DRINKING WATER QUALITY

QUICK FACTS

Improvements in water quality over the past century—in particular, the disinfection of water—resulted in one of the great public health achievements of the 20th century: a dramatic drop in the incidence of waterborne diseases, such as cholera and typhoid.[1]

About eighty-five percent of the American public gets its water from a public water system, regulated by the Environmental Protection Agency (EPA). Approximately 10%–15% of the U.S. population, mostly in rural areas, relies on private, federally unregulated supplies of drinking water, such as groundwater wells and surface water, not subject to EPA standards under the Safe Drinking Water Act.[2,3]

In some parts of the United States, arsenic occurs in groundwater at high levels and can present a potential health hazard to people whose primary drinking water source is private well water.[4] In addition, some agricultural areas have moderate to high risk of nitrate contamination in groundwater, which can also cause adverse health effects.[5]

As development in our modern society increases, there are growing numbers of activities that can contaminate our drinking water. Improper disposal of chemicals, animal and human wastes, wastes injected underground, and naturally occurring substances have the potential to contaminate drinking water. Drinking water that is not properly treated or disinfected or that travels through an improperly maintained distribution system may also pose a health risk.[6]

INTRODUCTION

A safe water supply is crucial to public health and plays a critical role in the success of our society and economy. Improvements in water quality over the past century—in particular, the disinfection of water—resulted in one of the great public health achievements of the 20th century: a dramatic drop in the incidence of waterborne diseases, such as cholera and typhoid. Before disinfection, the incidence of typhoid fever was approximately 100 cases per 100,000 population in 1900; by 1920, it had decreased to 33.8 cases per 100,000, and by 1950, to 1.7.[7] By 2000, there were no typhoid cases related to public drinking water in the U.S.[1]

The U.S. has one of the safest drinking water supplies in the world. People safely come in contact with water every day through drinking and eating, bathing, participating in recreational activities, and inhaling water vapor or mist.

DRINKING WATER QUALITY

PUBLIC WATER SUPPLIES

The U.S. Environmental Protection Agency (EPA) is authorized under the Safe Drinking Water Act (SDWA) to protect public health by regulating the nation's drinking water supplies in about 155,000 public water systems.[8] Eighty-five to ninety percent of the American public gets their drinking water from a public water system.[2]

PRIVATE DRINKING WATER SOURCES

Approximately 10%–15% of the U.S. population, mostly in rural areas, relies on private, federally unregulated supplies of drinking water such as groundwater wells and surface water not subject to EPA standards under the Safe Drinking Water Act or to regular monitoring by other entities.[3] A few state and local governments have regulations to protect users of private wells; but state regulations vary widely, and there is no requirement to report well water monitoring data at a national level.[9] The U.S. Geological Survey (USGS) is the nation's primary agency providing information and research on groundwater resources. They operate a national network of observation wells to measure well water quantity and quality. Although not a regulatory agency, the USGS collects data about water resources, water use, surface water, groundwater, and contaminant movement through these resources.

BOTTLED WATER

The U.S. Food and Drug Administration (FDA) regulates bottled water used for drinking. The FDA regulations for bottled water generally correspond with EPA standards for chemical or microbial contaminants. However, there are no requirements that bottled water quality data be reported to any federal agency or to the public.[10]

Increasingly, the U.S. population is turning to bottled water as a primary source of drinking water. There is no evidence that drinking bottled water is safer than drinking treated water from a tap. All drinking water, including bottled water, can be expected to contain small amounts of some contaminants. The quality of bottled water depends on the source and how or if the water is treated. Information about the source of the water and type of treatment is listed on the label.

DRINKING WATER CONTAMINANTS

The Safe Drinking Water Act establishes maximum contaminant levels (MCLs), the highest level of a contaminant that is allowed in drinking water, for over 80 potentially harmful microorganisms, organic and inorganic chemicals, metals, and radionuclides in drinking water.[11] MCLs for regulated contaminants are revised as research provides new information. The EPA also identifies and evaluates unregulated contaminants for possible future regulation.

