminium are usually not present in sufficient concentrations to affect the test for hardness (3).

Because hardness is a property not attributable to a single constituent, it is normally expressed in terms of an equivalent concentration of calcium carbonate ($CaCO_3$). Calculation of hardness is obtained by using the general formula:

Hardness (in mg/l) as $CaCO_3$ = M (in mg/l) * 50/EW of M ... EQN (1)

where M represents any polyvalent metallic ion.

<u>Classification of Hardness</u>

Hardness is generally classified in two categories, with respect to the metallic ions, and with respect to the anions associated with the metallic ion (3).

1) Calcium and Magnesium Hardness

Total hardness = Calcium + Magnesium hardness ...EQN (2)

2) Carbonate and Noncarbonate Hardness

Carbonate hardness is that part of the total hardness that is chemically equivalent to the bicarbonate plus carbonate alkalinities in solution.

Noncarbonate hardness = Total hardness − Carbonate hardness ... EQN (3)

Carbonate hardness was formerly called temporary hardness because it can be precipitated by boiling. Noncarbonate hardness was formerly called permanent hardness because it cannot be removed by boiling. Noncarbonate cations are associated with sulfate, chloride, and nitrate anions.

There are two different classifications of waters in terms of the degree of hardness. Durfor and Becker (5) used the following classifications:

Table 1. Classification of Hardness (5)

Hardness range, mg/l as $CaCO_3$	Classification
0 - 60	Soft
61 - 120	Moderately Hard
121 - 180	Hard
> 180	Very Hard

Sawyer (6) on the other hand, used the following classification:

Table 2. Classification of Hardness (6)

Hardness range, mg/l as $CaCO_3$	Classification
0 - 75	Soft
75 - 150	Moderately Hard
150 - 300	Hard
> 300	Very Hard

Both classifications are widely used. Durfor and Becker's classification is used in the World Health Organization's (WHO) Guidelines for Drinking Water Quality, Vol. 2 (7), U.S. Geological

Survey Water-Supply Paper 1473 (8), and the National Academy of Sciences Panel on the Geochemistry of Water in Relation to Cardiovascular Disease (4). Sawyer's classification is used in the U.S. Environmental Protection Agency's (EPA) Quality Criteria for Water (9).

Effects of Municipal Treatment

Treatment processes used in water treatment plants depend on the raw-water source and quality of finished water desired. In most hard-water cities the hardness concentration is lowered considerably by water treatment (4). Water can be softened by processes based on ion exchange and by processes based on chemical precipitation. In the ion-exchange method, calcium and magnesium are removed and replaced with sodium from a cation resin.

In the chemical precipitation process, hydrated lime ($Ca(OH)_2$) and soda ash (Na_2CO_3) are used. Treatment of water with lime removes the carbonate portion of hardness. Noncarbonate hardness (calcium and magnesium sulfates or chlorides) can be precipitated using soda ash. The addition of both lime and soda ash, the so-called lime-soda softening process, also increases the sodium content of the water.

Effects of Home Treatment (4)

There has been a considerable increase in the use of water softeners in residential homes in the last few years. Cation-exchange is the most widely-used water-softening process for residential units. The type of ion-exchange materials used include synthetic resins and gel zeolites. When water containing calcium and magnesium salts flows through the ion exchanger, the calcium and magnesium are adsorbed on the resin, which in turn simultaneously releases sodium ions in exchange. These sodium containing molecules are water soluble. For each calcium or magnesium ion removed, two sodium ions are introduced into the solution. Throughout the process, the concentrations of the anions remain unchanged. Small amounts of dissolved iron and manganese will also be removed.

Location of Hard and Soft Water Regions in the U.S.

The hardness of water varies considerably from place to place. In general, surface waters are softer than groundwaters. The four maps in Figures 1 through 4 show the hardness of surface water, groundwater, untreated public water supplies, and treated public water supplies in the U.S. (10).

Hardness of Surface Water

Figure 1 depicts the five separate ranges of hardness of surface waters in the U.S., with the hardest surface water

(>240 mg/l) found in parts of Nebraska, South Dakota, and North Dakota.

Hardness of Groundwater

Figure 2 shows the general pattern of hardness of groundwaters in the U.S. In general, hard waters originate in areas where the topsoil is thick and limestone formations are present. The large hard water area in the north central part of the U.S. is underlain mainly by limestone. The patterns shown on the map do not imply that all groundwater in a specific area have exactly the same hardness; they merely indicate that most of the groundwater in any given region displays the indicated hardness range.

Hardness of Untreated Public Water Supplies

Figure 3 indicates the average hardness of raw, untreated municipal water supplies. No distinction is made as to whether the water comes from surface water or groundwater sources. The hardness shown reflects only the average hardness, and does not depict the natural wide range in hardness that normally is encountered when all of the water resources of any particular state are examined.

Hardness of Finished Public Water Supplies

Figure 4 reveals the average hardness of finished water, which is the water actually delivered to homes after treatment. After municipal treatment, the hardness of water is usually reduced. In some municipalities where the raw water is extremely hard,

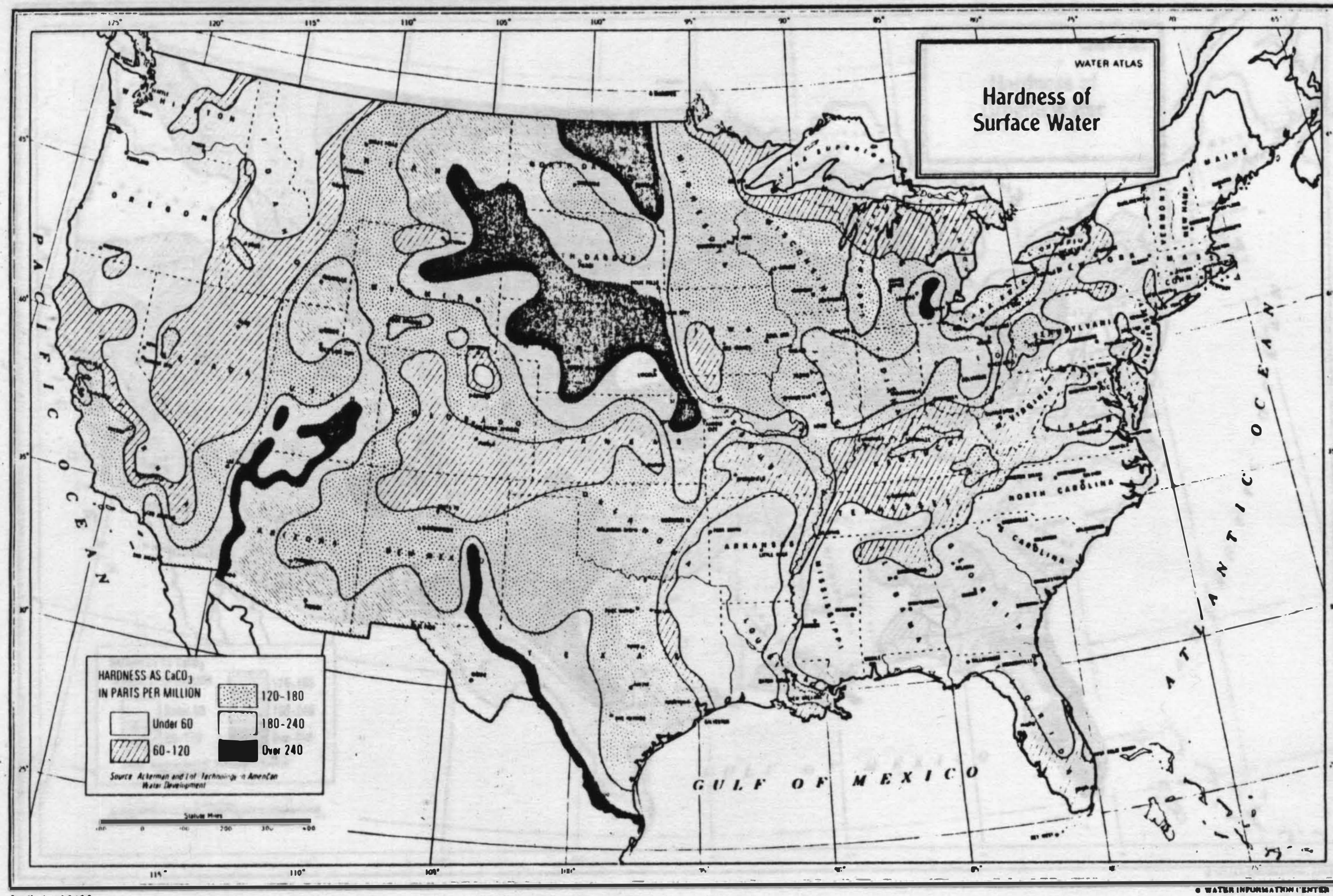

Figure 1. Hardness of Surface Water (10)

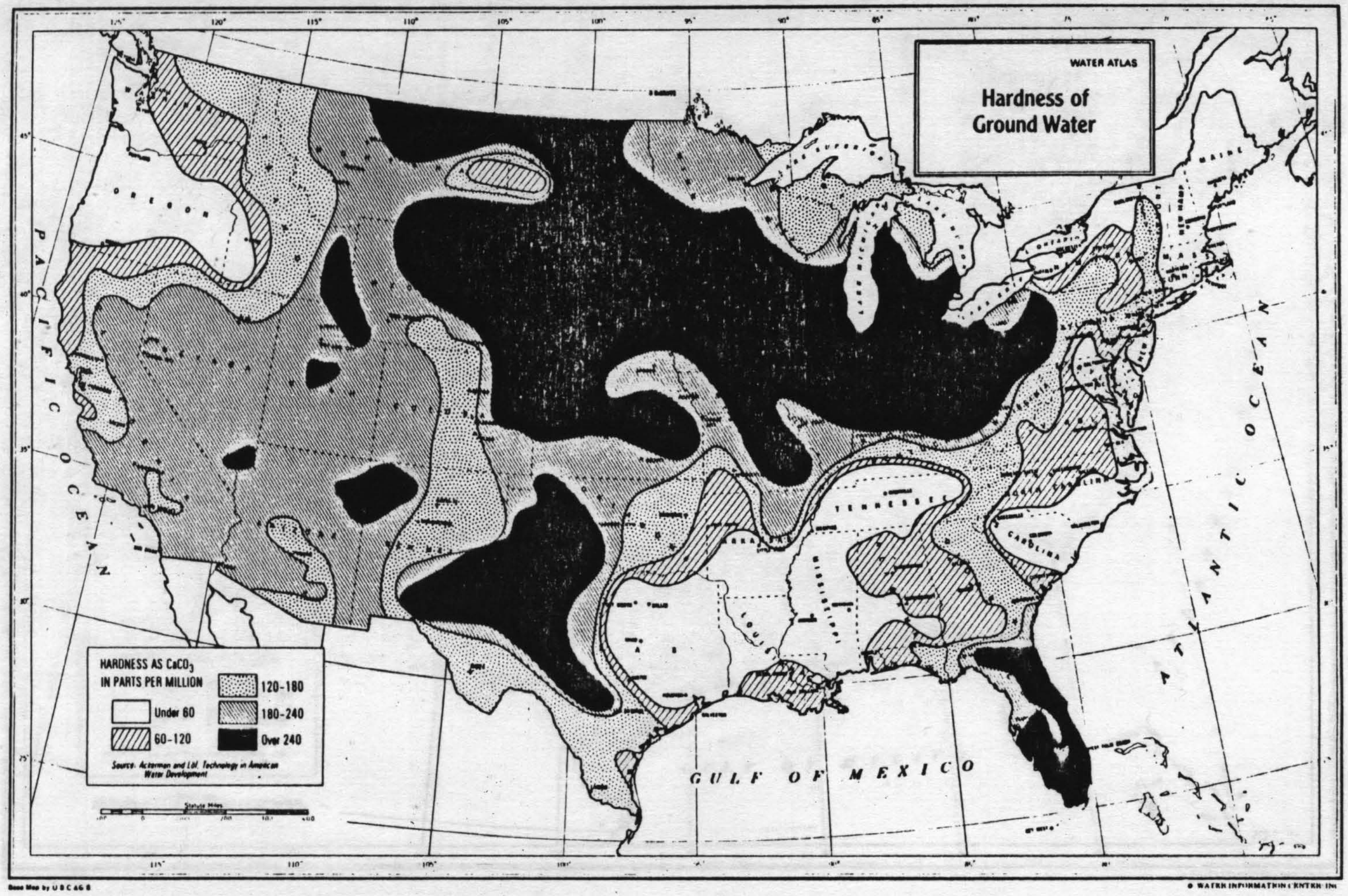

Figure 2. Hardness of Groundwater (10)

