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THE CONTRIBUTION OF DRINKING WATER TO TOTAL DAILY DIETARY INTAKES OF SELECTED TRACE MINERAL NUTRIENTS IN THE UNITED STATES

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I. INTRODUCTION

Although foods are the major source of mineral nutrients in the diet, drinking water can contribute variable fractions of the total intake. The magnitude of the drinking water contribution, however, has not been characterized because little work has been done to quantify its contribution. The major reason is that drinking water intake is not included in most dietary surveys, and programs that measure the concentrations of nutrients in the diet by analysis include only the water used to prepare the food items analyzed. These factors make it difficult to assess the contributions of drinking water to total nutrient exposure.

Inorganic minerals generally gain access to surface water and groundwater as a result of their presence in the earth's crust and their aqueous solubility. Accordingly, they may be widely distributed throughout the aquatic environment. Minerals are not uniformly distributed in earth materials, however, and the amount in water can vary significantly with local geologic and hydrologic conditions. Additional amounts of some nutrients can gain access to ambient water from anthropogenic activities, including industrial discharges, runoff from land, and waste disposal practices.

Some mineral nutrients are present in drinking water because of treatment processes. For example, fluoride is added directly to water to obtain final concentrations between 0.7 and 1.2 mg/L in drinking water systems that elect to fluoridate as a means of preventing dental decay. Calcium, zinc, manganese, phosphate, and sodium compounds may be added directly to water as a result of treatment processes such as pH adjustment or corrosion control. Other mineral nutrients such as copper and zinc can leach from plumbing materials; chromium and selenium can be present as impurities in paints, sands, and other water contact materials.

As part of its 2003 review of its drinking water regulations, the U.S. Environmental Protection Agency (EPA) has recently analyzed the concentrations of a large number of contaminants found in public water systems (PWSs). Several mineral nutrients (chromium, fluoride, and selenium) were assessed as part of this process. Data on others, such as manganese and sodium, were collected and evaluated during regulatory determination for the Contaminant Candidate List (CCL). These data can be used to provide information on the prevalence and magnitude of mineral nutrient exposures through drinking water in the United States.

As freshwater resources become scarce, the world will become increasingly reliant on desalination or demineralization to provide potable water. The process of desalination, either by flash evaporation or reverse osmosis, depletes the source water of its mineral contents. This has increased the interest in the role that drinking water minerals play in human nutrition.

It has been suggested that there may be adverse outcomes from reliance on desalinated or demineralized water as a result of the loss of mineral nutrients. Some individuals have proposed post treatment replenishment of the mineral nutrients that were removed. However, to determine whether the loss of mineral nutrients from water constitutes a nutritional problem, it must first be determined whether drinking water plays a significant role in the total dietary intake of trace minerals.

This report utilizes data on the dietary intake of selected mineral nutrients in the United States as well as data on the concentrations in drinking water to determine the relative contribution of food items and drinking water to total exposure. This review considers chromium, copper, fluoride, iron, manganese, selenium, sodium, and zinc.

II. SOURCES OF INFORMATION

The primary sources of the dietary information included in this report are the National Academy of Sciences Institute of Medicine (IOM) Dietary Reference Intake volumes that cover the mineral nutrients (1,2,3). These documents provide data on the Adequate Intakes (AIs), Estimated Average Requirements, Recommended Daily Allowances (RDAs), and Tolerable Upper Intake Levels (ULs) for each nutrient. Also included in the appropriate reference volume is information on population nutrient intake that was compiled from the National Health and Nutrition Survey III (NHANES III) for the years 1988 through 1994, the Continuing Survey of Food Intake by Individuals (CSFII) for 1991 through 1994, and the Total Diet Study (TDS) for 1991 to 1997.

The NHANES is a national U.S. population survey conducted periodically by the National Center for Health Statistics of the Centers for Disease Control and Prevention. In the NHANES, dietary data are gathered through a 24-hour recall interview conducted by a trained professional. In the 24-hour recall interview, the subject is asked to provide information on all food items consumed over the previous 24-hour period (food items and quantities). The interview is structured, and various props are used to help quantify portion sizes.

The CSFII is conducted by the U.S. Department of Agriculture on a periodic basis. One purpose of this survey is to provide information on the kinds and amounts of food eaten by the U.S. population. Each survey covers 3 years. In each of the survey years, a nationally representative sample of the population is interviewed to provide information on 2 nonconsecutive days of food intake using the 24-hour recall interview approach.

Additional data on dietary intake are provided by the U.S. Food and Drug Administration TDS. This survey differs from the NHANES III and CSFII approaches in that it relies on chemical analysis of a typical diet using foods purchased from four geographic regions of the country (northeast, south, north-central, and west). The composition of the typical diet for a number of age/sex groupings is derived from the CSFII data. The foods are prepared as they would be served and analyzed to measure the analytes of interest.

Data on the concentration of mineral nutrients in drinking water were provided primarily from two U.S. EPA reports. They are the Analysis of National Occurrence of the 1998 Contaminant Candidate List (CCL) Regulatory Determination Priority Contaminants in Public

Water Systems (4) and Occurrence Estimation Methodology and Occurrence Findings Report for the Six-Year Review of Existing National Primary Drinking Water Regulations (5).