Contamination of drinking water can occur at the source (in groundwater and surface water) as well as in the distribution system after disinfection has occurred. The sources and causes of water contamination include

- naturally occurring processes, e.g., extreme weather events,
- naturally occurring contaminants, e.g., arsenic,
- urbanization,
- agricultural land use practices,
- accidental or improper releases of contaminants or waste into water bodies, and
- decaying or damaged water infrastructure.[12]

MICROORGANISMS

Pathogens that might occur in drinking water include the following:

- *Escherichia coli, Salmonella, Campylobacter* and other bacteria;
- the protozoan parasites: *Cryptosporidium* and *Giardia lamblii*; and
- enteric viruses, e.g., norovirus and rotavirus.

These pathogens are typically found in untreated water as a result of contamination from human or animal fecal waste and are overwhelmingly responsible for reported disease outbreaks from drinking water and recreational water.

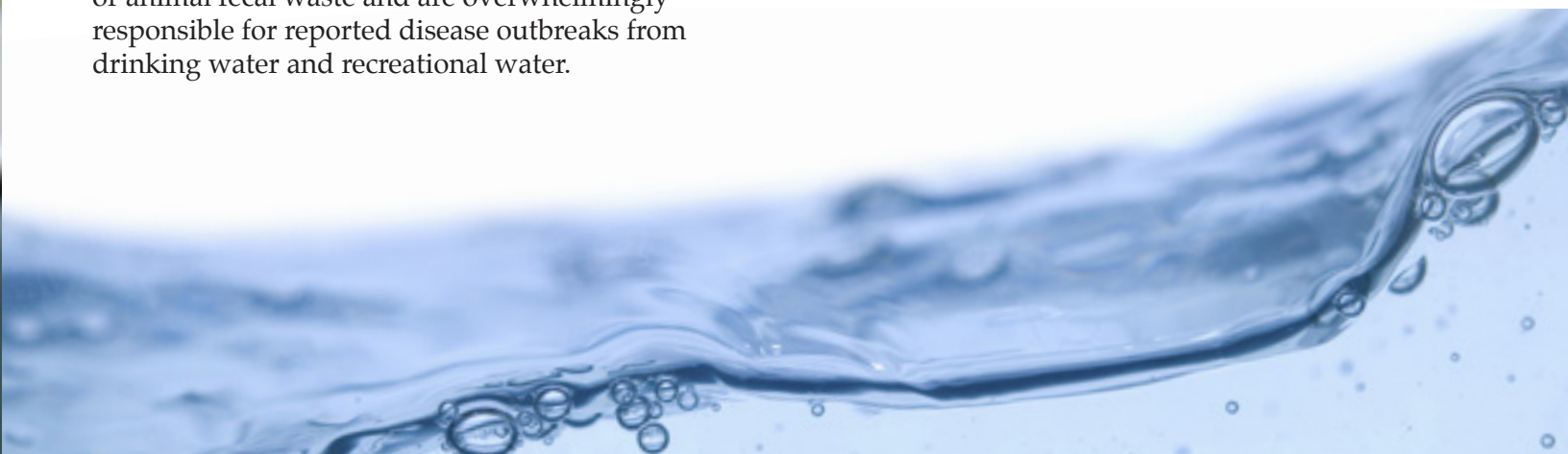
ORGANIC AND INORGANIC CHEMICAL CONTAMINANTS

Chemical contaminants likely to be found in drinking water include metals, fertilizers, pesticides and manufacturing wastes, and emissions.[13] Improper disposal of industrial wastes, metals discharged from petroleum refineries, fertilizer runoff, corrosion of household plumbing and discharge from industrial chemical factories are all causes of chemical contamination of drinking water. Drinking water treatment processes are designed to remove or reduce these contaminants to levels where they may be expected to cause no health effects.

Disinfectants added to water to control microbial contamination can also cause health effects if present in great enough concentrations. By-products of those disinfectants can also be responsible for causing adverse health effects and are regulated by the EPA to reduce that risk.[13]

RADIONUCLIDES

Radiation may exist in drinking water from nuclides dissolved in the water from natural sources in the earth or occasionally from releases from laboratories or nuclear power plants. A radionuclide is an atom with an unstable nucleus that, to become more stable, emits energy in the form of rays or high speed particles. This is called ionizing radiation. Approximately 80% of our exposure to radioactivity is natural, and another 20% is from man-made sources. We are exposed to naturally occurring radiation from radon gas emitting from rocks and soil and cosmic radiation from space. We also carry small amounts of potassium-40 (a radioactive isotope) in our bodies from the foods containing potassium.[14] The EPA regulates ionizing radiation in drinking water.[14]