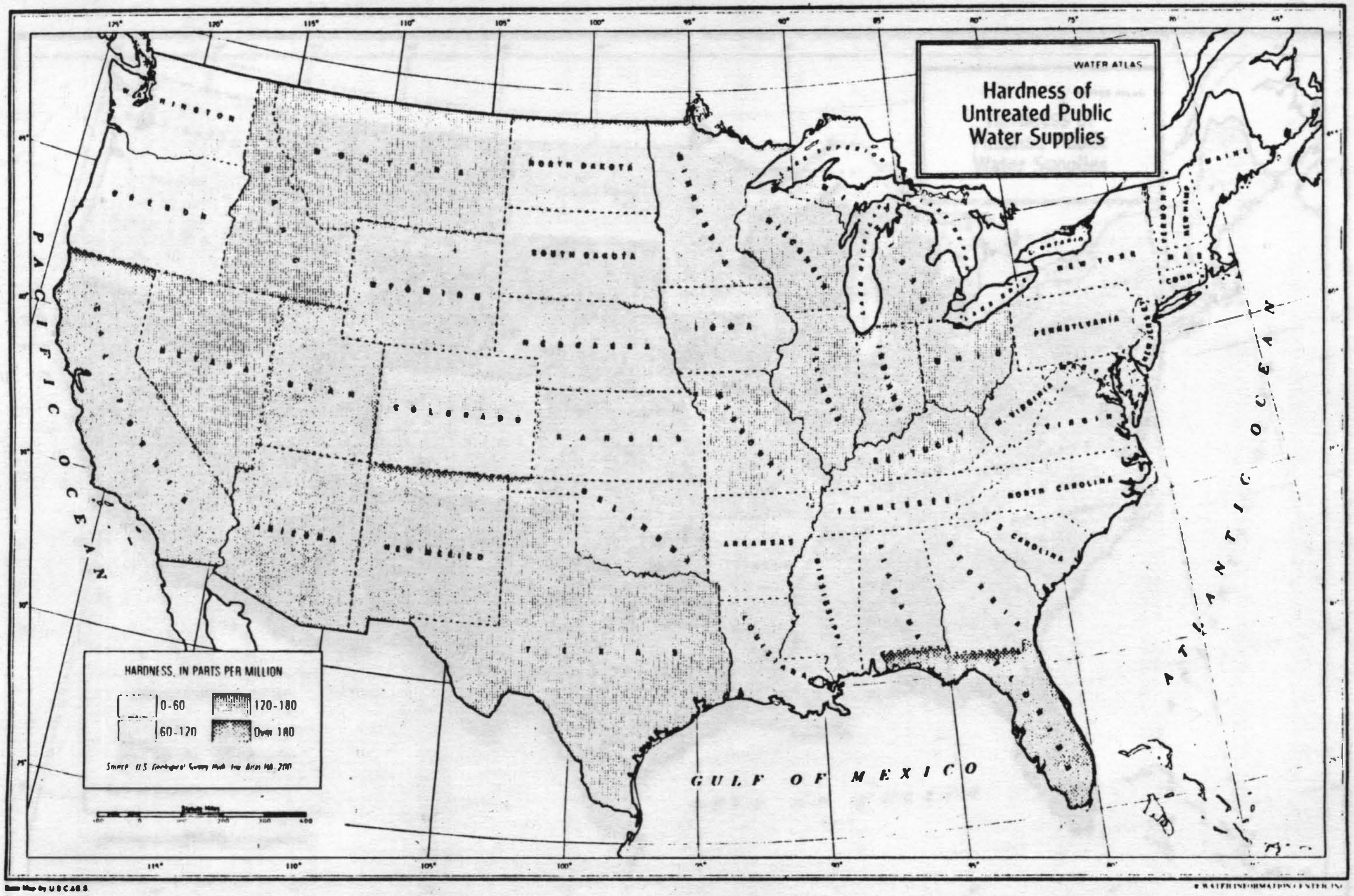

Figure 3. Hardness of Untreated Public Water Supplies (10)

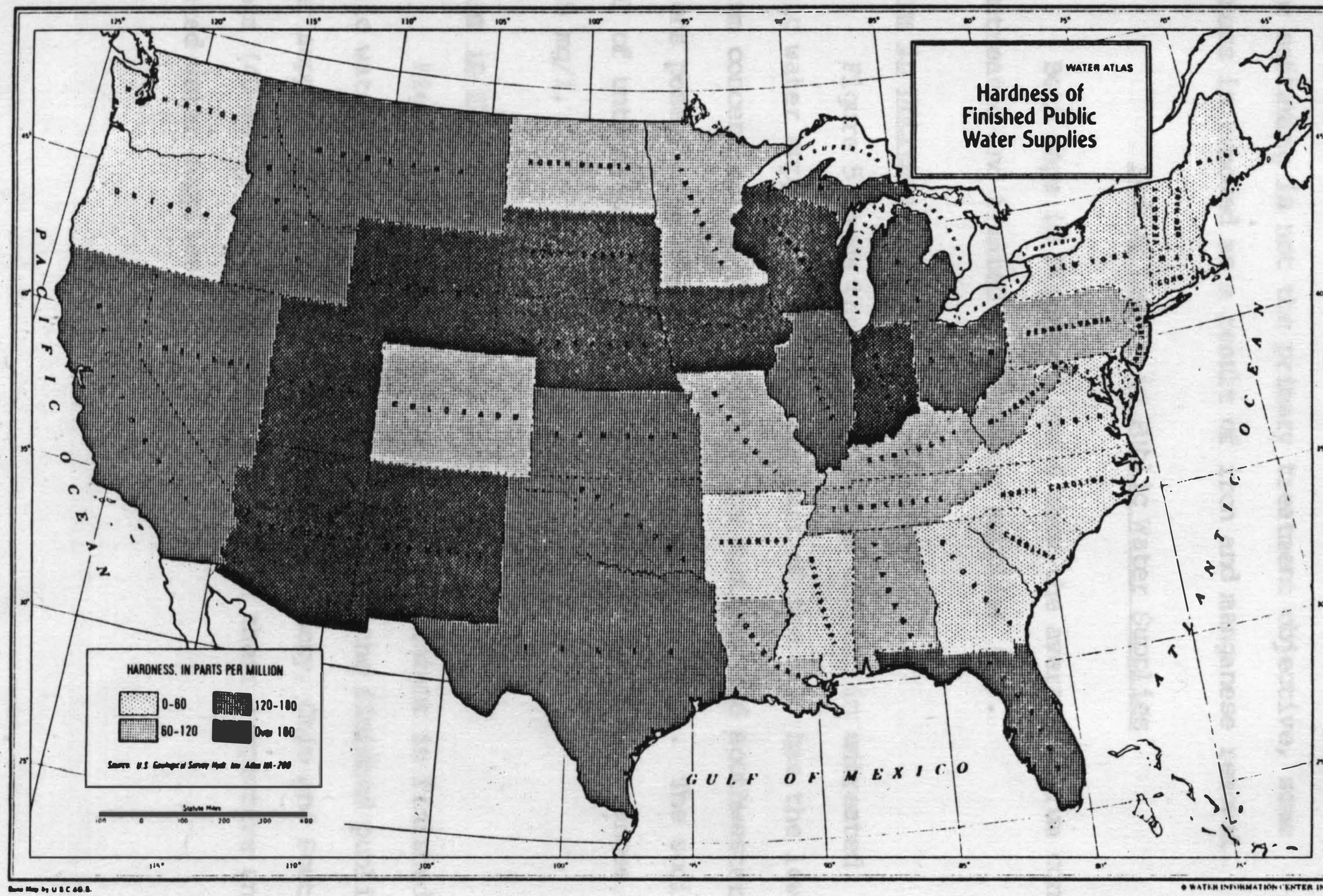

Figure 4. Hardness of Finished Public Water Supplies (10)

softening processes are used to reduce the degree of hardness. Even where softening is not the primary treatment objective, some hardness is removed as a result of iron and manganese removal.

Sodium Levels in Public Water Supplies

Both maps in Figures 5 and 6 show the average sodium content in untreated and treated public water supplies (10).

Sodium in Untreated Public Water Supplies

Figure 5 shows the average sodium content in untreated public water supplies. The eastern part of the U.S. has the lowest sodium concentrations (0-20 mg/l). The southern and southwestern regions possess the highest concentrations (>60 mg/l). The sodium level of untreated public water supplies in South Dakota ranges from 20-40 mg/l.

Sodium in Finished Public Water Supplies

Figure 6 presents the average sodium content in finished public water supplies. It is noteworthy that the finished public water supplies of Florida, Iowa, Kansas, Kentucky, Ohio and South Dakota (40-60 mg/l) contain more sodium than their respective untreated water supplies.

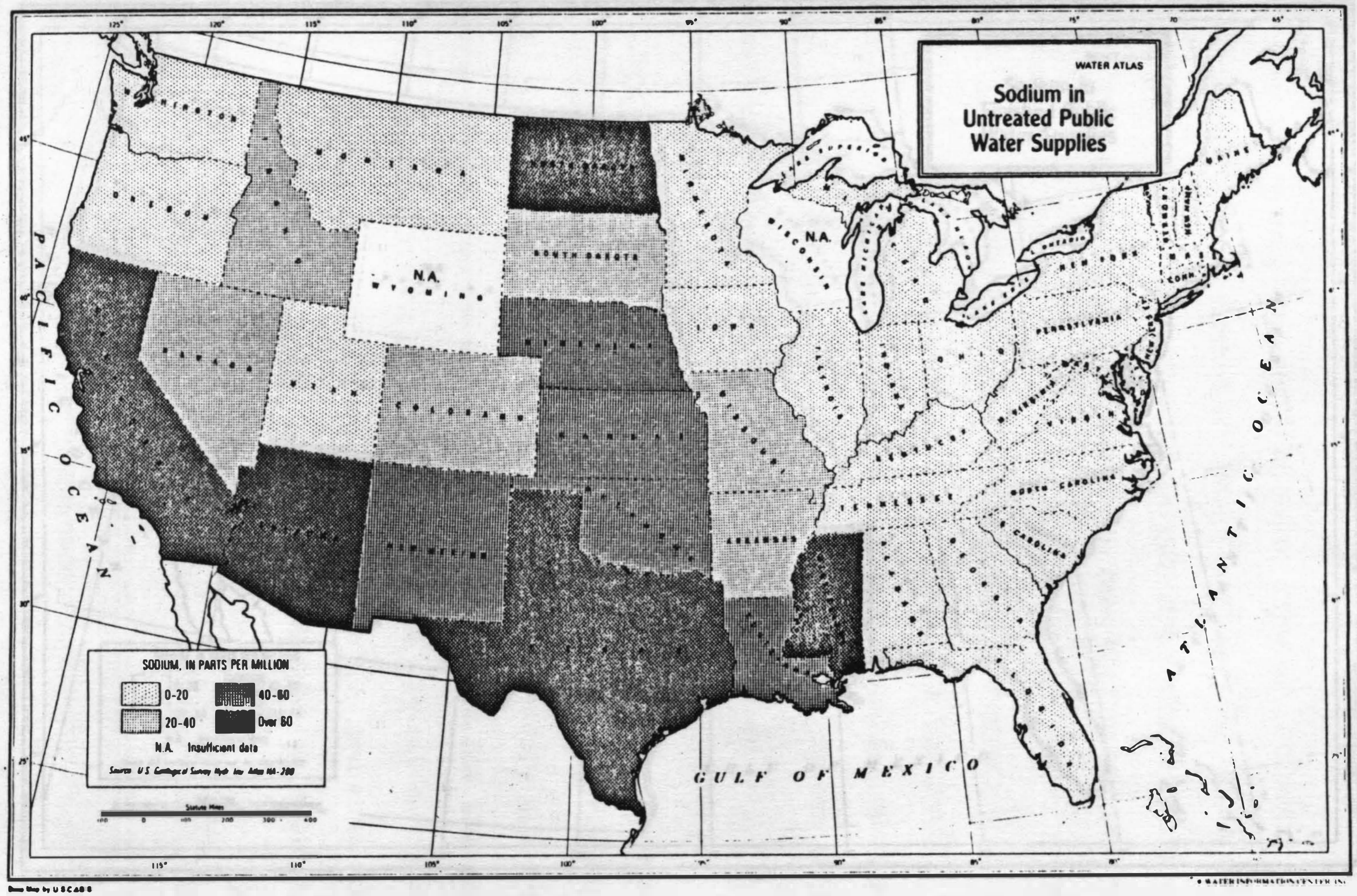

Figure 5. Sodium in Untreated Public Water Supplies (10)

