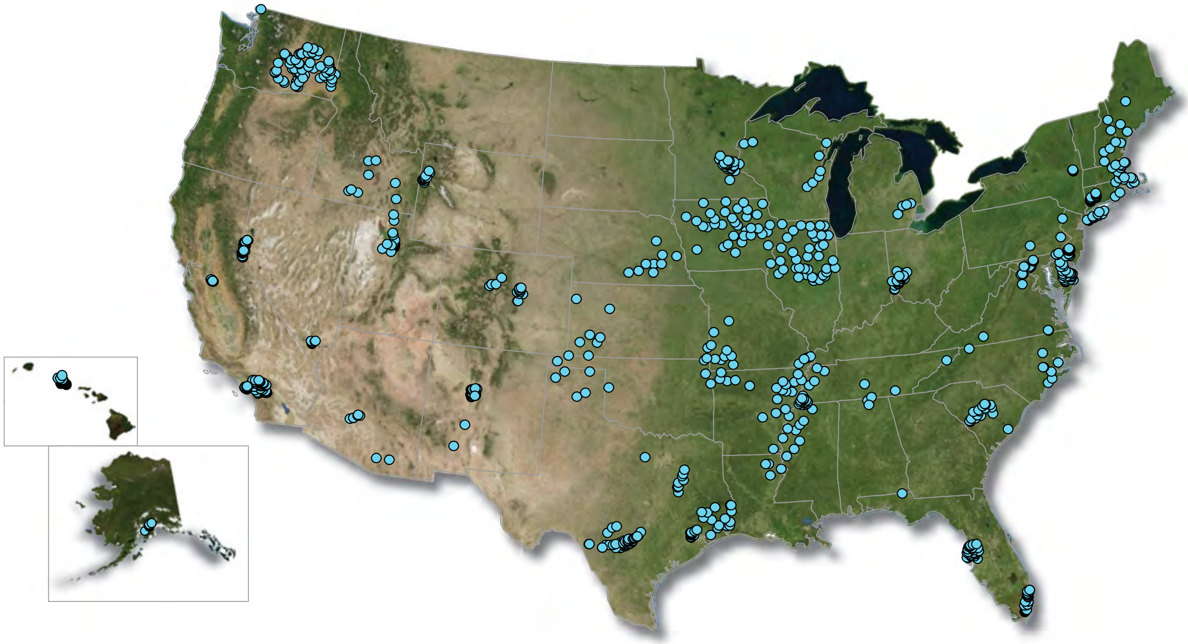
The Quality of Our Nation's Waters

Quality of Water from Public-Supply Wells in the United States, 1993–2007

Overview of Major Findings



National Water-Quality Assessment Program

Circular 1346

U.S. Department of the Interior
U.S. Geological Survey

Cover illustration: Map showing the 932 public-supply wells included in this study. World-imagery base map from ESRI (© 2009), based on source data from ESRI, i-cubed, USDA FSA, USGS, AEX, GeoEye, and Getmapping (http://server.arcgisonline.com/ArcGIS/rest/services/World_Imagery/MapServer).

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By Patricia L. Toccalino and Jessica A. Hopple

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U.S. Department of the Interior
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U.S. Geological Survey
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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with reliable scientific information that helps to enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov/). Information on the Nation's water resources is critical to ensuring long-term availability of water that is safe for drinking and recreation and is suitable for industry, irrigation, and fish and wildlife. Population growth and increasing demands for water make the availability of that water, now measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

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 (http://water.usgs.gov/nawqa). The NAWQA Program is designed to answer: What is the quality of our Nation's streams and groundwater? How are conditions changing over time? How do natural features and human activities affect the quality of streams and groundwater, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. From 1991–2001, the NAWQA Program completed interdisciplinary assessments and established a baseline understanding of water-quality conditions in 51 of the Nation's river basins and aquifers, referred to as Study Units (http://water.usgs.gov/nawqa/studyu.html).