HEALTH EFFECTS OF DRINKING WATER CONTAMINANTS

There is a broad range of health effects associated with exposure to drinking water contaminants. Ingestion or exposure to pathogens at sufficient doses can result in gastrointestinal illness with symptoms, such as diarrhea, nausea, stomach cramps and vomiting. Exposure to higher doses of chemicals, metals or radionuclides can produce biological responses, toxicological effects, and more severe health impacts including cancer, developmental or reproductive effects, neurological effects, and organ damage.[13,14]

TRACKING DRINKING WATER QUALITY

The best source of drinking water quality data is compiled by the EPA and the states in the Safe Drinking Water Information System (SDWIS). These data are provided through the routine monitoring of community water systems required under the Safe Drinking Water Act and state- or community-specific drinking water regulations.[15]

The Federal Safe Drinking Water Information System (SDWIS/FED) is a national EPA database system that stores information the EPA uses to monitor about 160,000 public water systems.[15] The SDWIS/FED contains basic information about the type of water system, the population served, and other system characteristics. The database also contains information about water system monitoring requirements and treatment techniques and violations of any regulated MCLs.

The State Safe Drinking Water Information System (SDWIS/STATE) is a database designed by the EPA to help states run their drinking water programs.[15] It includes concentrations of regulated contaminants and is more useful than SDWIS/FED for estimating hazards and exposures from drinking water at a state or local level.

Every six years the EPA conducts a review of the National Primary Drinking Water Regulations and collects complete records of compliance monitoring conducted by states.[16] The "EPA Six-Year Review" for 1998–2005 is the largest and most comprehensive drinking water contaminant occurrence dataset ever compiled and analyzed by the EPA. It contains data from 45 states and 89% of public water systems and includes information on 69 contaminants.[16]

The U.S. Geological Survey (USGS) operates two national programs that collect information on biological and chemical contaminants in drinking water wells. The USGS National Water Information System (NWIS) provides access to water resources data measuring stream flow, groundwater levels, and water quality collected at approximately 1.5 million sites in all 50 States, the District of Columbia, and Puerto Rico.[17]

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, state, and local information needs and decisions related to water quality management and policy.[18] During its first decade NAWQA completed assessments in 51 major river basins and aquifers across the nation, sampling at nearly 500 stream sites and more than 5,000 wells. Together, the 51 assessments characterized the source of water for more than 60% of the nation's drinking water and water for irrigation and industry. Each assessment provided baseline data and information on the occurrence of more than 600 compounds, including pesticides, nutrients, volatile organic compounds (VOCs), trace elements, and radon in water, and on the condition of stream habitat and fish, insect, and algal communities.[19] The contaminants most frequently measured at concentrations of potential health concern were inorganic contaminants, including radon, arsenic and nitrate.[20]

The NAWQA continues to address the status of water quality by adding monitoring in geographic gaps; investigating new contaminants, such as new pesticides, wastewater compounds, and chemicals in personal care products; and addressing the occurrence of contaminant mixtures and degradation products. Increased emphasis is placed on the quality of source water and drinking water.

This module will focus on three drinking water contaminants—arsenic, nitrates, and disinfection by-products—because they have been well studied and occur more frequently than other contaminants at levels that may be of public health significance.[21,22,23,24,25,26,27,28]

WHAT IS ARSENIC?

Arsenic is a naturally occurring element in certain types of soils and rock formations and can leach into groundwater and surface water. In some parts of the United States, arsenic occurs in groundwater at high levels and can present a potential health hazard to people whose primary drinking water source is private well water. Other possible sources of arsenic contamination in drinking water include

- pesticides (insecticides, herbicides and fungicides),
- leachate from landfills,[29]
- coal ash,
- wood preservative,
- feed additives for poultry and swine,
- cattle and sheep dips used to control lice and ticks,
- alloys used in lead acid batteries for automobiles, and
- semiconductors and light-emitting diodes.

HEALTH EFFECTS OF ARSENIC

Arsenic has been recognized from ancient times as an acute poison. Large oral doses of arsenic above 60,000 parts per billion (ppb) in food or water can produce sudden death. Levels of inorganic arsenic (the more toxic form of the element), ranging from about 300 to 30,000 ppb in food and water can cause irritation of the stomach and intestines, with symptoms such as pain, nausea, vomiting, and diarrhea. Arsenic is also associated with such adverse health effects as

- decreased production of red and white blood cells,
- abnormal heart rhythm,
- blood vessel damage, and
- impaired nerve function causing a "pins and needles" sensation in the hands and feet.