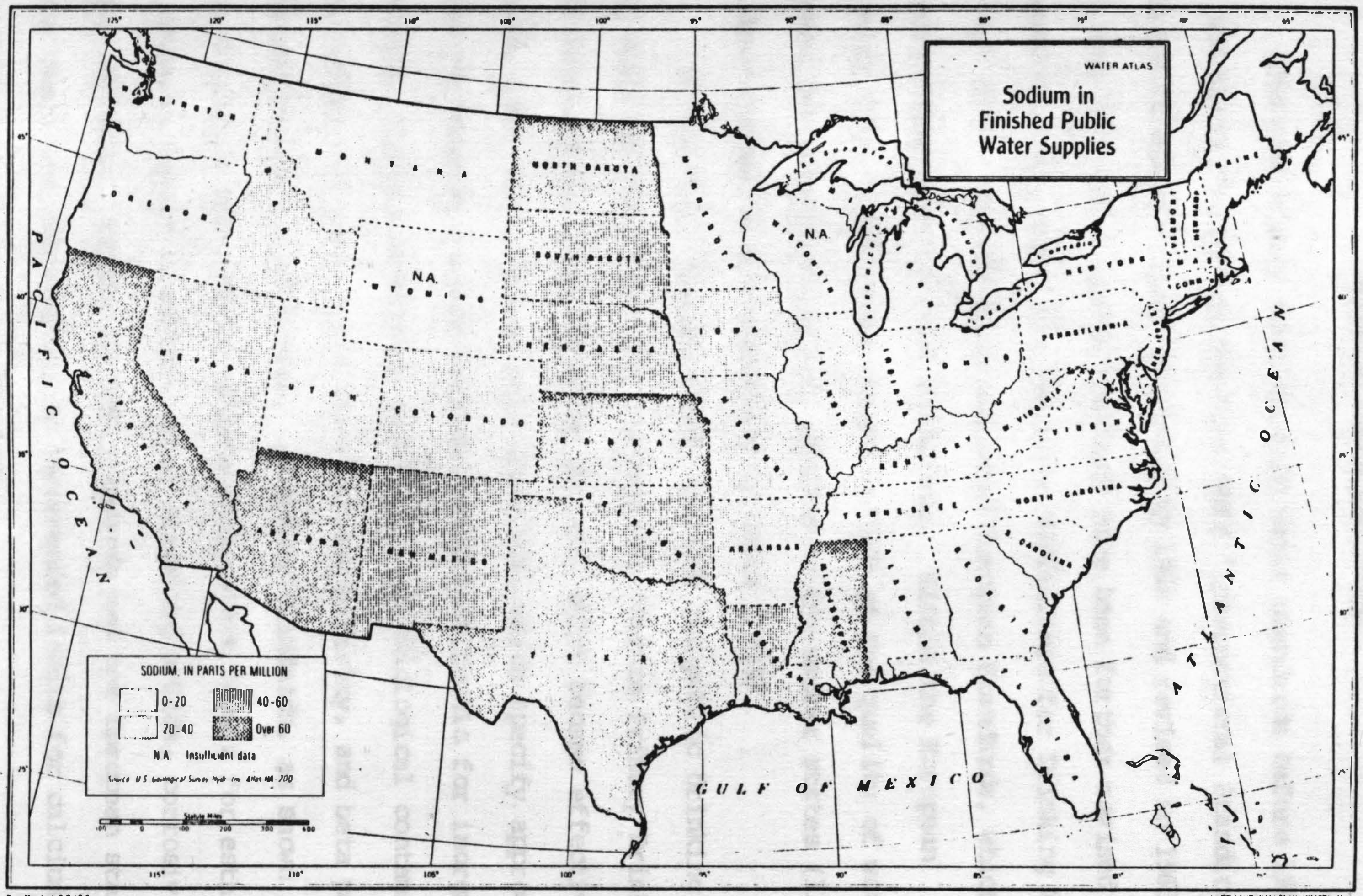

Figure 6. Sodium in Finished Public Water Supplies (10)

Drinking Water Standards

The most-widely used drinking water standards before 1983 were the World Health Organization (WHO) "International Standards for Drinking Water", first published in 1958 and revised in 1963, 1968, and 1971 (11). These standards have been further revised and reissued in 1983, under the new title "Guidelines for Drinking Water Quality" (12). The WHO also published European Standards, which are now merged into the WHO 1983 Guidelines. Within the European Community (EC), a directive issued in 1980 on the quality of water intended for human consumption, applies to the member states (130). All three standards are summarized in Table 3 (14).

In the U.S., the standards by which all public drinking water supplies are judged are the National Interim Primary Drinking Water Regulations, promulgated by the EPA, which became effective on June 24, 1977 (15). The primary standards, which specify approval limits for health, include maximum contaminant levels for inorganic chemicals, organic chemicals, turbidity, microbiological contamination, radium and gross alpha particle radioactivity, and beta particle and photon radioactivity. Secondary standards, as shown in Table 4 include recommended maximum contaminant levels for esthetics including inorganic chemicals, total dissolved solids, corrosivity, color, and odor. Unlike the WHO standards and the European standards, there are, at present, no recommended limits for calcium, magnesium, sodium, or total hardness.

Table 3. WHO Drinking Water Standards (14)

Substance or characteristic		Unit	WHO: 1983 Guidelines	WHO: 1971 International Standards		EC Directive 1980 relating to the quality of water intended for human consumption	
			Guideline value[a]		Upper limit of concentration (tentative)	Guide level (GL)	Maximum admissible concentration (MAC)
Inorganic constituents of health significance							
*Antimony	Sb						0.01
*Arsenic	As		0.05		0.05		0.05
*Cadmium	Cd		0.005		0.01		0.005
*Chromium	Cr		0.05				0.05
*Cyanide	CN		0.10		0.05		0.05
Fluoride	F	mg/l	1.5		0.9–1.7[b] 0.6–0.8[c]		1.5[b] 0.7[c]
*Lead	Pb		0.05		0.10		0.05[d]
*Mercury	Hg		0.001		0.001		0.001
*Nickel	Ni						0.05
Nitrates			10 (as N)		45 (as NO_3)	25 (as NO_3)	50 (as NO_3)
*Selenium	Se				0.01		0.01
Organic constituents of health significance							
*Pesticides and related products[e]			Volume I of the Guidelines lists 18 compounds and their guideline values				
individually							0.0001
in total							0.0005
*PAH—six reference substances		mg/l					0.0002
Other organochlorine compounds additional to pesticides etc						0.001	Haloform concentration must be as low as possible
				Highest desirable level	Maximum permissible level		
Other characteristics or substances							
Colour		Hazen	15	5	50	1	20
Odour			Inoffensive	Unobjectionable			2 or 3 TON[f]
Taste			Inoffensive	Unobjectionable			2 or 3 TON[f]
Suspended solids						None	
Turbidity		JTU	5	5	25	0.4	4
pH			6.5–8.5	7.0–8.5	6.5–9.2	6.5–8.5	9.5 (maximum value)
Temperature		°C				12	25
Aluminium	Al		0.20			0.05	0.20
Ammonium	NH_4					0.05	0.50
Barium	Ba					0.10	
Boron	B					1.0	
Calcium	Ca			75	200	100	
Chloride	Cl		250	200	600	25	
Copper	Cu			0.05		0.10[g]	
Hydrogen sulphide	H_2S		Not detectable				Not detectable
Iron	Fe		0.30	0.10	1.0	0.05	0.20
Magnesium	Mg			30[h]	150	30	50
Manganese	Mn		0.10	0.05	0.50	0.02	0.05
Nitrite	NO_2	mg/l					0.10
Phosphorus pentoxide	P_2O_5					0.40	5.0
Potassium	K					10	12
Silver	Ag						0.01
Sodium	Na		200			20	175[i]
Sulphate	SO_4		400	200	400	25	250
Zinc	Zn			5.0	15	0.10[g]	
Anionic detergents				0.2	1.0		0.20[j]
Mineral oil				0.01	0.30		0.01[k]
Phenolic compounds				0.001	0.002		0.0005[l]
Total dissolved solids			1000	500	1500		1500
Conductivity		µS/cm				400	
Total hardness as $CaCO_3$		mg/l	500	100	500		—[m]

(a) The guideline value must be interpreted according to comments made in Volume I of the Guidelines. It is not to be interpreted as a maximum permissible value
(b) For water temperature 10–12 °C (WHO), 8–12 °C (EC)
(c) For water temperature 26.3–32.6 °C (WHO), 25–30 °C (EC)
(d) Applies to running water or after flushing lead pipes
(e) Includes insecticides, herbicides, fungicides, PCBs, and PCTs
(f) TON = threshold odour number, dilutions 2 at 12 °C, 3 at 25 °C
(g) Measured at outlet of works
(h) May be up to 150 mg/l as sulphate reduces below 250 mg/l
(i) To be reduced to 150 mg/l by year 1987
(j) Value quoted for 'surfactants (reacting with methyl blue)'
(k) Value quoted for 'dissolved or emulsified hydrocarbons (after extraction by petroleum ether): mineral oils'
(l) Excludes natural phenols not reacting with chlorine
(m) Minimum hardness after softening must be 60 mg/l Ca (equivalent to 150 mg/l as $CaCO_3$)
*Classified as 'Toxic Substances' in the EC Directive

Table 4. EPA Primary and Secondary Drinking Water Standards (15)

Primary Standards for Maximum Contaminant Levels
(Approval Limits for Health)

Microbiological contaminants

When 10-ml portions of water are tested by the multiple-tube fermentation method, not more than 10% in any month shall show the presence of coliform bacteria. No more than three portions from one sample shall contain coliforms where less than 20 samples are tested per month; in larger systems, no more than three portions may be positive in 5% of the samples analyzed. (If the portions tested are 100 ml, not more than 60% shall show presence of coliforms.) When the membrane filter technique is used with 100-ml portions, the arithmetic mean coliform density shall not exceed 1 per 100 ml. The maximum density in one sample is 4 per 100 ml for less than 20 samples per month, or 5% of the samples where more than 20 samples are tested per month.

Inorganic chemicals in milligrams per liter

Arsenic	0.05	Mercury	0.002
Barium	1.0	Nitrate (as N)	10.0
Cadmium	0.010	Selenium	0.01
Chromium	0.05	Silver	0.05
Lead	0.05		

Recommended and approval limits in milligrams per liter for fluoride are based on the annual average of the maximum daily air temperatures.

Temperature (°F)	Recommended Optimum	Approval Limit
53.7 and below	1.2	2.4
53.8–58.3	1.1	2.2
58.4–63.8	1.0	2.0
63.9–70.6	0.9	1.8
70.7–79.2	0.8	1.6
79.3–90.5	0.7	1.4

Organic chemicals in milligrams per liter

Chlorinated hydrocarbons	
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
Chlorophenoxys	
2,4-D	0.1
2,4,5-TP (Silvex)	0.01

Trihalomethanes

Total trihalomethanes	0.10

Radionuclides in picocuries per liter

Natural	
Gross alpha activity	15
Radium-226 + radium-228	5
Man-made	
Gross beta activity	50
Tritium	20,000
Strontium-90	8

Turbidity

The monthly average shall not exceed 1 turbidity unit (TU). (With state approval 5 TU may be allowed provided it does not interfere with disinfection, maintenance of chlorine residual, or bacteriological testing.) The maximum two-day average is 5 TU.

Secondary Standards for Recommended Contaminant Levels
(Limits for Esthetics)

Chloride	250 mg/l
Color	15 color units
Copper	1 mg/l
Corrosivity	Noncorrosive
Foaming agents	0.5 mg/l
Iron	0.3 mg/l
Manganese	0.05 mg/l
Odor	3 threshold odor number
pH	6.5–8.5
Sulfate	250 mg/l
Total dissolved solids	500 mg/l
Zinc	5 mg/l

Recently, publicity and controversy regarding sodium's role in hypertension has been generated as a result of EPA's proposal to remove sodium from a list of drinking water contaminants scheduled for regulation (16). The Safe Drinking Water Act Amendments of 1986 list 83 drinking water contaminants that EPA must regulate by 1989. The same act also allows EPA to substitute up to seven contaminants if the agency determines that this action would provide better public health protection. At this time (1988), there is still no definite answer as to whether sodium will be removed from the list.