The data for copper, iron, manganese, sodium, and zinc primarily come from the National Inorganic and Radionuclide Survey (NIRS) conducted from 1984 through 1986 (4). The data represent only PWSs that rely on groundwater as their drinking water source. Each system tested was randomly selected to be statistically representative of groundwater systems in 49 States and Puerto Rico. When there were PWS data from surface water systems on these same nutrients, they were also evaluated (4).

The NIRS study provided data on many cationic inorganic ions in water including calcium and magnesium. Neither of these minerals is included in this report. However, they were found in 99.7% of systems for calcium and 98.7% of systems for magnesium. Mean concentrations (49 mg/L for calcium and 16 mg/L for magnesium) were low compared to their dietary requirements. The 90th percentile values (97 mg/L for calcium and 36 mg/L for magnesium) would make more substantial contributions to dietary intake,

The data for chromium, fluoride, and selenium come from the monitoring data collected by 16 States as part of their compliance with the National Potable Drinking Water Regulations (5). The 16 States represent a cross-section of PWSs across the United States that submitted their data to the U.S. EPA in a format that could be utilized in the analysis and met selected quality control criteria.

Copper, iron, and zinc are included in this report even though they were not covered in the U.S. EPA reports identified above. They are important mineral nutrients and are frequently present in water because of geology, industrial discharge, leaching from pipes or conveyance materials, and/or addition as treatment chemicals. Alternate sources of information were used for this group of nutrients and include:

- Unpublished NIRS data (4)
- Data submitted to the U.S. EPA under the requirements of the Lead and Copper Rule
- Information from Agency for Toxic Substances and Disease Registry (ATSDR) toxicological profiles
- U.S. EPA Secondary Drinking Water Standards
- National Science Foundation (NSF) International/American National Standards Institute (ANSI) standards for drinking water treatment chemicals

III. DATA AND ANALYSIS

To determine whether drinking water provides a significant portion of the total dietary intake for each of the selected nutrients, data on dietary exposures and intake recommendations were compiled from the IOM (1,2,3). The 5th, 50th, and 95th percentile dietary intakes for all ages from the NHANES III, CSFII, and TDS—as compiled by the IOM—were abstracted, where available, and are summarized in Table 1.

Table 1. Dietary Intake (All Individuals)

Mineral	Percentile			Source
	5th	50th	95th	
Chromium	NA	NA	NA	ND
Copper (mg/day)	0.72	1.24	2.09	NHANES III
Copper (mg/day)	0.58	1.1	2.01	CSFII
Copper (mg/day)	0.22	0.57	1.39	TDS
Fluoride (mg/day)	NA	NA	NA	ND
Iron (mg/day)	7.7	14.1	25.8	NHANES III
Iron (mg/day)	7.4	14.3	26.7	CSFII
Iron (mg/day)	3.83	9.74	24.26	TDS
Manganese (mg/day)	0.49	1.71	4.79	TDS
Selenium (Φg/day)	57	106	193	NHANES III
Sodium (mg/day)	NA	3000	NA	TDS
Zinc (mg/day)	6.1	10.7	18.4	NHANES III
Zinc (mg/day)	5.5	10.4	18.8	CSFII
Zinc (mg/day)	2.84	7.36	18.63	TDS

NA = not analyzed; ND = no data. Note: Adapted from IOM (2,3) and Pennington and Schoen (6)

The RDA and/or AI values plus the UL recommendations for adults also were extracted from the IOM reports and are compiled in Table 2. The RDA values represent target nutrient intakes for specific age/sex groupings and are considered to be adequate to cover the nutritional needs of about 97% of the population. In cases where the data are not adequate to establish an RDA for a nutrient, the IOM sets an AI value that appears to provide an adequate nutrient intake for at least 50% of the target population. The UL value, on the other hand, is a recommended upper bound on nutrient intake that should not be exceeded on a daily basis. Intakes at or below the UL are not anticipated to cause any adverse effects.

Table 2. Adult Dietary Reference Intakes

Mineral	RDA or AI (female/male) (mg/day)	UL(mg/day)
Chromium	0.024/0.035 [a]	NE
Copper	0.9	10
Fluoride	3/4[a]	10
Iron	18/8	45
Manganese	1.6/2.2	11
Selenium	0.055	0.4
Sodium	2500	NE
Zinc	8/11	40

[a] AI value NE = none established. Note: Adapted from IOM (1,2,3)

The data on mineral intakes from drinking water vary according to the information source and are summarized in Table 3. Information from U.S. EPA reports (4,5) provided data on the percentage of the population exposed below the Minimum Reporting Level (MRL) for each mineral. The MRL is the mean of the minimum reporting levels reported by the States. Information was also available on the percentage of the population exposed at concentrations above the regulatory Maximum Contaminant Level (MCL) or the Health Reference Level (HRL). The HRL is the health-based benchmark that was used in examining occurrence during the CCL regulatory determination process. The HRL was derived using the methodology that the U.S. EPA Office of Water uses for calculating a Lifetime Health Advisory.