National and regional assessments are ongoing in the second decade (2001–2012) of the NAWQA Program as 42 of the 51 Study Units are selectively reassessed. These assessments extend the findings in the Study Units by determining status and trends at sites that have been consistently monitored for more than a decade, and filling critical gaps in characterizing the quality of surface water and groundwater. For example, increased emphasis has been placed on assessing the quality of source water and finished water associated with the Nation's community water systems. During the second decade, NAWQA is addressing five national priority topics that build an understanding of how natural features and human activities affect water quality, and establish links between sources of contaminants, the transport of those contaminants through the hydrologic system, and the potential effects of contaminants on humans and aquatic ecosystems. Included are studies of the fate of agricultural chemicals, effects of urbanization on stream ecosystems, bioaccumulation of mercury in stream ecosystems, effects of nutrient enrichment on aquatic ecosystems, and transport of contaminants to public-supply wells. In addition, national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, trace elements, and aquatic ecology are continuing.

The USGS aims to disseminate credible, timely, and relevant science information to address practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—federal, state, regional, interstate, tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Matthew C. Larsen
Associate Director for Water

Introduction to this report and the NAWQA series

The Quality of Our Nation’s Waters

This report is one of a series of publications, The Quality of Our Nation’s Waters, which describe major findings of the NAWQA Program on water-quality issues of regional and national concern. This report presents a national assessment of the quality of source (untreated) water from 932 public-supply wells and source and finished (treated) water from a subset of 94 wells. The 932 public-supply wells are widely distributed nationally; they are located in selected parts of 41 states, and withdraw water from parts of 30 regionally extensive aquifers used for public water supply. Compared to previous investigations of public-well water quality, "Quality of Water from Public-Supply Wells in the United States, 1993–2007—Overview of Major Findings" greatly expands the number of individual contaminants and contaminant mixtures assessed in groundwater from public-supply wells. Other reports in this series focus on specific water-quality constituents of concern, such as pesticides and volatile organic compounds in groundwater and surface water, the effects of contaminants and habitat conditions on aquatic ecosystem health, and on the quality of water from private domestic wells. Each report builds toward a more comprehensive understanding of regional and national water resources.

The information in this series is intended primarily for those interested or involved in resource management and protection, conservation, regulation, and policymaking at regional and national levels. In addition, the information is relevant to those at a local level who wish to know more about the general quality of streams and groundwater in areas near where they live and how that quality compares with other areas across the Nation.

Donna N. Myers
Chief, Office of Water Quality
U.S. Geological Survey

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Summary of Major Findings and Implications

About 105 million people in the United States—more than one-third of the Nation’s population—receive their drinking water from about 140,000 public water systems that use groundwater as their source. Although the quality of *finished* drinking water (after treatment and before distribution) from these public water systems is regulated by the U.S. Environmental Protection Agency (USEPA) under the Safe Drinking Water Act (SDWA), long-term protection and management of groundwater, a vital source of drinking water, requires an understanding of the occurrence of contaminants in untreated source water. Sources of drinking water potentially are vulnerable to a wide range of man-made and naturally occurring contaminants, including many that are not regulated in drinking water under the SDWA.

Examples of wellhead plumbing typical of public wells sampled in this study.
(Photographs by Michael Rosen and Nicholas Smith, U.S. Geological Survey.)

In this study by the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS), chemical water-quality conditions were assessed in *source* (untreated) groundwater from 932 public-supply wells, hereafter referred to as public wells, and in source and finished water from a subset of 94 wells. The public wells are located in selected parts of 41 states and withdraw water from parts of 30 regionally extensive water-supply aquifers, which constitute about one-half of the principal aquifers in the United States. Although the wells sampled in this study represent less than 1 percent of all groundwater-supplied public water systems in the United States, they are widely distributed nationally and were randomly selected within the sampled hydrogeologic settings to represent typical aquifer conditions. All source-water samples were collected prior to any treatment or blending that potentially could alter contaminant concentrations. As a result, the sampled groundwater represents the quality of the source water and not necessarily the quality of finished water ingested by the people served by these public wells[1].

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[1] Annual consumer confidence reports provided by water utilities are a source of information about finished-water quality in local communities. See "More Information for People Served by Public Water Utilities" on page 43.