As for hardness, it is felt that the final level achieved is principally a function of economics and thus, a criterion for raw waters used for public water supplies is deemed not practical (9).

<u>Health Effects of Water Hardness</u>

The relationship between the hardness of drinking water and morbidity and mortality has been the subject of many investigations since the studies, almost 30 years ago, of Kobayashi in Japan (1957) (17) and Shroeder (1960) (18) in the United States. Research on this relationship has been carried out in many countries, including the United Kingdom, U.S. and Canada. Many of the studies reveal a consistent relationship between the hardness of drinking water and the incidence of CVD and, to a lesser extent, several other diseases. The results of these studies suggest that water hardness protects against disease (7).

Water Hardness and Cardiovascular Disease

CVD is the leading cause of death in the U.S. Kobayashi was the first to indicate that CVD might be related to drinking water composition when, in 1957, he showed an association between the acidity of water and cerebrovascular mortality in Japan (17). Since then, numerous studies have been carried out in several countries around the world. Generally these reports have contributed evidence supporting hypotheses that areas with hard water tend to have lower death rates and less CVD than areas with soft water (17-35). Besides Japan and the United States, this positive correlation of cardiovascular death rates and softness of water was quickly confirmed in the United Kingdom and later in Sweden (24), the Netherlands (25), Canada (26), South America (27), and Norway (28). Some small-scale studies, however, have not confirmed the relationship (36-42). It appears that the reported inverse relationship between mortality from CVD and hardness of local drinking water supplies appears to be considerably less distinctive in small regional studies. Furthermore, almost all of the researchers agreed that the final word on the "water story" has not been told and additional investigations are needed.

With the voluminous amount of literature available in this field, it is not surprising that this topic has been the subject of many comprehensive reviews. Neri gave an extensive synopsis of the literature from 1957 to 1973, where he reviewed 49 studies from nine different countries (43). Since then, additional studies and reviews have been carried out with the same general pattern of differences in results and conclusions emerging. Some believed that current knowledge was sufficient to justify action with respect to water treatment (Dept. of Health and Social Security, 1974 (44); Shaper, 1974 (32); Hudson and Gilreas, 1976 (31); Shaper, 1984 (35)). In the 1974 Report of the Advisory Panel of the Committee on Medical Aspects of Food Policy (nutrition) on Diet in Relation to Cardiovascular and Cerebrovascular Disease, a British panel recommended:

> "that any proposal for softening the water supply in any part of the country should be considered in the light of knowledge about the observed positive relationship between the death rate from ischemic heart disease (I.H.D.) and the softness of the local water supply" (44).

Shaper gave the following viewpoint in the Journal of the American Medical Association in 1974, reflecting a summary of reports over the past 18 years:

> "As evidence accumulates, it looks more and more likely that there is something, either in the drinking water or closely associated with the drinking water, that affects the rate of heart attacks and stroke in this country and many others..it might be reasonable to urge caution on those with hard water supply who wish to soften their water. In particular, those in hard water areas who do soften their water supplies might regard it judicious to leave one tap still producing hard water for drinking" (32).

Shaper, in 1984, presented the following report in the British Medical Journal:

> "A recent review summarizes the practical implications of current research on the softness of drinking water and cardiovascular disease. The main conclusions of the British Regional Heart Study confirm that there is a highly significant inverse relation between the hardness of drinking water and mortality from cardio-vascular disease. This relation persists when age, sex, and socioeconomic and climatic effects are taken into account, and is not shown for mortality from non-cardiovascular disease" (35).

Others have felt that any action to curtail softening or increase hardness for drinking would be unwise at present (Punsar, 1973 (45); Heyden, 1976 (46); Wolman, 1976 (47); National Research Council, 1980 (48)). Heyden, in the Journal of Chronic Diseases 1976, wrote:

> "This review is intended to...demonstrate the difficulty of the promoters of the hypotheses to provide any biological explanation for the mechanism of the alleged protective influence of hard water on CVD or death from it" (46).

Wolman, in the Journal of the American Waterworks Association 1976, suggested:

> "In view of material so far presented, it is reasonable to suggest that precipitate action to abandonment, adjustment, or removal of one source in favor of another should await more definitive evidence than so far available" (47).

In the National Research Council's 1980 publication, "Drinking Water and Health Vol. 3", it was concluded that:

> "Given the current status of knowledge regarding water hardness and the incidence of cardiovascular disease, it is not appropriate at this time to recommend a national policy to modify the hardness or softness of public water supplies. The data do not indicate clearly which (if any) additions to soft water would benefit human health" (48).

Still others have expressed serious doubt as to whether hardness of drinking water had any link at all with the incidence of CVD (National Academy of Science, Panel on the Geochemistry of Water in relation to Cardiovascular Disease, 1979). The panel concluded that:

> "Extensive review of the epidemiological literature indicates that there may be a water factor associated with cardiovascular disease. Its existence, however, is far from certain. The factor can hardly be softness (or hardness) as such because of its biological implausibility and the numerous exceptions to the negative association of hardness with cardiovascular disease" (4).

None of the reviews, however, indicated that further investigations should be discouraged; in fact, almost all specifically called for further investigations. The panel on the Geochemistry of Water in Relation to Cardiovascular Disease in their recommendations stated that:

> "One striking conclusion emerges from this detailed study of the geochemistry of water in relation to cardiovascular disease: The relation is clearly equivocal. It is obvious that additional studies with considerably more scientific rigor are required if the issue of a relation between water hardness and cardiovascular diseases is to be resolved satisfactorily" (4).

Comstock, <u>et al</u>, in the American Journal of Epidemiology 1980, summed it up best:

> "Even though all available evidence indicates that its effect be slight at best, the fact remains that even the removal of a low attributing risk would save a large number of lives" (49).

It is obviously clear that after three decades of research and investigations, the very basic question of whether water hardness is related to CVD is far from being answered. Other questions also surround the issues of what elements in hard or soft water would contribute to such a relationship, if one does exist. Current knowledge is derived largely from "ecological" epidemiological studies, in which individual exposures or risk factors have generally not been considered (50). In general, when studies encompass large geographical areas, hard water is correlated with low CVD rates. This correlation breaks down when smaller areas are considered. Comstock, <u>et al</u>, 1980, concluded that:

> "There is almost no excuse for any more ecologic studies. Future work needs to deal with individuals and with elementary facts such as the amount of water consumed by American adults, its sources, the effects of water on foods, and the effects of additives such as coffee, tea and soft drink syrups on water" (49).

In the course of these investigations, several hypotheses have been proposed by proponents of the "water story" in attempts to account for the relation between water hardness and CVD. The two most quoted hypotheses relate to:

1. constituents in hard water being protective in some way, and
2. harmful elements in soft water (e.g., metals leaching from piping materials) promoting the disease (51).

<u>Protective Effect of Hard Water</u>

The first hypothesis can be further classified into two parts: protective effect from bulk constituents of hard water; and protective action of trace elements in hard water.

<u>Protective Effect from Bulk Constituents of Hard Water</u>. In the first part of the hypothesis, investigators have attributed the disease-protective effect of hard water to the presence of calcium and magnesium. When calcium and magnesium are separately correlated with CVD rates, calcium appears to correlate with greater significance in the United Kingdom, whereas in the U.S., the correlations are about equally strong for both calcium and magnesium. In the U.S., the studies of Hudson and Gilreas, 1976, concluded that:

> "1. In communities having low total hardness, the CVD mortality rate was 24 percent higher than in communities with hard water.
> 2. In communities with low magnesium hardness, CVD mortality was higher by 17 percent than in communities with high magnesium hardness.
> 3. In communities with low calcium hardness, CVD mortality was higher by 22 percent than in communities with high calcium hardness" (31).

Ingols and Craft presented a hypothesis in the Journal of American Waterworks Association, 1976, that the higher concentrations of calcium ions in hard waters provided protection against the passage of metallic ions from food or water through the intestinal wall to the vascular system (52). However, in some Canadian studies, magnesium has been indicated as the most significant factor. Neri, in the Journal of the American Waterworks Association, 1975, pointed out that:

> "Magnesium appears to be the element that is most probably responsible for associatons between cardiovascular mortality and water hardness" (29).

It has also been suggested that some hard waters may contain sufficient magnesium as to prevent borderline magnesium deficiencies in some persons, thereby reducing their liability to sudden cardiac death (4).

In Copenhagen, Denmark, researchers found that heart attack victims given magnesium chloride experienced fewer deaths than victims given a placebo (53). The Danish findings suggest that patients with suspected heart attacks should be treated with intravenous infusions of magnesium immediately after admission to the hospital, to counteract low magnesium in the blood.

In Finland, where the heart-attack death rate is very high, a nationwide study was initiated six years ago to determine if heart-attack rates would be lowered by adding magnesium chloride and potassium chloride to regular table salt (54). The study has not been completed, but preliminary results showed that, for patients given salt with the two minerals added, the average blood pressure went down, and the heart-attack death rate decreased by 25 percent.

The suggestion of a protective effect for magnesium in the Finnish data is consistent with the Canadian data. British mortality rates, however, have shown little or no correlation with magnesium (4).

Because calcium and magnesium levels in public water supplies correlate so closely with each other, estimations of their possible independent effects are difficult to make by any means, unless study areas can be found where calcium levels are high in relation to those of magnesium or vice-versa.

In attempting to analyze the effects of either calcium or magnesium, it should be noted that both minerals enjoy a reciprocal relationship in muscular tissues (54). Calcium stimulates muscles to contract. Magnesium allows the muscles to relax. When the body gets low on calcium, it can borrow from the reserves in the bones. However, when it is low in magnesium, it must obtain it from the muscles. As magnesium is withdrawn from the muscles, calcium rushes in. This results in a tightening of the muscles. Many researchers now believe that this lack of magnesium may cause vein and artery walls to contract, causing high blood pressure, heart attacks, and strokes (54).

<u>Protective Effect of Trace Elements</u>. The second part of the hypothesis involving constituents in hard water being protective

relates to the protective action of trace elements in hard water. Trace metals may be present in natural groundwater or surface water. The sources of these trace metals are associated with either natural processes or man's activities. The association of trace metals in drinking water with hardness shows little relationship and may vary widely (4).

From reviews of studies reported in the literature, if hard water contains protective beneficial elements (other than calcium and magnesium), chromium emerges as the most likely candidate. Although chromium is an essential nutrient for humans, the estimation of its dietary requirement is difficult because of the great difference in bioavailability of this element in different foods. Nonetheless, an estimated adequate and safe intake for chromium of 0.05 to 0.2 mg/day has been established (48). EPA's maximum contaminant level is 0.05 mg/l.

Chromium was associated with hardness in American and Finnish waters in every study reported (4). In a report on tap water in 500 Canadian towns, chromium was particularly elevated in areas with the hardest waters (43). Consequently, in the North American and Finnish data, chromium in drinking water appeared to be a possible link in the association between hard water and low cardiovascular death rates, a positive factor because of its consistently positive association with water hardness. The data of Punsar et al on two areas within Finland lent support to this view (55).

Chromium levels were substantially lower in the higher-mortality eastern area (0.003 mg/l) than in the lower-mortality western area (0.009 mg/l). The failure to find a relationship in Britain weakens this view, however, because Britain is where hardness appears to show the strongest association to CVD.

<u>Harmful Effects of Soft Water</u>

The second hypothesis postulates the presence of some harmful elements in soft water. It is interesting to note that this hypothesis may have more significance than the former in trying to account for the relationship between hardness and CVD. Schroeder concluded in his 1974 survey that the emphasis on hardness as a factor has decreased, suggesting instead that the corrosiveness of soft water may be the most important influence on death rates from arteriosclerotic heart disease (20). Here, too, the hypothesis can be subdivided into 2 categories: the first dealing with the corrosiveness of soft water, and the second addressing the issue of elevated sodium levels in soft water.

<u>Corrosiveness of Soft Water</u>. Soft water tends to be more corrosive than hard water. (7) Consequently, certain trace metals are found in higher concentrations in soft than in hard water. Based on limited available information, cadmium and lead have been suspected to be possibly involved in the introduction of CVD.