Chronic exposure to arsenic at lower exposure levels has also been shown to have human health implications.[30] Exposure to hundreds of micrograms per liter ($\mu g/L$) of arsenic found in the drinking water of Taiwan, Chile, Argentina, Mexico, Bangladesh, and India

has been associated with many adverse health effects including lung, bladder, liver, and skin cancers.[31,32,33,34] In fact, the carcinogenic effects of chronic exposure to inorganic arsenic in drinking water have been well established.[35] However, data are largely from studies conducted in southwest Taiwan and other regions where drinking water arsenic levels are much higher than those typically seen in the United States.

At the present time, the maximum contaminant level (MCL) in the United States for arsenic is 10 μg/L, recently reduced from 50 μg/L by the EPA in January 2006.[36] Human exposure data suggest that there is an increased risk of lung and bladder cancer at arsenic concentrations below the previous MCL of 50 μg/L. But, more data are needed to directly quantify cancer risks and other potential health risks for U.S. populations given the relatively low exposure to inorganic arsenic.[37] Arsenic has been identified as a human carcinogen by the International Agency for Research in Cancer (IARC).[38]

Other adverse health effects of arsenic exposure include

- nausea,
- cardiovascular disease,[39,40,41]
- developmental and reproductive effects,[42,43]
- skin keratosis and hyperpigmentation,[44]
- increased risk of peripheral vascular disease, and
- increased risk of mortality from heart disease and hypertension.

The risk of potential health effects increases with increasing dose and duration of exposure.[45]

STATUS AND TRENDS OF ARSENIC

Most drinking water in the United States contains an average of 2 µg/L of arsenic, well below the MCL of 10 μg/L. Yet in the north central and western regions of the country, approximately 12% of water supplies from surface water and 12% of supplies from groundwater sources have levels exceeding 20 µg/L. In addition, most arsenic concentrations in rivers and lakes are below 10 µg/L, but arsenic has been found in groundwater at concentrations up to 3400 μg/L in some western states.[29]

Table 1. Number of people receiving drinking water from public water supplies with one or more samples reported to be greater than the MCL for arsenic[46]

State	Population exposure to arsenic at 0.01 mg/L	State	Population exposure to arsenic at 0.01 mg/L
CA	13,280,982	NE	57,170
AZ	4,799,509	KY	56,804
NM	764,452	AL	48,842
NJ	753,876	NY	43,254
MI	745,619	ND	33,565
NV	546,637	CO	31,795
UT	521,996	IA	26,647
ID	399,686	NC	21,285
AK	285,512	MT	20,653
OK	274,257	VA	19,118
MN	248,365	GA	16,343
IL	224,068	MO	11,164
TX	215,265	VT	7,204
IN	151,633	AR	4,784
MA	136,331	DE	4,442
OH	118,852	CT	4,339
NH	116,064	WY	3,753
WI	87,688	WV	3,603
MD	83,479	SD	3,075
TN	75,771	FL	880
ME	73,901	SC	766
OR	73,597	RI	95
		HI	NR

NR – none reported

The EPA, in its "Six Year Review of National Public Drinking Water Resources" analysis completed in 2009, concluded that public water systems in 44 states tested at least once for arsenic at levels higher than the MCL.

WHAT ARE NITRATES AND NITRITES?

Nitrate was first identified as a public health threat in drinking water in 1945. High nitrate levels from private drinking water wells were shown to cause methemoglobinemia or "blue baby syndrome" in infants who were fed formula prepared using well water. Nitrates are converted to nitrite. Nitrite binds with hemoglobin to form methemoglobin, a compound that does not bind oxygen, resulting in reduced oxygen transported from the lungs to tissues.[47] Infants under 6 months of age are the population at risk because their stomach and intestinal tract are less acidic and support the bacteria responsible for converting nitrate to nitrite.[48]

Nitrate (NO^3) and nitrite (NO^2) are regulated under the Safe Drinking Water Act with MCLs of 10 and 1 mg/L, respectively.[47]

Sources of nitrate in the environment include

- natural soil organic nitrogen
- atmospheric sources of nitrate and nitric acid from air pollution emissions from industry and vehicle emissions
- nitrogen fertilizers used in agricultural and residential settings
- runoff or leaching of livestock wastes
- sewage from septic systems

Predominantly agricultural areas and certain regions of the United States, e.g., the agricultural Midwest, have a moderate to high risk of nitrate contamination in groundwater.