Table 3. Population Exposure to Mineral Nutrients Through Drinking Water

Mineral	Minimum Reporting Level (mg/L)	Population Exposed (%)	MCL or HRL (mg/L)	Population Exposed (%)
Chromium	0.01	29	0.1	1
Copper	1.3	NA	1.3	NA
Fluoride	0.1	97	4	5
Manganese	0.001	55	0.3 [a]	3
Selenium	0.005	23	0.05	0.3
Sodium	0.91	100	120 [a]	8.3

[a] HRL value NA = not available. Note: Adapted from U.S. EPA (4,5)

A single exceedance of the MCL does not constitute a violation of the National Primary Drinking Water Regulations since violations are based on the average of four quarterly readings. However, when the HRL is the benchmark for comparison (manganese, sodium), the occurrence data come from unregulated contaminant monitoring, and the values are based on a single exceedance of the HRL rather than on an average of quarterly readings. Information on the median concentration of the detections and the 99th percentile concentration of the detections, when available, was used in the analysis.

In the analysis of the data described above, the percentage of the population exposed below the MRL was compared with the 5th and 50th percentile dietary intakes to examine the contribution of drinking water to dietary intake for this segment of the population. In most cases, population estimates were rounded to the nearest whole percent. An average drinking water intake from all sources of 1.2 L/day, as determined by the U.S. EPA (7), was used for this analysis rather than the 84th percentile 2 L/day value. The percentage of the population exposed to concentrations between the MRL and the MCL/HRL also was compared with the 5th and 50th percentile dietary intakes. The portions of the population exposed to levels greater than the MCL or HRL were compared with the 95th percentile dietary intakes to determine whether there might be a toxicity concern. For this analysis, the 2 L/day drinking water intake value (7) was used in determining the drinking water exposure.

There are several limitations in the present analysis. In three cases (chromium, fluoride, and sodium), complete dietary intake data were not available. For these three chemicals, the drinking water exposure was compared with the AI level (chromium, fluoride) or the average dietary intake (sodium) rather than with population percentile data. In addition, the drinking water measurements often covered a wide range of concentrations because they were analyzed by the U.S. EPA for different purposes. The concentration interval range limits the precision of the drinking water contribution assessment. Also, some of the drinking water data provided estimates of the exposed populations, whereas in other cases, the data apply to PWSs or homes. The data limitations are mentioned in the relevant discussions that follow.

IV. RESULTS

The results of the analyses described above are presented in the following paragraphs. The nutrients are discussed in alphabetical order.

1. Chromium

Chromium participates in the control of glucose uptake by cells and thus appears to play a role in maintaining serum glucose levels (3). Dietary chromium is present as chromium III; the chromium levels for drinking water apply to total chromium. However, the chromium VI oxidation state is reduced to chromium III in the gastrointestinal track when chromium VI intakes are low (3). The data on exposure of the population to chromium in drinking water indicate that 71% of the population receive levels less than 0.01 mg/L and 29% receive levels between 0.01 mg/L and 0.1 mg/L. Only 0.001% receive concentrations greater than 0.1 mg/L (5).

Chromium intakes have not been monitored through the NHANES, CSFII, or TDS. Accordingly, the contributions from drinking water are evaluated against the adult dietary recommendation. The AI for chromium is 24 Φg/day for adult females and 35 Φg/day for adult males. Table 4 provides a comparison of the drinking water contribution for chromium to the dietary recommendations. No data indicate toxicity from dietary exposures to chromium, and thus the IOM did not set a UL.

Table 4. Estimated Chromium Exposure

Drinking Water (Φg/day)	Population (%)	Food (AI) (Φg/day)	Adult AI (%)
<1.2[a]	71	24-35	3-5
1.2-120[a]	29	24-35	3-500
>200[b]	–0.001	No UL	No UL

[a] Drinking water contribution was determined by multiplying the concentration by 1.2 L/day.
[b] Drinking water contribution was determined by multiplying the concentration by 2 L/day.

A few duplicate diet studies of chromium intake suggest that the population intake may be marginal in some cases (3). A duplicate diet study is one in which participants collect portion sizes identical to what they consume for analysis. The collected samples are then homogenized and assayed for the analyte of interest.

The data in Table 4 indicate that chromium in drinking water can make a significant contribution to total exposure for systems that have concentrations near the MCL. Individuals exposed at or above the MCL are receiving 5 to 10 times the dietary requirement from drinking water, but only a small portion of the U.S. population is likely to be exposed at these levels. For 71% of the population, chromium contributions to total intake are minimal (3% to 5%).

2. Copper

Copper is an important constituent of a number of enzyme systems, including those responsible for utilization of iron, protection against free-radical oxygen species, and maturation of collagen

(3). It is sometimes added to impounded surface water to prevent the growth of algae, but its presence in drinking water is largely the result of corrosion of metallic copper used in the distribution system. Copper concentrations in drinking water fluctuate as a result of variations in water characteristics such as pH, hardness, and water chemistry.

The copper concentration of drinking water in the United States is measured at the tap and is reported to the State only under conditions where greater than 10% of the samples exceed the regulatory action level of 1.3 mg/L. Accordingly, the U.S. EPA does not have monitoring data for copper that are comparable to those for some other regulated mineral nutrients. In the United States, the median values for first-draw 90th percentile exceedances from 1991 to 1999 were slightly greater than 2 mg/L (7307 samples). Ten percent of the samples with exceedances had copper concentrations greater than 5 mg/L, and 1% were greater than 10 mg/L (8). Data from the NIRS indicate that 79% of the samples from groundwater systems had detections; the median concentration was 0.02 mg/L. The NIRS samples were taken at the entry to the distribution system and do not represent at-the-tap samples.