In addressing the issue of toxic materials being responsible for the correlation between water hardness and CVD, it is essential to investigate the sources of these metals. Only very low levels of almost all trace metals, including the heavy metals cadmium and lead, have been found in the finished water of treatment plants. Where the water is aggressive, soft, or has a low pH, particularly high lead levels can result. These conditions tend to produce the highest levels of all trace elements.

The distibution of soft water has been linked to the corrosion of distribution piping and household plumbing in several U.S. cities, thus contributing to the metal content of drinking water. Craun and McCabe reported that in Boston, where a high percentage of homes had lead service lines, lead in the tap water was present in concentrations high enough to affect the human body burden of lead (30). Neri et al. analyzed tap water samples from 500 Canadian towns and detected lead in 92 percent of them. When EPA sampled residential tap water from plumbing less than two years old, it found 93 percent of the faucets with lead concentrations exceeding 20 ppb. EPA's current drinking water standard is 50 ppb, though regulations will probably soon carry a lead level "health goal" of 10 ppb. No beneficial health effects of lead have yet been found. The main chronic adverse effects of lead are those produced in the hematopoietic systems, central and peripheral nervous system, and kidneys.

Anderson et al, however, found lead levels in slightly higher concentrations in hard water towns (29). The relation of lead concentrations to soft water has not been shown consistently enough to make lead appear to be a promising explanatory link in the relationship of soft water and CVD.

Some researchers have speculated that soft water contributes to cardiovascular mortality by causing hypertension resulting from cadmium corroded from plumbing materials, particularly galvanized pipe (4). Cadmium is a very toxic element and is not a trace element that is essential to nutrition. The role of cadmium as a predisposing factor in hypertension is controversial. While epidemiological investigations indicated a positive correlation between CVD and ambient cadmium level, no direct cause-effect relationship has been established (48).

Schroeder and Kramer showed that corrosiveness of municipal drinking water was associated with elevated cardiovascular death rates and argued that this supported their view that cadmium corroded from galvanized pipe could be the water factor in CVD (20). However, studies of the relationship between trace elements and water hardness in North America and Finland did not reveal any evidence of substantial cadmium corrosion by soft water.

While corrosion of piping is a known source of cadmium in water, these data indicate that this source might be irrelevent in public water supplies. In summary, data on cadmium in tap water are much too fragmentary to allow an evaluation of its possible role in CVD.

Sodium in Soft Water. The estimated adequate and safe dietary intakes are summarized in Table 5. Investigations have associated high sodium levels in drinking water with elevated blood pressures and hypertension (58)(59)(60)(61). It is a well-known fact that hypertension greatly increases the risk of developing coronary heart disease, and cerebral thrombosis resulting from occlusive atherosclerosis, and hypertensive cerebral hemorrhage (the two most common types of stroke). Hypertension also affects the heart (hypertensive heart disease and cardiac failure) and kidneys (arteriolar nephroslerosis). The blood pressure distribution patterns for systolic and diastolic pressures of high school students living in a community with elevated levels of sodium in the drinking water showed a significant upward shift as compared with the patterns for matched students in a neighboring community with low sodium levels in the drinking water (60). Other studies, however, have failed to support these investigations (62)(63)(64).

Table 5. Recommended Daily Sodium Intakes

Individual	Daily Adequate and Safe Intake, mg	Ref.
Normal Adult	1,100 - 3,300 or 1 gm per kg of fluid and food intake	(56)(57)
Infants	115 - 750	(57)
Adults, restricted diets	2000	(50)
Adults, severely restricted diet	<500	(50)

Twenty percent of the adult U.S. population has hypertension (65). In hypertension subjects, a lowering of blood pressure may be effected by reducing total sodium intake. A maximum level of sodium in drinking water of 20 mg/l has been suggested by the American Heart Association (66). The sodium content of drinking water is extremely variable. A typical level of sodium in drinking water is 28 mg/l, with a maximum of 220 mg/l (48).

Some investigations also show a relationship between water sodium and crib deaths (67). The findings show hypernatraemia to be a signficiant factor leading to crib death. It appears that sodium levels of about 50 mg/l in the drinking water may contribute towards increasing mortality.

EPA's announcement of its proposal to remove sodium from the list of contaminants scheduled for regulation has evoked much controversy. Opinions are divided over the proposal. The Natural Resources Defense Council (NRDC), a strong opponent, pointed out that existing levels of sodium in about one-half of the drinking water supplies is high enough to have serious adverse effects for those with high blood pressure. Supporters of the EPA proposal were the Salt Institute, and the Water Quality Association (WQA), which represents manufacturers and retailers of water quality improvement products. The WQA agrees with EPA's conclusion that both sodium and chloride, not sodium alone, may be associated with blood pressure effects in sensitive individuals. (16). The Salt Institute cited several studies that linked hypertension to calcium deficiencies, and not to increased sodium levels. (16)

The Safe Drinking Water Committee has recommended that sodium concentrations in drinking water be maintained at the lowest practicable levels, and trends towards increasing it as a result of water-softening procedures should be discouraged (50). This raises the question of whether water should be softened at home. Cation-exchange is the basis of the most widely-used water-softening process for residential units. In this process, two sodium ions are introduced into the solution for each calcium ion removed, and two more sodium ions for each magnesium ion removed. It is suggested that a drinking tap be used to bypass the home softener (68). The Safe Drinking Water Committee also recommended that in instances where water is to be softened (by ion-exchange) domestically, a three-line system be used so that only water for bathing and laundry would be softened, and not the water for drinking (48).

Water Hardness and Other Diseases

Besides CVD, other diseases have been associated with the hardness of the local drinking water supply. The results of several studies have indicated that a variety of diseases, including certain nervous system defects, anencephaly, perinatal mortality, and various types of cancer are negatively correlated with the hardness of water (7). In a study conducted in the United Kingdom, incidences of anencephaly were tested against total hardness, pH, calcium, sodium and magnesium concentrations of local water supplies (69). The results indicated that the incidence of anencephalus was negatively correlated with the total hardness, calcium content, pH and to a certain extent the sodium content of the local drinking water.

Osteoporosis and the Role of Calcium

Definition

Osteoporosis literally means porous bones, whereby the bone density decreases along with increasing brittleness. It is a disease that accelerates the natural loss of bone-tissue mass that accompanies aging. It causes the skeleton to become extremely porous and fragile, such that a bone will break from the most minor trauma or spontaneously fracture with no external trauma at all.

Experts estimate that 20 million Americans may have osteoporosis, many without knowing it (70). The disease is responsible for approximately 1.3 million fractures every year (70). Because women are more likely than men to suffer from it, it has been called a woman's disease. Men are less likely than women to be afflicted with osteoporosis until later in life and seldom suffer as severely because they have 30 percent more bone mass on the average and do not undergo the sudden drop in estrogen that accompanies menopause. About 25 percent of all white women in America have had one fracture or more by the age of 65, due largely to osteoporosis (71). Research data collected by the National Institute on Aging shows that 1 in 4 postmenopausal white women are affected by this disease, and 1 in 8 men over 60 (71).

<u>Calcium and the Prevention of Osteoporosis</u>

Ideally, osteoporosis can be prevented by building strong bones before reaching 35, and maintaining a strong bone mass through menopause and the latter years. Not surprisingly, a survey of the literature identifies calcium as the cornerstone of most programs to prevent osteoporosis. Calcium is a vital part of bone formation and the replacement of bone cells. Bone tissue consists of calcium and phosphorus in a network of collagen fibers. The calcium gives strength and hardness to bones, without which the bones would be like jelly.

Clearly, osteoporosis is a serious public-health problem, and the number of women afflicted with osteoporosis is rising because of the increasing U.S. life expectancy. Recently, the role of dietary calcium in the prevention of osteoporosis has been widely publicized in the popular press (72)(73)(74). What is not so clear, however, is the uncertainty among researchers as to whether calcium will in fact prevent osteoporosis. Just as controversy surrounds the issue of hard water and CVD, there exists arguments regarding calcium's role in the prevention of osteoporosis.

The calcium craze can be traced back to a conference of experts convened by the National Institutes of Health (NIH) in April, 1984. A statement issued by the panel listed calcium along with the female hormone estrogen as the mainstays of prevention and management of osteoporosis (75). Wide media coverage followed, and not surprisingly, makers of calcium supplements spent large sums in advertising campaigns that proved influential.

Some recent reports in the popular press, however, have downplayed the importance of calcium, casting doubts upon calcium's role in osteoporosis (75)(76). At a later NIH workshop, scientists noted that factors such as lack of estrogen, put women at greater risk than low-calcium diets.

It is important to bear in mind that in the heat of the calcium craze, a vital message got lost: Researchers never claimed calcium as a panacea for osteoporosis in the first place. The truth is calcium does play a significant role in the prevention of osteoporosis, but so does getting enough regular weight-bearing exercise, quitting cigarettes, and moderating alcohol intake. Researchers at the NIH workshop made it clear that while calcium is not the cure-all for osteoporosis, people should still consume more of it (76).

The yardstick for evaluating calcium intake has long been the Recommended Dietary Allowance (RDA), established by the Food and Nutrition Board of the National Research Council (57). The last set of RDA's was published in 1980 and is presented in Table 6. As shown in this table, the daily calcium recommendation for men and women aged 19 or older is 800 mg. However, this recommendation has been challenged by the expert panel convened by the NIH. The panel emphasized that the RDA for calcium is evidently too low, particulary for postmenopausal women, and may well be too low for elderly men, too (77). Until the time of menopause, the panel recommends that 1000 mg of calcium be taken daily. If a woman begins estrogen therapy after menopause, the panel recommends maintaining this same calcium level of 1000 mg per day. On the other hand, if a woman passes menopause and does not take estrogen therapy, the panel recommends a daily calcium intake of 1500 mg. The American Society for Bone and Mineral Research recommends up to 1500 mg of calcium for a woman during and after menopause (71). Today, health experts generally recommend an intake of 1,000 to 1,500 milligrams daily, particularly for women. It is estimated that the average woman in America consumes about 450 mg to 500 mg of calcium daily, which is far below the recommended intake.

Sources of Calcium

The milk group is the primary source of calcium in the American diet. A cup of milk contributes about 284-347 mg of calcium; a cup of low-fat yogurt about 345-415 mg. Other food sources include certain seafoods, fruits, and vegetables. In order for the body to absorb calcium efficiently, certain nutrients are needed.

Table 6. United States Recommended Daily Dietary Allowances (57)

	Age (years)	Weight (kg)	Weight (lb)	Height (cm)	Height (in)	Protein (g)	Fat-Soluble Vitamins: Vitamin A (μg RE)[b]	Vitamin D (μg)[c]	Vitamin E (mg α-TE)[d]	Water-Soluble Vitamins: Vitamin C (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg NE)[e]	Vitamin B-6 (mg)	Folacin[f] (μg)	Vitamin B-12 (μg)	Minerals: Calcium (mg)	Phosphorus (mg)	Magnesium (mg)	Iron (mg)	Zinc (mg)	Iodine (μg)
Infants	0.0–0.5	6	13	60	24	kg × 2.2	420	10	3	35	0.3	0.4	6	0.3	30	0.5[g]	360	240	50	10	3	40
	0.5–1.0	9	20	71	28	kg × 2.0	400	10	4	35	0.5	0.6	8	0.6	45	1.5	540	360	70	15	5	50
Children	1–3	13	29	90	35	23	400	10	5	45	0.7	0.8	9	0.9	100	2.0	800	800	150	15	10	70
	4–6	20	44	112	44	30	500	10	6	45	0.9	1.0	11	1.3	200	2.5	800	800	200	10	10	90
	7–10	28	62	132	52	34	700	10	7	45	1.2	1.4	16	1.6	300	3.0	800	800	250	10	10	120
Males	11–14	45	99	157	62	45	1000	10	8	50	1.4	1.6	18	1.8	400	3.0	1200	1200	350	18	15	150
	15–18	66	145	176	69	56	1000	10	10	60	1.4	1.7	18	2.0	400	3.0	1200	1200	400	18	15	150
	19–22	70	154	177	70	56	1000	7.5	10	60	1.5	1.7	19	2.2	400	3.0	800	800	350	10	15	150
	23–50	70	154	178	70	56	1000	5	10	60	1.4	1.6	18	2.2	400	3.0	800	800	350	10	15	150
	51+	70	154	178	70	56	1000	5	10	60	1.2	1.4	16	2.2	400	3.0	800	800	350	10	15	150
Females	11–14	46	101	157	62	46	800	10	8	50	1.1	1.3	15	1.8	400	3.0	1200	1200	300	18	15	150
	15–18	55	120	163	64	46	800	10	8	60	1.1	1.3	14	2.0	400	3.0	1200	1200	300	18	15	150
	19–22	55	120	163	64	44	800	7.5	8	60	1.1	1.3	14	2.0	400	3.0	800	800	300	18	15	150
	23–50	55	120	163	64	44	800	5	8	60	1.0	1.2	13	2.0	400	3.0	800	800	300	18	15	150
	51+	55	120	163	64	44	800	5	8	60	1.0	1.2	13	2.0	400	3.0	800	800	300	10	15	150
Pregnant						+30	+200	+5	+2	+20	+0.4	+0.3	+2	+0.6	+400	+1.0	+400	+400	+150	[h]	+5	+25
Lactating						+20	+400	+5	+3	+40	+0.5	+0.5	+5	+0.5	+100	+1.0	+400	+400	+150	[h]	+10	+50

[a] The allowances are intended to provide for individual variations among most normal persons as they live in the United States under usual environmental stresses. Diets should be based on a variety of common foods in order to provide other nutrients for which human requirements have been less well defined. See text for detailed discussion of allowances and of nutrients not tabulated. See Table 1 (p. 20) for weights and heights by individual year of age. See Table 3 (p. 23) for suggested average energy intakes.