THE HEALTH EFFECTS OF NITRATES AND NITRITES

Symptoms of nitrate or nitrite exposure include shortness of breath and blueness of the skin. In extreme cases, death by asphyxiation can occur. In addition, exposure to nitrate has been linked to adverse reproductive effects. However, human health studies of the effect of nitrate on reproductive toxicity are inconclusive.[49] Animal studies have observed adverse reproductive effects at higher doses of nitrate and nitrite. However, epidemiological reports of an association between exposure to nitrates in drinking water and spontaneous abortions, intra-uterine growth restriction, or various birth defects are restricted by uncertainties associated with a lack of individual exposure assessment, the likely presence of other contaminants, and the influence of other risk factors.

Exposure to nitrate has also been linked to cancer. Studies have shown that occupationally exposed nitrate fertilizer workers have a slightly increased incidence of stomach cancer.[50,51] Yet, there are uncertainties associated with the evidence linking long-term exposure to higher nitrate levels in drinking water with an increased cancer incidence. For example, cancer at several sites (i.e., gastric, colorectal, bladder, urinary tract, brain, esophagus, ovarian and non-Hodgkin lymphoma) has been linked to exposure to nitrate in drinking water in some cohort, case-control, and ecological studies.[24,52,53,54,55,56] However, a number of studies seeking to link nitrate intake to increased tumor incidence outside the gastrointestinal tract did not find an association with exposure to nitrate and tumor formation.[57,58,59,60,61] Some researchers suggest that significant regional differences in cancer risk may exist due to regional differences in well water content.

TRENDS FOR NITRATES AND NITRITES

In assessments conducted in 2006 by the EPA, over 31 million Americans were receiving drinking water from public water supplies in which one or more samples tested as having nitrate contamination greater than the MCL (10 mg/L).[60] The largest numbers of individuals receiving water from a water supply that had tested (at least once) for increased levels of nitrate were in California and Ohio. In contrast, Hawaii, North Dakota, New Mexico, South Dakota, Tennessee and Arizona reported that *no* individuals were receiving their water from regulated water systems that tested for levels of nitrate higher than the MCL.[6]

Table 2. Number of people receiving drinking water from public water supplies with one or more samples reported greater than the MCL for nitrates[46]

State	Population-Exposure to Nitrates >10 mg/L
CA	27,341,514
OH	1,352,964
AZ	824,186
IA	458,504
TX	397,138
NY	190,619
FL	121,275
WI	112,347
MI	103,836
ID	76,149
MD	68,736
MN	68,623
NJ	67,792
NC	38,376
DE	33,594
CO	30,389
OK	30,307
IN	28,385
OR	21,245
IL	18,196
AL	9,709
MA	8,597
WY	6,440

State	Population-Exposure to Nitrates >10 mg/L
SC	5,064
ME	4,449
NV	3,979
WV	3,087
CT	2,337
AK	1,973
NH	1,912
RI	1,835
UT	1,643
KY	1,110
VT	779
VA	586
NE	254
MT	245
GA	100
MO	25
HI	NR
ND	NR
NM	NR
SD	NR
TN	NR
AR	NR

NR – none reported

WHAT ARE DISINFECTION BY-PRODUCTS?

Drinking water disinfection, which eliminated disease pathogens from the water supply, contributed markedly to the drop in infant and child mortality and the increase in life expectancy the United States enjoyed during the 20th century.[7] Although not without its own potential public health risks, disinfection enables most people in the United States to enjoy a water supply that is safe from infectious agents.

Chlorine is the most commonly used chemical for drinking water disinfection. However, chlorine reacts with other organic compounds in water to produce a number of disinfection by-products including the halogenated hydrocarbons, trihalomethanes, and haloacetic acids.[63] Halogenated hydrocarbons are organic compounds that contain carbon and hydrogen atoms (hydrocarbons) and include a halogen atom such as chlorine or bromine. Trihalomethanes (THM) (e.g., chloroform) are a group of four chemicals that are formed along with other disinfection by-products when chlorine or other disinfectants react with naturally occurring organic and inorganic matter in water.[62] Haloacetic acids (HAA) are formed in the same manner as THM.