Results from a number of studies in Canada and the United States indicate that copper levels in drinking water can range from 0.005 to >30 mg/L (8,9,10). Levels of copper in running or fully flushed water tend to be low, whereas those in standing or partially flushed water samples are more variable and can be substantially higher. In four Nova Scotia communities, the first-draw water concentrations were greater than 1 mg/L in 53% of the homes (11). In a study from Sweden, the 10th percentile copper concentration in 4703 samples of unflushed water from homes was 0.17 mg/L, and the 90th percentile value was 2.11 mg/L (12). The median concentration was 0.72 mg/L.

Data on copper from the diet are available from the NHANES III, CSFII, and TDS. The TDS data indicate lower copper intakes than NHANES III and CSFII (Table 2) and were not used for Table 5. Since complete data on copper in drinking water are not available from the United States, the Pettersson and Rasmussen (12) data from Sweden are used to compare copper intakes from drinking water with those from the diet (Table 5). It is important to note that the drinking water guideline for copper in Sweden is 2 mg/L, which is greater than the 1.3 mg/L action level in the United States.

Table 5. Estimated Copper Exposure

Drinking Water (mg/day)	Homes (%)	Food[a] (mg/day)	Food Intake (%)
0.2 [b]	10	0.6-0.7	29-33
		1.1-1.2	17-18
>0.2-0.9[b]	40	0.6-0.7	29-150
		1.1-1.2	17-82
0.9-2.5 [b]	40	0.6-0.7	129-417
		1.1-1.2	75-227
>4.22[c]	10	2.0-2.1	>200

[a] Where there are two entries in the food column, the first applies to the 5th percentile dietary intake and the second to the 50th percentile dietary intake.

[b] Drinking water contribution was determined by multiplying the concentration by 1.2 L/day.

[c] Drinking water contribution was determined by multiplying the concentration by 2 L/day.

The values in Table 5 show that drinking water can supply a considerable portion of the daily copper intake for a substantial portion of the population. However, the copper intake from the combination of food and drinking water is unlikely to exceed the UL of 10 mg/L in most, but not all, instances. Drinking water concentrations greater than 4 mg/L, when combined with the 95th percentile dietary intakes, could equal or exceed the UL for copper.

3. Fluoride

Fluoride plays a role in the development of tooth enamel in young children and possibly in strengthening the bone matrix throughout life (1). In many areas of the United States, fluoride is added to drinking water as part of a program to reduce the incidence of dental caries. Because of considerable public interest, the U.S. EPA analyzed the population exposed at the minimum level recommended for fluoridation (0.7 mg/L) and the U.S. EPA Secondary Maximum Contaminant Level (SMCL) of 2 mg/L, in addition to systems exposed above the MRL and MCL (5). The SMCL was established to protect against moderate and severe dental fluorosis in young children.

The data on exposure of the population to fluoride indicate that only 3% of the population receive levels less than 0.1 mg/L, 44% receive average levels between 0.1 and 0.7, 51% are exposed to levels between 0.7 and 2 mg/L, and 1.8% are exposed to average levels between 2 and 4 mg/L (5). Only 0.09% of the population receive drinking water with average concentrations greater than 4 mg/L.

Fluoride intakes have not been monitored through the NHANES, CSFII, or TDS. Accordingly, the contributions from drinking water are evaluated against the dietary recommendations (AI). The AI for fluoride is 3 mg/day for adult females and 4 mg/day for adult males. Table 6 provides a comparison of the drinking water contribution for fluoride with the dietary recommendations. The UL for adults is 10 mg/day.

Table 6. Estimated Fluoride Exposure

Drinking Water (mg/day)	Population (%)	Food (AI) (mg/day)	Adult AI (%)
<0.12[a]	3	3-4	3-4
>0.12-0.84[a]	44	3-4	3-28
>0.84-2.4[a]	51	3-4	21-80
>2.4-4.8[a]	1.8	3-4	60-160
>8[b]	<0.09	10 (UL)	80

[a] Drinking water contribution was determined by multiplying the concentration by 1.2 L/day.
[b] Drinking water contribution was determined by multiplying the concentration by 2 L/day.

The data presented in Table 6 show that fluoride in drinking water can make a significant contribution to total exposure for most individuals, especially those living in areas that are fluoridated. The major contribution of fluoride in drinking water is recognized in all surveys of dietary fluoride intake (1). However, even with a concentration of 4 mg/L and a drinking water intake of 2 L/day, the dietary adult UL for fluoride is not exceeded, and only a small percentage of the population is exposed to levels in excess of 4 mg/L.