[b] Retinol equivalents. 1 retinol equivalent = 1 μg retinol or 6 μg β carotene. See text for calculation of vitamin A activity of diets as retinol equivalents.

[c] As cholecalciferol. 10 μg cholecalciferol = 400 IU of vitamin D.

[d] α-tocopherol equivalents. 1 mg d-α tocopherol = 1 α-TE. See text for variation in allowances and calculation of vitamin E activity of the diet as α-tocopherol equivalents.

[e] 1 NE (niacin equivalent) is equal to 1 mg of niacin or 60 mg of dietary tryptophan.

[f] The folacin allowances refer to dietary sources as determined by *Lactobacillus casei* assay after treatment with enzymes (conjugases) to make polyglutamyl forms of the vitamin available to the test organism.

[g] The recommended dietary allowance for vitamin B-12 in infants is based on average concentration of the vitamin in human milk. The allowances after weaning are based on energy intake (as recommended by the American Academy of Pediatrics) and consideration of other factors, such as intestinal absorption; see text.

[h] The increased requirement during pregnancy cannot be met by the iron content of habitual American diets nor by the existing iron stores of many women; therefore the use of 30–60 mg of supplemental iron is recommended. Iron needs during lactation are not substantially different from those of nonpregnant women, but continued supplementation of the mother for 2–3 months after parturition is advisable in order to replenish stores depleted by pregnancy.

Nutritionists have known for decades that vitamin D is essential to health because it helps the body to absorb calcium. Lactose also helps the body to absorb calcium though it is not required for calcium absorption. The USRDA is based on the premise that the daily excretion of calcium is 320 mg and that only 40 percent of dietary calcium is absorbed by the average American (48). The excretion rate and absorption percentage vary according to age and physiological state.

In light of the publicity surrounding the calcium craze, millions of Americans have included calcium supplements in their diet. The most common forms of calcium found in supplements are calcium carbonate, calcium lactage, calcium phosphate, and calcium chloride (77).

Calcium from Drinking Water

From a review of the literature, several nutritionists have suggested hard water as a source of calcium (70)(77). Though it is unlikely that calcium from the tap contributes a significant percentage of the daily requirements, it is no doubt a useful and economical source. It is recommended that an adult drink an average of 2 liters or 8 glasses of water a day. Thus, if a certain source of water contains 100 mg/l of calcium, it would contribute about 200 mg of calcium to the daily diet.

The contribution of drinking water to calcium nutrition was also reviewed by the Safe Drinking Water Committee (48). This will be examined in the next section.

Contribution of Drinking Water to Mineral Nutrition

The Safe Drinking Water Act of 1974 (PL93-523) required the EPA to arrange for a study that would be used as the scientific basis for revision or ratification of the Interim Primary Drinking Water Regulations that were promulgated under the Act. The study was conducted by the Committee on Safe Drinking Water of the National Research Council, supported by a contract between the EPA and the National Academy of Sciences. Results of these studies were published in Drinking Water and Health (National Academy of Sciences, 1977) (50). The Safe Drinking Water Amendments of 1977 called for revisions of the studies "reflecting new information which has become available since the most recent previous report (and which) shall be reported to the Congress each two years thereafter". Results of studies completed by the Safe Drinking Water Committee since 1977 are contained in subsequent volumes of Drinking Water and Health. In volume 3 (National Academy Press, 1980) a review was conducted on the contribution of drinking water to mineral nutrition in humans. The following information was largely obtained from that volume (48).

Calcium

In a survey of U.S. surface waters from 1957 to 1969, calcium concentrations were found to range from 11.0 to 173.0 mg/l for 510 determinations. Finished water that was sampled in public water supplies for the 100 largest cities in the U.S. contained almost as much calcium (range, 1-145 mg/l). However, the calcium concentrations in 93 percent of the city supplies were less than 50 mg/l. Simiar results were reported in a Canadian study. Zoeteman and Brinkmann reported that the public water supplies for 21 large European cities contained between 7 and 140 mg/l of calcium.

Based on an average calcium concentration of 26 mg/l and a maximum concentration of 145 mg/l in public water supplies and assuming that the average adult consumes 2 liters of this water daily, then the drinking water would contribute an average of 52 mg/day and a maximum of 290 mg/day. Thus, on an average basis, this would contribute approximately 6.5 percent of the adult RDA (800 mg/l). For hard waters with high calcium levels, the water would contribute approximately 36 percent of the adult RDA. Thus, public drinking water generally contributes a small amount to total calcium intake, but in some cases it can be a major contributor. Where cases of dietary calcium deficiencies occurs, the presence of calcium in drinking water may provide nutritional benefits.

Magnesium

From 1957 to 1969, magnesium concentrations in U.S. surface waters ranged from 8.5 to 137 mg/l for 1143 determinations. Finished water in public water supplies for the 100 largest cities in the U.S. had magnesium levels ranging from 0-120 mg/l. However, the concentration of magnesium in 96 percent of the water supplies had less than 20 mg/l.

According to the USRDA, the daily requirements for females from age 11 onwards is 300 mg. The RDA for pregnant and lactating women is 450 mg. For males aged 11 to 14 and 19 onwards, the requirement is 350 mg/day and 400 mg/day is the recommended amount for males aged between 15 and 18 (see Table 7). Based on a mean magnesium concentration of 6.25 mg/l and a maximum of 120 mg/l, a daily intake of 2 liters of drinking water would supply an average of approximately 12 mg and a maximum of up to 240 mg of magnesium per day. For Canadian and Western European drinking waters, the daily contribution would be approximately 20 and 24 mg respectively. In areas where the magensium concentration is high, over 50 percent of the RDA could come from 2 liters of water. Thus, drinking water could provide a nutritionally significant amount of magnesium for individuals consuming a diet that is marginally deficient in magnesium, especially in areas where the magnesium concentration in water is high.

Chromium

Chromium is an essential nutrient for humans. Based on average concentrations in food and water, drinking water could contribute a substantial proportion of the daily chromium intake. In some instances, the contribution of drinking water to the daily intake of chromium may be greater than the contribution of the diet. Thus, water is an important source, especially as evidence suggests that chromium deficiency may be a problem in the U.S.

Summary

Generally, as far as the hardness of treated public water supplies is concerned, states along the east coast and the upper west coast have the softest waters. Mid-western states, especially those with hard groundwaters, have the hardest drinking waters. South Dakota's public water supplies have a hardness of above 180 mg/l.

An extensive review of the literature on the relationship between water hardness and CVD indicates that this 30-year old controversy is still far from being settled. About the only aspect of the subject that investigators agree on is that further studies are warranted. Generally, the majority of the studies show a negative correlation between water hardness and CVD, i.e. the harder the water, the lower the incidences of CVD. However, studies carried out on smaller scales have failed to support these findings.

Several hypotheses have been proposed in attempts to account for the relationship. The two most quoted hypotheses relate to: constituents in hard water being protective in some way; or substances in soft water promoting the disease.

In light of the potential health benefits involved, several special committees and panels were established to review the matter and make their recommendations. It is interesting to note that panels and researchers in the United Kingdom were much more inclined towards calling for non-softening of drinking water supplies. In the U.S., more caution appears to be exercised and the ambiguity of several reviews were reflected in their conclusions. Nevertheless, there were researchers calling for actions to be taken with regards to the hardness of water and others who felt that any action to modify the hardness of drinking waters would be unwise.

Despite the debate regarding the extent to which calcium helps in the prevention of osteoporosis, there are generally few arguments that it does play a significant role. There are, however, some controversies regarding the daily requirement of dietary calcium. The most recent USRDA's published in 1980 recommends 800 mg of calcium daily for men and women aged 19 or older. This recommendation has been challenged by an expert panel convened by the NIH, which recommends 1000 mg of calcium per day for women up until the time of menopause. If a woman passes menopause and does not take estrogen therapy, the panel recommends a daily calcium intake of

1500 mg. Experts today generally recommend between 1000 to 1500 mg/day.

It is estimated that the average woman in America consumes insufficient amounts of calcium. Several sources of calcium were identified, including drinking water. It is felt that public drinking water generally contributes a small amount to the total calcium intake, though in some cases it can be a major contributor. Where cases of dietary calcium deficiencies occur, the presence of calcium in drinking water may provide nutritional benefits. Likewise, drinking water could also be a potentially important source of magnesium and certain trace minerals like chromium.

RESEARCH PROCEDURE

Introduction and Method of Approach

The overall objectives of this study were to determine the health benefits derived from drinking hard water and the percentage of people in two South Dakota cities, Brookings and Sioux Falls who drink water softened by home ion-exchange units. To achieve these objectives, an extensive literature review was conducted first. Sources that were consulted include trade journals, mostly in the environmental, water supply, and medical fields, textbooks, and popular press articles.

The review yielded an abundance of literature on the subject. It soon became apparent that while the importance of calcium and magnesium, the principal causes of hardness in water, had long been recognized, their contribution from drinking water had largely been ignored. Likewise, sodium's association with elevated blood pressure and hypertension was no secret. However, the fact that ion-exchange water softeners add sodium into drinking water had not received the amount of publicity it should.

Residential Sampling Procedures

To determine the number of people in Brookings and Sioux Falls who drink home-softened water, a mail survey was devised. It was decided that only residential homes would be sampled. Apartment buildings and commercial establishments were excluded. Dr. Linda Baer, demographer in the Sociology Department at South Dakota State University, was consulted and with her advice, it was decided that a survey of 10 to 15 percent of the metered residential water accounts would provide an adequate sample size.

Names of water customers in Brookings were obtained from the City Water Department. Using a computer program in Fortran, 400 randomly-selected names were generated. These 400 residences represented about 12.3 percent of the total number of residences in Brookings. The questionnaire that was mailed to the residential water users can be found in Table 7. In an attempt to improve questionnaire response, the questions were printed on a postage-paid self-addressed card. In addition, the local newspaper carried an article explaining the purpose of the questionnaire and requested that cooperation be extended to the University by promptly completing and returning the questionnaires. This article may be found in Appendix A.

In the case of Sioux Falls, the list of names for the sample population were randomly selected by the Sioux Falls Water Utilities Department. Questionnaires were mailed to 3450 (15 percent of the total) residential water customers. Besides an article in the Sioux Falls daily, The Argus Leader, copies of the news release were carbon-copied to both television and radio stations, hospitals, and the Sioux Falls Shopping News.

Table 7. Research Questionnaire

RESEARCH QUESTIONNAIRE
(optional to fill-in name and address)

NAME: ______________________________

ADDRESS: ______________________________

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1. Do you have a water softener at your place of residence?
   Yes ___ No ___

If you answered No to Question 1, stop here and just mail this card. If you answered Yes to Question 1, please go on.

2. Do you have one or more taps where hard water is available for drinking? Yes ___ No ___ Not Sure ___

3. If you checked "Not Sure" in Question 2, do you want us to verify whether or not hard water is available at your tap? Yes ___ No ___

If you answered Yes to Question 3, be sure you have included your name and address above.

Thank you for your participation in this research project. Please mail this card to us at your earliest convenience. No postage required.