Until 2003, the MCL for total trihalomethanes (TTHM) was 100 parts per million (ppm). However, emerging scientific evidence indicated that 100 ppm was too high to sufficiently protect public health. As of 2003, the MCL for TTHM was lowered to 80 ppm.[13] The MCL for regulated haloacetic acids is 60 ppb.

HEALTH EFFECTS OF DISINFECTION BY-PRODUCTS

Long-term exposure to disinfection by-products in drinking water has been associated with bladder cancer[64,65,66,67,68,69,70,71,72] and adverse reproductive effects.[73,74,75] Household exposures to tap water other than drinking water, e.g., showering or bathing, are also important sources of expo-

sure to disinfection by-products.[73,74,75,76,77] It has not been proven definitively that drinking chlorinated water causes bladder cancer. However, the EPA estimated that the lower TTHM MCL would result in avoiding between 188 and 333 cases of bladder cancer each year for the first 25 years after the rule was promulgated. Although the EPA was not able to estimate the number of adverse reproductive outcomes that could be avoided by lowering the TTHM MCL, it did estimate that 3.8 million infants are born each year to mothers served by a drinking water supply that uses disinfectant as part of their water treatment process.[78]

TRENDS OF DISINFECTION BY-PRODUCTS

During 2004–2009, the number of individuals affected by violations of the standards for disinfection by-products in drinking water has increased significantly in medium, small, and very small water systems. In contrast, since 2004, the number of individuals who receive their water from a large or very large water system and were affected by a violation of the disinfection by-products standards has decreased significantly.

Table 3. Population affected by health-based violations of disinfection by-products standard for drinking water by size of system[79]

Year	Very Small 25-500*	Small 501-3,300	Medium 3,301-10,000	Large 10,001-100,000	Very Large >100,000	Total
2009	101,915	754,537	1,043,531	1,387,713	532,597	3,820,293
2008	98,147	849,756	1,224,557	1,569,709	209,225	3,951,394
2007	102,726	889,675	1,207,929	1,585,893	263,362	4,049,585
2006	104,540	1,040,109	1,410,896	1,880,893		4,436,438
2005	96,829	1,194,425	1,753,462	2,083,147	901,000	6,028,863
2004	13,613	239,795	359,708	2,355,202	4,629,814	7,598,132

* number of service connections

WHAT YOU CAN DO

- If you receive drinking water from a community water system, read the Consumer Confidence Report that is sent to you by your water supplier. By law, the report is made available to every customer of a community water system. The report will provide information on the source of your water supply, the level of any regulated contaminants detected in the water, the health effects of contaminants detected above the safety limit, and your water system's compliance with other drinking water regulations. The report will also tell you where you can find additional information about your local drinking water supply.
- If you receive drinking water from a groundwater well, have your well tested at least once a year. The EPA recommends that water be tested every year for bacteria, nitrates, total dissolved solids, and pH levels. If you suspect other contaminants, test for those. Always use a state certified laboratory that conducts drinking water tests.
- If there is an immediate threat to your health due to a violation of a drinking water regulation or standard, the Safe Drinking Water Act requires that your water system notify you promptly through the media or posted signs. It is important that you follow any instructions your water system may give you in the notice.
- Some people may wish to take special precautions with the water they drink. If you are immune compromised (e.g., have HIV/AIDS), are undergoing chemotherapy, or take steroids, you might be more susceptible to microbial contaminants in drinking water. If you or someone you know falls into one of these categories, talk to your health care provider to find out if you need to take special precautions, such as boiling your water.
- Help prevent contamination. Reduce or eliminate pesticide use. Reduce the amount of trash you create: reuse containers, recycle plastics, aluminum, and glass. Recycle used oil. Take measures to reduce paved or impermeable surfaces. Use public transportation. Be careful what you put into your septic system; harmful chemicals may end up in your drinking water.

ADDITIONAL RESOURCES

- CDC's Environmental Public Health Tracking Web site at www.cdc.gov/ephtracking.
- CDC's Drinking Water Web site at http://www.cdc.gov/healthywater/drinking/
- EPA's Safe Drinking Water Hotline at 1-800-426-4791 and Web site at http://water.epa.gov/drink/hotline/
- EPA's Drinking Water Web site at http://water.epa.gov/drink/.
- United States Geological Services Web site on Chemical and Pathogenic Contaminant Exposure by Drinking Water at http://health.usgs.gov/dw_contaminants/.

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