Because of their increased susceptibility to dental fluorosis at ages younger than 8 or 9 years, children are of particular interest with regard to fluoride exposure. Accordingly, it is important to look at the ULs of intake for this group. The average drinking water intake for children during the period of dentition for the permanent teeth is 528 mL/day (7) to 600 mL/day

(1). The average drinking water intake for children aged 1 to 10 years is 528 mL/day, and 600 mL is the average formula intake for infants aged 6 months to 1 year. The UL values for children in the age group of concern are 0.9 mg/day for infants aged 6 months to 1 year, 1.3 mg/day for children aged 1 to 3 years, and 2.2 mg/day for children aged 4 to 8 years (1). Accordingly, infants aged 6 months to 1 year can ingest 600 mL/day of formula prepared from drinking water containing 1.5 mg/L fluoride but not higher concentrations without exceeding the UL for this age group. Children in the 1- to 9-year-old age group will not exceed the AI for their respective age group if they ingest water at or below the U.S. EPA SMCL of 2 mg/L at the average drinking water intake for this group—even with a 90th percentile intake of 1 L/day for the 3- to 9-year-old age group. The U.S. EPA requires public notification for systems that exceed the SMCL and recommends an alternative drinking water source for children younger than 9 years.

4. Iron

Historically, iron was one of the first trace minerals to receive an RDA because of its critical role in the synthesis of hemoglobin and other heme proteins (3). Accordingly, there is a considerable amount of information on iron intake from foods. Fewer data are available on the concentrations of iron in drinking water. Iron contamination of water often results from its presence in the earth's crust. Iron also can gain access to drinking water from the corrosion of cast iron pipes and the use of iron salts as coagulants in treatment (13).

Iron is not regulated by the U.S. EPA and has not been a subject of unregulated contaminant monitoring. However, iron was monitored in the NIRS and was detected in 75% of the groundwater systems sampled. The minimum detection level was 0.009 mg/L, and the maximum was 7.4 mg/L. The median iron concentration was 0.060 mg/L, and the 99th percentile detection value was 3.3 mg/L. Note that the detection level is variable and thus may cause an underestimation of the systems with detections. There is a U.S. EPA SMCL of 0.3 mg/L to protect against the effects of iron on the taste and color of drinking water. The SMCL value, however, is not enforceable unless a State chooses to make the secondary value a primary standard under State law.

Although data on percentages of the population exposed to varying levels of iron are not available, it is possible to make some judgment regarding the iron that can be contributed to daily dietary intake from drinking water by using the median of the detections from the NIRS and the 99th percentile value as an upper level benchmark.

Dietary iron has been monitored through the NHANES III, CSFII, and TDS (Table 1). There is some variability in the data, and the TDS estimates for the 5th and 50th percentile dietary intakes fall below those from NHANES III and CSFII estimates (Table 1). Accordingly, they were not used for Table 7.

The RDA for iron is 18 mg/day for females of childbearing age (to account for replenishment of menstrual losses) and 8 mg/day for males. Individuals at the lower end of the population exposure curve (5%) fail to consume recommended levels and would benefit from iron in drinking water. The iron from average drinking water intake could increase the food exposure by only 1% but would increase intake by about 5% at levels close to the SMCL. Drinking water intake of iron at concentrations near the SMCL can make a small contribution to total intake for individuals with low dietary intakes.

Table 7. Estimated Iron Exposure

Drinking Water (mg/day)	Systems (%)	Food[a] (mg/day)	Food Intake (%)
<0.009	25	7-8	<1
		14	<1
<0.07[b]	38	7-8	1
		14	<1
0.07-4[b]	36	7-8	1-57
		14	<1-29
>6.6[c]	1	26-27	>24-25

[a] Where there are two entries in the food column, the first applies to the 5th percentile dietary intake and the second to the 50th percentile dietary intake.

[b] Drinking water contribution was determined by multiplying the concentration by 1.2 L/day.

[c] Drinking water contribution was determined by multiplying the concentration by 2 L/day.

The 50th percentile dietary intake group has an estimated daily iron intake that ranges from 10 to 14 g. This is adequate to meet the dietary needs of males but not females. An added 3 to 4 mg/day from 1.2 L of drinking water would be adequate to raise the intake for females too close to the RDA. The 95th percentile dietary intake is 25 to 28 mg/day. The 0.6 mg/day that would be contributed by ingesting 2 L of water at the U.S. SMCL would not increase total iron intake to a level that would exceed the UL of 45 mg/day. Concentrations of iron in drinking water at levels of 2 to 3 mg/L might pose a problem for individuals who suffer from iron storage disease (hemochromatosis) (3).

5. Manganese

Manganese is a cofactor for a number of enzyme systems involved in carbohydrate, amino acid, and lipid metabolism (3). It is widely distributed in the diet, especially for those following a vegetarian regime. Data from the NIRS indicate that 45% of the population are exposed to manganese through their drinking water at concentrations less than 1 Φg/L. Fifty-two percent are exposed at concentrations between 1 Φg/L and 300 Φg/L, and 3% are exposed at concentrations greater than 300 Φg/L (4,14). The median value for the detections was 10 Φg/L, and the 99th percentile value was 630 Φg/L.