PRESENTATION AND DISCUSSION OF DATA

The data presented and discussed in this section consists of tables and figures showing the percentages of homes in Brookings and Sioux Falls where only soft water is available for drinking. A summary of the responses obtained from the questionnaire survey is shown in Table 8. Figures 7 to 10 illustrate the results in pie chart form.

Brookings Survey

There are 3248 residential water users served by the Brookings municipal water system (78). As shown in Table 8, questionnaires were mailed to 400 (12.3 percent) randomly-selected users from this total. A total of 232 completed questionnaires were returned. This return, of 58.0 percent, is considered an excellent survey response. Furthermore, the 232 responses represent 7.1 percent of the total sample population, which is sufficient to make reasonably accurate projections for the total population of residential water users.

Of the responses received, 187 (or 80.6 percent) residential water customers had home water softeners. Of those using home softeners, 161 (or 86.1 percent) of the residences responding were plumbed so that hard water from the city mains was available at the tap for drinking. The remaining 26 residences (or 13.9 percent) having home softeners did not have separate taps for drinking hard water.

Consequently, based on these results, approximately 14 percent of those residences in Brookings having home water softeners used the home-softened water for drinking rather than hard water from the city service line supplying water to the residence. These results are shown graphically in Figures 7 and 8.

Table 8. Summary of Questionnaire Response in Brookings and Sioux Falls

	Brookings	Sioux Falls
Total Residential Water Accounts	3,248	23,000
Questionnaires Distributed	400	3,450
Percentage of Residences Receiving Questionnaires	12.3	15.0
Questionnaires Returned	232	1,369
Percentage Returned	58.0	39.7
Residences (with softeners) indicating hard water is available for drinking	161	758
Residences (with softeners) indicating only soft water is available for drinking	26	146
Residences without softeners	45	465

Based on 2.46 persons per household (79) it is estimated that 895 persons in Brookings drink home-softened water. This number is considered a conservative estimate because it includes only one-family residential users and not those living in apartments. Calculations are shown in Appendix B.

Table 9 shows the concentrations of total hardness, calcium, magnesium, and sodium in unsoftened tap water (80) and home-softened water in Brookings and Sioux Falls (Calculations in Appendix C).

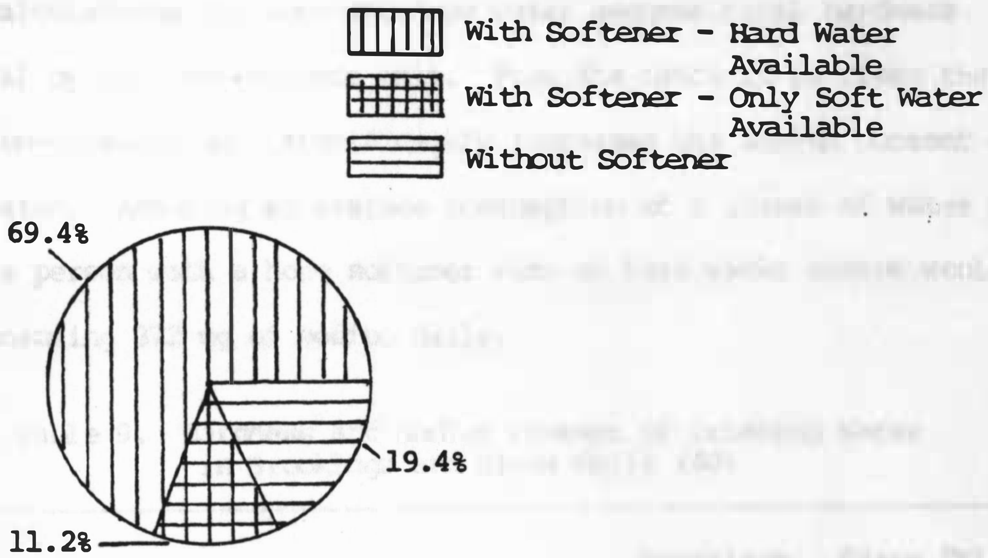

Figure 7. Projection of Hard and Soft Water Consumption Among Residents in Brookings

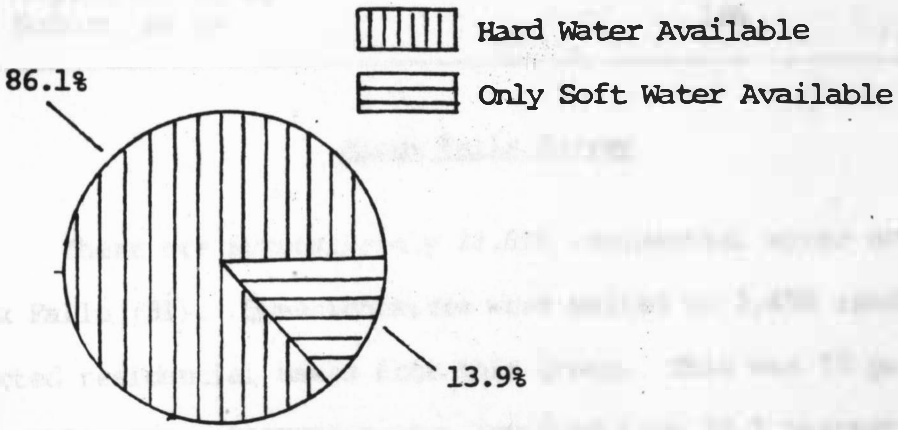

Figure 8. Projection of Hard and Soft Water Consumption Among Water-Softener Owners in Brookings

The calculations for home-softened water assumes total hardness removal by the ion-exchange unit. From the table it is clear that the ion-exchange unit significantly increases the sodium content of the water. Assuming an average consumption of 2 liters of water per day, a person with a home softener with no hard water source would be consuming 372 mg of sodium daily.

Table 9. Hardness and Sodium Content of Drinking Water in Brookings and Sioux Falls (80)

	Brookings	Sioux Falls
Unsoftened water, mg/l		
Total hardness as $CaCO_3$	380	302
Calcium, as Ca	93	71
Magnesium, as mg	36	30
Sodium, as Na	11	24
Home-softened water, mg/l		
Total hardness as $CaCO_3$	0	0
Calcium, as Ca	0	0
Magnesium, as mg	0	0
Sodium, as Na	186	162

Sioux Falls Survey

There are approximately 23,000 residential water accounts in Sioux Falls (81). Questionnaires were mailed to 3,450 randomly-selected residential users from this group. This was 15 percent of the total group. Responses were received from 39.7 percent (1,369) of the 3,450 questionnaires mailed. This response rate is lower than obtained in Brookings, however it is considered an excellent

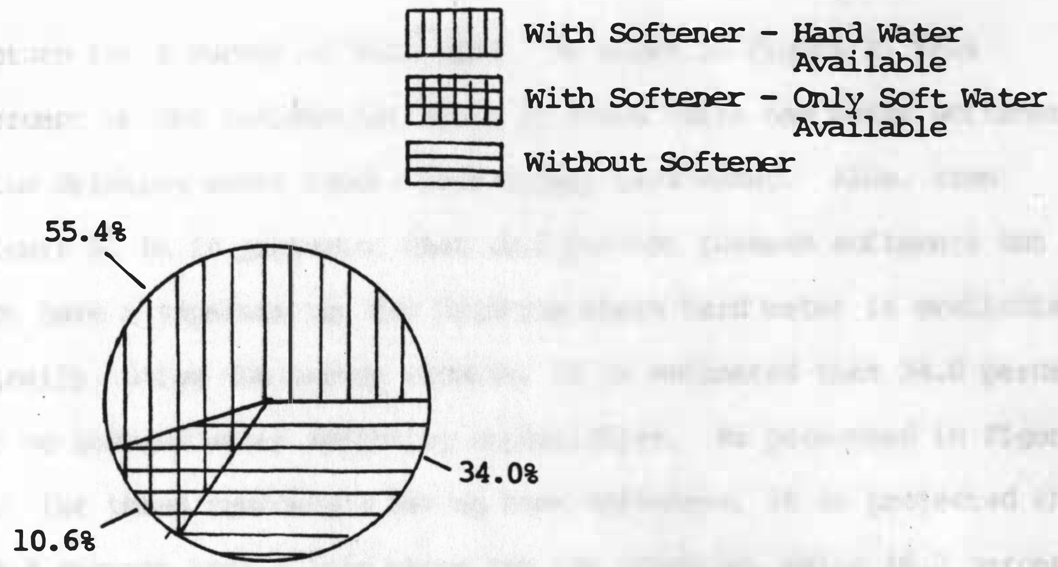

Figure 9. Projection of Hard and Soft Water Consumption Among Residents in Sioux Falls

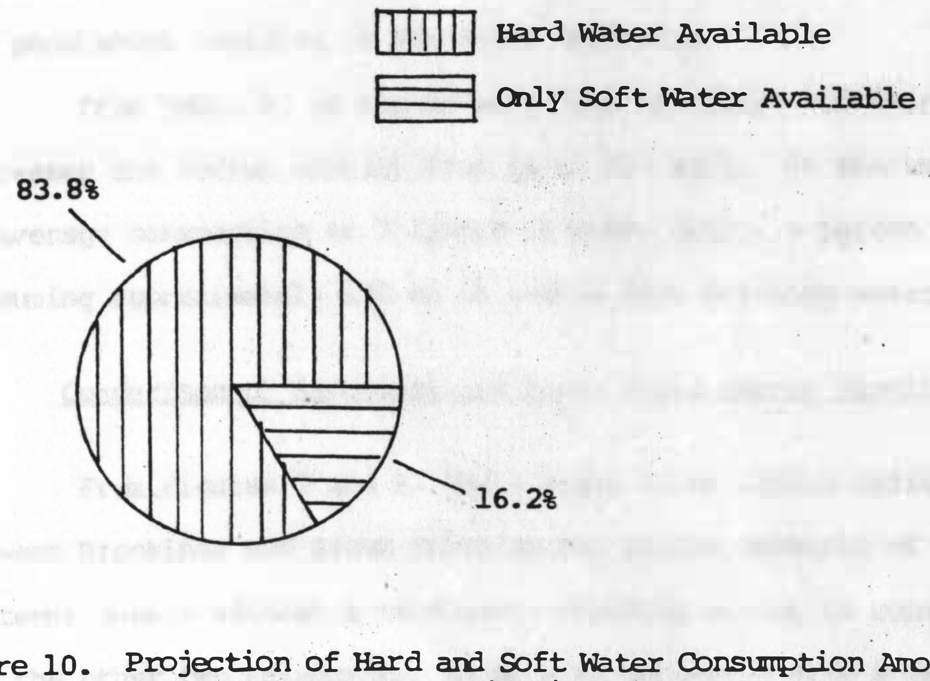

Figure 10. Projection of Hard and Soft Water Consumption Among Water-Softener Owners in Sioux Falls

return for a survey of this kind. As shown in Figure 9, 55.4 percent of the residential users in Sioux Falls had water softeners plus drinking water tap(s) that supply hard water. Also, from Figure 9, it is projected that 10.6 percent possess softeners but do not have a separate tap for drinking where hard water is available. Finally, using the survey results, it is estimated that 34.0 percent do no possess water softening capabilities. As presented in Figure 10, for those residences having home softeners, it is projected that 83.8 percent have a hard water tap for drinking, while 16.2 percent drink the softened water. Using the same estimated number of persons per household as in Brookings, it is estimated that 6,000 persons in Sioux Falls drink home-softened water. This again is a conservative number as it does not take into account the portion of the population residing in apartment buildings.

From Table 9, it can be seen that the water softening unit increases the sodium content from 24 to 163 mg/l. On the basis of an average consumption of 2 liters of water daily, a person would be consuming approximately 324 mg of sodium from drinking water.

Comparison of Brookings and Sioux Falls Survey Results

From Figures 7 and 9, there seems to be little difference between Brookings and Sioux Falls as far as the category of home softener owners without a hard water drinking source is concerned. For the other two categories, those with softeners plus a hard water source for drinking, and those without softening capabilities, there appears to be substantial differences between both cities. A statistical analysis was performed (see Appendix D) to test the hypothesis, and the results confirmed the above observations.

However, a similar analysis carried out based on percentages from Figures 8 and 10 showed little difference between water-softener owners with a hard water source in Brookings and in Sioux Falls when we consider only those homes with softening capabilities.

This indicates that for residential homes with softeners, the proportion of those with and without a hard water source for drinking is essentially the same between Brookings and Sioux Falls. However, when we consider the whole residential population (with and without softeners), substantial differences arise because a much larger number of residential homes in Sioux Falls do not have softeners. This is probably due to the wider range of economic conditions affecting the standard of living in Sioux Falls.