Dietary manganese intakes have been monitored only through the TDS. These estimates suggest that the 5th percentile dietary intake is about 490 Φg/day. Average intake is about 1.7 mg/day, and the 95th percentile dietary intake is about 4.8 mg/day. The adult RDA for manganese is 1.6 mg/day for females and 2.2 mg/day for males. The adult upper limit is 11 mg/day. The data for manganese indicate that there is considerable variability in dietary intake and that average intakes are close to dietary requirements. However, about 50% of the population receive less than the RDA through their food supply. Table 8 provides a comparison of the drinking water contribution for manganese to the dietary recommendations.

The data presented in Table 8 suggest that manganese in drinking water can make a significant contribution to total intake for those at the lower end of the food intake distribution curve when concentrations in water approach the HRL. However, such exposures are infrequent given that the median of all detections was 10 Φg/L.

Table 8. Estimated Manganese Exposure

Drinking Water (Φg/day)	Population (%)	Food[a] (Φg/day)	Food Intake (%)
<1.2[b]	45	490	<1
		1700	<1
1.2-360[b]	52	490	<1-74
		1700	<1-21
>6002[c]	3	4800	>13

[a] Where there are two entries in the food column, the first applies to the 5th percentile dietary intake and the second to the 50th percentile dietary intake.

[b] Drinking water contribution was determined by multiplying the concentration by 1.2 L/day.

[c] Drinking water contribution was determined by multiplying the concentration by 2 L/day.

Manganese concentrations greater than the HRL are unlikely to have an adverse impact, ven on those in the 95th percentile dietary intake category. The combination of 2L of water at he HRL (600 Φg/day) and the 95th percentile dietary intake (4800 Φg/day) are less than the UL of 11,000 Φg/day. However, a 2 L/day intake of water from the 1% of systems with the highest manganese concentrations (>630 Φg/L), when combined with the 95th percentile dietary intake, would exceed the UL for manganese. The critical effect on which the UL is based is an increase in serum manganese levels and in the activity of manganese-dependent superoxide dismutase with a lowest-observed-adverse-effect level of 15 mg/day (3). This effect is considered marginally adverse.

6. Selenium

Selenium is a key component of several important enzymes, including glutathione reductase, iodothyronine deiodinase, and thioredoxin reductase (2). It is present in foods primarily as selenomethionine and selenocysteine; selenium in drinking water is more likely to be present as selenite or selenate ions (15). The data on exposure of the population to selenium in drinking water indicate that 77% of the population receive levels less than 5 Φg/L and 23% receive levels between 5 and 50 Φg/L (5). Only 0.002% receive concentrations greater than 50 Φg/L.

Dietary selenium intakes have been monitored through the CSFII and TDS. The estimates from these studies (Table 1) indicate that the 5th percentile dietary intake is about 57 Φg/day. The average intake is about 106 Φg/day, and the 95th percentile intake is about 193 Φg/day. The adult RDA for selenium is 55 Φg/day for females and males; the adult UL is 400 Φg/day. The dietary data for selenium indicate that the diet contains adequate quantities to satisfy requirements, even for individuals at the low end of the population intake distribution. Table 9 provides a comparison of the drinking water contributions for selenium to the dietary recommendations.

The data presented in Table 9 indicate that selenium in drinking water does not make a significant contribution to total selenium intake for most of the population. For example, selenium is 11% or less than the intake from foods in 77% of the drinking water systems. However, for those receiving concentrations near the MCL, the selenium in drinking water can provide one-half or more of the total dietary intake. Selenium concentrations greater than the MCL are unlikely to have adverse impacts, even on those in the 95th percentile dietary intake category. The combination of 2L of water at the MCL (100 Φg/day) and the 95th percentile dietary intake (193 Φg/day) is less than the UL of 400 Φg/day.

Table 9. Estimated Selenium Exposure

Drinking Water (Φg/day)	Population (%)	Food[a] (Φg/day)	Food Intake (%)
<6[b]	77	57	11
		106	6
6-60[b]	23	57	11-105
		106	6-57
>100[c]	0.002	193	>52

[a] Where there are two entries in the food column, the first applies to the 5th percentile dietary intake and the second to the 50th percentile dietary intake.

[b] The drinking water contribution was determined by multiplying the concentration by 1.2 L/day.

[c] The drinking water contribution was determined by multiplying the concentration by 2 L/day.

7. Sodium

Sodium is the principal electrolyte found in extracellular fluid. The balance between the concentrations of sodium and potassium (the principal intracellular electrolyte) is critical in the transmission of electrical impulses across the cell membrane (16). Sodium levels in serum also play a role in maintaining cellular osmotic pressure within mammalian systems.

Sodium is widely distributed in drinking water; it has been detected in almost all surface and groundwater systems evaluated. However, the levels are minimal compared with those in the diet. All samples in the NIRS contained sodium. For 82% of the population, the concentrations fell between 0.9 and 60 mg/L; for 10%, the levels fell between 60 and 120 mg/L; and for 8%, the levels were greater than 120 mg/L, the HRL benchmark. The 99% concentration for all samples was 517 mg/L, and the median concentration was 16.6 mg/L.

Data on surface water concentrations of sodium are minimal, but data from five States (Alabama, California, Illinois, New Jersey, and Oregon) were analyzed by the U.S. EPA (4,17). With the exception of the State of California, 90% or more of the population received drinking water with less than 60 mg/L. In California, only 23% received water with levels below 60 mg/L. However, even in California, the concentration exceeded 120 mg/L for only 1.5% of the population.

Only limited data could be identified for dietary exposure to sodium. The data from the 1982-1991 TDS showed an average intake for women (aged 25 to 30 years) of 1950 mg/day; men in the same age group had an intake of 2986 mg/day (6). These values are likely to be an underestimate of actual intake since they do not include discretional salt added at the table. The data support the widely accepted assumption that sodium intake for many in the population exceeds the recommended 2500 mg/day (16).

The data in Table 10 indicate that drinking water makes a minimal contribution to total dietary exposure to sodium, even for the small portion of the population who receive water with levels above 120 mg/L. The 99% concentration from groundwater was 519 mg/L. With a 2 L/day intake of drinking water, the sodium from water would be 32% (males) to 52% (females) of that from the average diet and could be of concern for a person with salt-sensitive hypertension. However, the adverse taste of water with this sodium concentration would be likely to minimize intake. The 99% concentrations for the surface water systems ranged from 150 to 379 mg/L.

Table 10. Estimated Sodium Exposure

Drinking Water (mg/day)	Population (%)	Food[a] (mg/day)	Average Intake (%)
<1.1[b]	0	2000-3000	–4[c]
1.1-72[b]	82	2000-3000	<1-4
72-144[b]	10	2000-3000	2-7
>240[d]	8	2000-3000	>8-12

[a] Averages for males and females (6).

[b] Drinking water contribution was determined by multiplying the concentration by 1.2 L/day.

[c] No percentage of the population at that level.

[d] Drinking water contribution was determined by multiplying the concentration by 2 L/day.

8. Zinc

Zinc is a component of more than 200 enzymes that are critical to processes such as those involved in DNA replication and gene expression (3). As with iron, there is a considerable amount of information on zinc intake from foods, but fewer data are available on the concentrations in drinking water.

Zinc is not regulated by the U.S. EPA and has not been a subject of unregulated contaminant monitoring. Zinc was included in the NIRS. It was detected in 87% of the samples, with a median detection of 0.2 mg/L and a maximum of 0.65 mg/L. Another survey (18) cited by the ATSDR (19) provided some information on the zinc found in tapwater in the United States. The minimum value reported was 0.025 mg/L, and the median value was 0.114 mg/L. Seventy-five percent of the samples contained less than 0.236 mg/L, and the maximum was 1.447 mg/L.

Zinc contamination of water can result from its presence in the earth's crust, leaching from galvanized materials for transport or storage of drinking water, and the addition of zinc orthophosphate products for corrosion control. The concentration of zinc that can be added to water for corrosion control is limited to 2 mg/L (13). There is an SMCL of 5 mg/L to protect against adverse taste effects.

As with iron, data on the percentage of the population exposed to varying levels of zinc through drinking water are not available. However, it is possible to make some judgment using the data of Greathouse and Osborne (18) and the SMCL as an upper level benchmark.

Zinc in the diet has been monitored through the NHANES III, CSFII, and TDS (Table 1). As with iron, the TDS estimates for the 5th and 50th percentile dietary intakes fall below NHANES III and CSFII estimates and were not used for Table 11. In most cases, zinc intake from drinking water does not make a significant contribution to total exposure. For PWSs that treat for corrosion control with zinc orthophosphates, the zinc from drinking water can increase that from food by 24% for individuals with an average zinc intake and by 40% for those in the 5th percentile dietary intake. At concentrations near the SMCL, zinc can make a significant contribution to total intake, increasing it by 50% or more.

The RDA for zinc is 8 mg/day for females and 11 mg/day for males. Individuals at the lower end of the population exposure curve fail to consume recommended levels and would benefit from zinc in drinking water where zinc orthophosphate is used for corrosion control or at levels close to the SMCL. These concentrations would increase zinc food intakes (3-6 mg/day) by about 2.5 to 6 mg. The 50th percentile population group has an estimated daily zinc intake that ranges from 7 to 11 mg/day and would not benefit as much from zinc contributed by drinking water. The 95th percentile dietary intake of zinc is 18 to 19 mg/day. The 10 mg/day that would be contributed by ingesting 2 L/day of water at the SMCL would not increase the total zinc intake to a level that would exceed the UL of 40 mg/day.

Table 11. Estimated Zinc Exposure

Drinking Water (mg/day[b])	Systems (%)	Food[a] (mg/day)	Food Intake (%)
0.03-0.14[c]	50	6 10-11	<1-2 – 1
0.14-0.28[c]	25	6 10-11	2-5 1-3
0.6-2.9[d]	25	18-19	3-16

[a] Where there are two entries in the food column, the first applies to the 5th percentile dietary intake and the second to the 50th percentile dietary intake.

[b] Greathouse and Osborne (18).

[c] Drinking water contribution was determined by multiplying the concentration by 1.2 L/day.

[d] Drinking water contribution was determined by multiplying the concentration by 2 L/day.

V. CONCLUSIONS

Although all of the minerals from drinking water evaluated in this report (chromium, copper, fluoride, iron, manganese, selenium, sodium, and zinc) can make significant contributions to dietary intake for some segments of the population, the affected population is generally small, and the contributions of potable water are most significant as the concentrations approach the MCL or HRL. This situation is fairly uncommon except in areas that are geologically rich in the mineral in question or, more importantly, when there is a source of the mineral from drinking water treatment chemicals (fluoride, iron, zinc) or as a result of leaching from drinking water contact materials (copper, zinc).