Assuming that Brookings and Sioux Falls are typical of South Dakota cities, it would be expected that approximately 10 percent of the urban residential population of South Dakota communities consume home-softened water, or about 15 percent of water softener owners. This, of course, is based just on residential homes and does not take into account apartment dwellers.

Plumbing Code

A review of the National Standard Plumbing Code indicates that there are no provisions regarding plumbing practices with respect to the installation of water softeners in residences (78). An inquiry was made to the National Association of Plumbing-Heating-Cooling Contractors for an up-to-date view of the matter and their reply (in Appendix E) seems to substantiate this situation.

Based on the literature review concerning health effects of hard water and the contribution of hard water to mineral nutrition, plus the results of the Brookings and Sioux Falls survey, it appears that a section in the code encouraging the consumption of hard water and discouraging the drinking of sodium-rich home-softened water is warranted. Though the benefits derived from this practice may be minimal when considering other risk factors such as cigarette smoking, stress, and lack of exercise (in the prevention of heart disease), and other sources such as dairy products and calcium supplements (in the prevention of osteoporosis), the fact remains that, since drinking water is an obligatory dietary ingredient, the effects of having such a section in the code would be in the best interests of the public.

However, even if the code does not provide for the installation of a by-pass around the softener, local authorities have the right, in view of local conditions, to impose additional safety requirements in the interest of public health (Appendix E).

CONCLUSIONS

From the research conducted, the following conclusions have been drawn:

From the literature:

1. In terms of finished public water supplied to the service connections of the users, most of the mid-western, southern, and south-western states have hard water supplies whereas the majority of the eastern, south-eastern, and north-western states have soft water supplies.
2. It appears that elements in hard water, expecially calcium and magnesium, and to a much lesser extent, chromium, have been linked to lower cardiovascular mortality with enough consistency and regularity for them to merit justification as important elements in the prevention of cardiovascular diseases.
3. The increased sodium content of home-softened water poses a health hazard, especially for those on sodium-restricted diets.
4. The corrosiveness of soft water has been associated with increased levels of lead and cadmium in drinking water though there exists little evidence that these heavy metals are related to cardiovascular diseases.

5. Currently, there appears to be two schools of thought with respect to the role of water hardness in cardiovascular diseases. The majority of researchers believe that the hardness of drinking water does affect the rate of cardiovascular disorders whereas some believe otherwise. However, all agree that current knowledge is not conclusive and future research is definitely warranted.
6. Experts today generally recommend a daily calcium intake of 1000 mg. For a woman passing menopause and not taking estrogen therapy, a daily calcium intake of 1500 mg is recommended.
7. Hard water can be a significant contributor of calcium, magnesium, and chromium dietary nutrition, especially for those individuals with borderline deficiency requirements. Based on maximum concentration levels, drinking water could supply 36 percent and 50 percent of the adult RDA for calcium and magnesium respectively.

From the results of questionnaire surveys:

1. It appears that a substantial number of people in Brookings and Sioux Falls, South Dakota are drinking home-softened water because their plumbing does not provide a drinking tap where hard water is available.
2. These numbers when correlated with one another proved highly significant.

3. Assuming that Brookings and Sioux Falls are typical of South Dakota cities, it is expected that approximately 15 percent of water softener owners in residential homes in South Dakota drink the softened water.
4. Currently, there are no provisions in the National Standard Plumbing Code that deal with water softeners specifically for residences.

In view of the conclusions presented above, it appears that a section in the code encouraging the drinking of hard water and discouraging the drinking of home softened water should be considered.

FUTURE STUDY

The research presented suggests that further work should be conducted to define more completely the extent to which the hardness or softness of drinking water is affecting public health. With more extensive data in this area, a more convincing argument could be presented to initiate changes in the Plumbing Code, as it pertains to the installation of water softeners. Possible areas of future study could include the following:

1. A survey of apartment houses in Brookings and Sioux Falls would expand the scope of the survey results already collected and should require relatively little additional effort to determine the effect it would have on the present results.
2. A survey to determine if a relationship exists between incidences of cardiovascular disorders, osteoporosis and the availability of hard or soft water at the tap in residential homes might be of interest.
3. A mail survey of other South Dakota and Minnesota communities to determine the extent to which home-softened water is being consumed as drinking water would expand the scope of data regarding this topic.

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APPENDIX A

Newspaper Articles Regarding Survey

Newspaper Articles Regarding Surveys

The articles below are reproduced from the Brookings Register, October 15, 1987 and the Argus Leader, December 30, 1987.

Drinking water survey planned

In a survey by the Civil Engineering Department of South Dakota State University and the Brookings Water Department randomly-selected residents of Brookings will soon have the chance to report on the their drinking water.

According to Dwayne Rollag, head of the Civil Engineering Department at SDSU, the drinking water available in Brookings is classified as hard water. Scientists believe that drinking this hard water, rather than chemically softened water, imparts health benefits, specifically reducing the chances of cardiovascular disease.

Since home softeners add sodium to the water drinking softened water would be harmful to anyone on a sodium restricted diet. The survey intends to discover how many people in Brookings drink softened water rather than hard water.

Those selected for the survey will receive questionnaires in the mail shortly.

Argus Leader, Sioux Falls, S.D. Wednesday, Dec. 30, 1987

City to survey water drinking habits

By JULIE BOLDING
Argus Leader Staff

About 1,800 Sioux Falls water customers will be getting questionnaires asking whether they drink softened or hard water.

The study is being made to determine how many Sioux Falls residents drink hard water coming from the city water plant or water that has gone through home water softeners, Utilities Director Richard Willer said. The questionnaires will be mailed after Friday.

Although the city water plant uses lime to remove some of the mineral content of pumped well water, that water can be softened further in tanks in which sodium ions are exchanged for ions from minerals that contribute to water hardness, such as calcium.

Numerous scientific studies have concluded the incidence of cardiovascular disease is lower in areas where people drink hard water or don't drink softened water, said Dwayne Rollag, a professor who heads the Civil Engineering Department at South Dakota State University. It hasn't been conclusively proven that drinking softened water has negative health effects, but a conclusion can be drawn that at least it's not beneficial to the cardiovascular system to drink it, he said.

"At least people should be aware of the fact that there is an alternative," he said. "I think if I were a water consumer, and I wasn't aware of what kind of water I was drinking, I'd appreciate knowing about the situation."

Many physicians say that reducing sodium intake will reduce hypertension, Rollag said. People in the water-softener industry, however, have cited studies that say it's sodium chloride, the scientific name for table salt, that is detrimental to those with hypertension, not sodium alone, he said.

In some cases, homeowners may not know that their pipes to water faucets were hooked up to the softeners for cost-saving reasons, Rollag said. Pipes to taps used for drinking water can be switched so that hard water doesn't go through the softener, he said.

Rollag's department will conduct the survey, along with the city Water Department and Research Committee of the South Dakota section of the American Water Works Association. Preliminary results could be available in March.

Water consumers in Brookings already have been surveyed. Not many residents drank soft water, he said. Rollag said some Brookings residents were not sure whether their drinking water had gone through their softeners. Those who didn't know could call the city water department for assistance in finding out. A similar service is planned for Sioux Falls, Rollag said.

APPENDIX B

Population Projection Calculations

Population Projection Calculations

Brookings

Total Water Accounts	3,248
Percentage owning softeners where only soft water is available for drinking	11.2
Average number of people per household	2.46

Number of people in Brookings drinking home-softened water (only residences)

$$= 0.11 \times 3{,}248 \times 2.46 = 894.9$$

$$\approx 895$$

Sioux Falls

Total Water Accounts	23,000
Percentage owning softeners where only soft water is available for drinking	10.6
Average number of people per household	2.46

Number of people in Sioux Falls drinking home-softened water (only residences)

$$= 0.106 \times 23{,}000 \times 2.46 = 5{,}997.5$$

$$\approx 6{,}000$$

APPENDIX C

Calculations for Sodium Content in Home-Softened Water

Calculations for Sodium Content in Home-Softened Water

Brookings

Convert Ca, Mg, and Na of unsoftened water from mg/l to meq/l.

	mg/l	EW	meq/l
Ca	93	20	4.65
mg	36	12.2	2.95
Na	11	23.0	0.48

where $\text{meq/l} = \frac{\text{mg/l}}{\text{EW}}$

Assuming total hardness removal,

Total concentration of sodium in home-softened water

= (4.65 + 2.95 + 0.48) x 23.0 = 185.84 mg/l

Sioux Falls

Based on similar assumptions and calculations, the sodium content in home-softened water in Sioux Falls is

(3.55 + 2.46 + 1.04) x 23.0 = 162.15 mg/l

APPENDIX D

Statistical Analysis

Statistical Analysis

A. Based on the distribution of responses in Figures 7 and 9, a test of hypothesis was performed to see if any differences exist between Brookings and Sioux Falls.

1. For water softener owners without a hard water source for drinking.

$H_o = (P_B - P_{SF}) = 0$

$H_a = (P_B - P_{SF}) > 0$

Rejection Region = $Z > Z_\alpha = Z_{.05} = 1.645$

Test Statistic: $Z = \dfrac{(P_1 - P_2)}{\sqrt{P\,q\,(\frac{1}{n_1} + \frac{1}{n_2})}}$

where $P = \dfrac{26 + 146}{232 + 1369} = 0.107$

$q = 1 - 0.108 = 0.893$

$$Z = \frac{(0.112 - 0.106)}{\sqrt{(0.107)(0.893)(\frac{1}{232} + \frac{1}{1369})}}$$

$= 0.273 < 1.645$

Failed to reject null hypothesis

Therefore, there is little difference between Brookings and Sioux Falls.

2. For water softener owners with a hard water source for drinking.

$H_o = (P_B - P_{SF}) = 0$

$H_a = (P_B - P_{SF}) > 0$

Rejection Region = $Z > Z_\alpha = Z_{.05} = 1.645$

Test Statistic = $Z = \dfrac{(0.694 - 0.554)}{\sqrt{(0.574)(.426)(\frac{1}{232} + \frac{1}{1369})}}$

$= 3.988 > 1.645$

Reject null hypothesis

Therefore, there is significant difference between Brookings and Sioux Falls.

3. For residential homes without softening capabilities.

$H_o = (P_{SF} - P_B) = 0$

$H_a = (P_{SF} - P_B) > 0$

Rejection Region = $Z > Z_\alpha = Z_{.05} = 1.645$

Test Statistic = $Z = \dfrac{(0.34 - 0.194)}{\sqrt{(0.319)(0.681)(\frac{1}{232} + \frac{1}{1369})}}$

$= 4.412 > 1.645$

Reject null hypothesis

Therefore, there is significant difference between Brookings and Sioux Falls.

B. Based on the distribution of responses in Figures 8 and 10, a test of hypothesis was performed to see if any difference exists between Brookings and Sioux Falls.

$H_o = (P_{SF} - P_B) = 0$

$H_a = (P_{SF} - P_B) > 0$

Rejection Region = $Z > Z_\alpha = Z_{.05} = 1.645$

$$\text{Test Statistic} = Z = \frac{(0.162 - 0.139)}{\sqrt{(0.158)(0.842)(\frac{1}{187} + \frac{1}{904})}}$$

$$= 0.785 < 1.645$$

Failed to reject null hypothesis.

Therefore, there is little difference between Brookings and Sioux Falls.

APPENDIX E

Letter from the National Association of Plumbing-Heating-Cooling Contractors

National Association of Plumbing-Heating-Cooling Contractors

Pride In Our Past—Faith In Our Future

March 10, 1988

Wong Hock Chin
P.O. Box 7036 SDSU
Brookings, SD 57007

Dear Sir:

In response to your inquiry dated Jan 28, 1988, please review the following:

1. There are no provisions in the National Standard Plumbing Code that deal with water softeners specifically for residence.

2. A water softener is an appliance and should be installed as per manufacturer's instruction.

3. A tap that is made to bypass a water softener is covered by internal water piping installation requirements. In a residence you must have potable water for cooking and drinking, but you are not required to have a water softener.

This is not to say that due to local conditions, the building official and/or jurisdiction having authority cannot superimpose additional safety requirements for the public's welfare. I hope this has helped you solve your immediate problem.

Sincerely,

Robert L. Warren
Director of Technical Services

RW/as/5048T

180 S. Washington St., P.O. Box 6808, Falls Church, VA 22046-1148 • 703/237-8100