Individuals who would receive the greatest benefit from the presence of minerals in drinking water are those individuals with marginal intakes from food sources. In the United States, the 50th percentile dietary intakes from food appear to be adequate in most cases, with the exception of iron intakes by women. Accordingly, the intake from drinking water does not have a great impact on total exposure or physiological response.

The situation may well be very different in areas of the world where food is scarce or for those who do not benefit from the nutrient fortification programs that have been established in the United States. In cases where average intakes of mineral nutrients are below recommended levels, the minerals contributed by drinking water would become proportionally more important than indicated by U.S. data. From a toxicological perspective, the comparisons of the upper intakes from water plus food did not exceed the dietary UL recommendation for adults. This might partially be a reflection of the nature of the available data. For example, in a few cases where data from the upper extremes of exposure are available (copper and manganese), some individuals could be exposed above the UL.

Some sensitive population issues must be considered when examining the data presented in this report. Individuals with Wilson's disease must restrict their dietary copper intake, individuals with hemochromatosis have similar limitations on total dietary iron, and salt-sensitive hypertensive individuals must take measures to limit their sodium intake. Children are sensitive to dietary fluoride during the years of tooth formation, and levels of fluoride in drinking water near the SMCL (2 mg/L) and MCL (4 mg/L) can cause dental fluorosis in cases where drinking water intakes are higher than the average during this time period.

This report should be regarded as a preliminary effort to compare the contribution of waterborne minerals to overall nutritional health and well-being. Additional studies must be undertaken, especially in those areas with marginal intakes of these minerals from foods and/or high concentrations in drinking water. Programs that may be established to fortify desalinated or demineralized water must consider the effects on sensitive populations as well as the beneficial aspects of such measures.

References

1. Dietary reference intakes for calcium, phosphorous, magnesium, vitamin D, and fluoride. Institute of Medicine. National Academy of Sciences. National Academy Press. Washington, DC, 1997.
2. Dietary reference intakes for vitamin C, vitamin E, selenium, and carotenoids. Institute of Medicine. National Academy of Sciences. National Academy Press. Washington, DC, 2000.
3. Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. A Report of the Panel on Micronutrients, Subcomittees on Upper Reference Levels of Nutrients and of Interpretation and Use of Dietary Reference Intakes, and the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes. Food and Nutrition Board, Institute of Medicine, National Academy of Sciences. National Academy Press. Washington, DC, 2001.
4. Analysis of national occurrence of the 1998 contaminant candidate list (CCL) regulatory determination priority contaminants in public water systems. Office of Water. EPA 815-D-01-002. Washington, DC, 2002.
5. Occurrence estimation methodology and occurrence findings report for the six-year review of existing national primary drinking water regulations. Office of Water. EPA-815-R-03-006. Washington, DC, 2003.
6. Pennington JA, Schoen SA. Total Diet Study: Estimated dietary intakes of nutritional elements 1982-1991. Int J Vitam Nutr Res 1996;66:350-362.
7. Estimated per capita water ingestion in the United States. Office of Water. EPA-822-00-008. Washington, DC, 2000.
8. Copper in drinking water. National Research Council (NRC). National Academy of Sciences. National Academy Press. Washington, DC, 2000.
9. Maximum contaminant level goals and national primary drinking water regulations for lead and copper; final rule. Federal Register 56(110), 26460-26564. U.S. Environmental Protection Agency, 7 June 1991.
10. Health Canada. Copper. In: Guidelines for Canadian drinking water quality. Supporting documentation. Ottawa, Ontario, 1992.
11. Toxicological profile for copper (draft for public comment). U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry (ATSDR) (Subcontract No. ATSDR-205-1999-00024). Atlanta, GA, 2002.
12. Pettersson R, Rasmussen F. Daily intake of copper from drinking water among young children in Sweden. Environ Health Perspect 1999;107(6):441-446.
13. Drinking water treatment chemicals - health effects. American National Standard/National Science Foundation (NSF) international standard for drinking water additives. ANSI/NSF 60 - 2000. NSF International, Ann Arbor, MI, 2000.
14. Health effects support document for manganese. Office of Water. EPA-822-00-008. Washington, DC, 2003.
15. Toxicological profile for selenium (draft for public comment). U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry (ATSDR) (Subcontract No. ATSDR-205-1999-00024). Atlanta, GA, 2002.
16. Recommended dietary allowances. National Research Council. National Academy of Sciences. National Academy Press. Washington, DC, 1989.

17. Drinking water advisory: consumer acceptability advice and health effects analysis on sodium. Office of Water. EPA 822-R-03-006. Washington, DC, 2003.
18. Greathouse DG, Osborne RH. Preliminary report on nationwide study of drinking water and cardiovascular diseases. J Environ Path Toxicol Oncol 1980;4:65-76 (as cited in ATSDR 1994).
19. Toxicological profile for zinc. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry (Subcontract No. ATSDR- 205-88-0608). Atlanta, GA, 1994.