A greater number of chemical contaminants—as many as 337—both naturally occurring and man-made, were assessed in this study than in any previous national study of public wells (Appendixes 1 and 2). Consistent with the terminology used in the SDWA, all constituents analyzed in water samples in this study are referred to as "contaminants," regardless of their source, concentration, or potential for health effects (see sidebar on page 3). Eighty-three percent (279) of the contaminants analyzed in this study are not regulated in drinking water under the SDWA. The USEPA uses USGS data on the occurrence of unregulated contaminants to fulfill part of the SDWA requirements for determining whether specific contaminants should be regulated in drinking water in the future. By focusing primarily on source-water quality, and by analyzing many contaminants that are not regulated in drinking water by USEPA, this study complements the extensive sampling of public water systems that is routinely conducted for the purposes of regulatory compliance monitoring by federal, state, and local drinking-water programs.

The objectives of this study were to evaluate (1) the occurrence of contaminants in source water from public wells and their potential significance to human health, (2) whether contaminants that occur in source water also occur in finished water after treatment, and (3) the occurrence and characteristics of contaminant mixtures. To evaluate the potential significance of contaminant occurrence to human health, contaminant concentrations were compared to regulatory Maximum Contaminant Levels (MCLs) or non-regulatory Health-Based Screening Levels (HBSLs)—collectively referred to as human-health benchmarks in this study (see sidebars on pages 4 and 19).

The major findings and implications of this study are summarized below and the results are described in greater detail in the remainder of the report. These findings build upon water-quality data from previous public-well studies and provide new information to agencies and organizations that manage the protection of drinking water and human health.

What is a Contaminant?

A contaminant is defined in the Safe Drinking Water Act (SDWA) as "any physical, chemical, biological, or radiological substance or matter in water" (U.S. Code, 1996). This broad definition of contaminant includes every substance that may be dissolved or suspended in water—everything but the water molecule itself. The presence of a contaminant in water does not necessarily mean that there is a human-health concern.

Whether a particular contaminant in water is potentially harmful to human health depends on the contaminant’s toxicity and concentration in drinking water. Other factors include the susceptibility of individuals, amount of water consumed, and duration of exposure (U.S. Environmental Protection Agency, 2008a). For example, some contaminants that typically occur naturally, such as selenium and chromium, are essential trace elements and are required in low doses for normal physiologic function, but high doses can cause adverse health effects (Eaton and Klaassen, 2001). By contrast, man-made organic contaminants, such as pesticides, are not required by humans at any dose, and may or may not cause adverse effects in humans depending on factors such as exposure and toxicity.

A total of six water-quality properties (such as pH) and as many as 337 chemical contaminants were analyzed in source-water samples from public wells in this study (Appendixes 1 and 2); the contaminants originate from a wide range of natural and man-made sources. Most of the 44 inorganic contaminants analyzed in this study—including trace elements, radionuclides, and nutrients—occur naturally, although concentrations of some inorganic contaminants in groundwater may be altered by human activities. For example, nitrate from natural sources is present in most wells, but concentrations often are increased by contributions from man-made sources in agricultural and urban areas. By contrast, most of the 293 organic contaminants analyzed in this study—including pesticide compounds, volatile organic compounds, personal-care and domestic-use products, and other organic contaminants such as manufacturing additives—are man-made, although some also may form in groundwater through various chemical and biological transformation processes.

Human-Health Benchmarks Used in This Study: Regulatory Maximum Contaminant Levels and Non-Regulatory Health-Based Screening Levels

As used in this study, regulated contaminants are those contaminants for which the U.S. Environmental Protection Agency (USEPA) has established drinking-water standards (Maximum Contaminant Levels or MCLs) under the Safe Drinking Water Act (SDWA), and unregulated contaminants are those that are not regulated in drinking water under the SDWA and therefore do not have MCLs. Contaminants that are not federally regulated in drinking water under the SDWA may be regulated in drinking water by some states, and also may be regulated in other contexts and under other statutes, such as the Federal Insecticide, Fungicide, and Rodenticide Act.

For the purposes of placing study findings in the context of human health, concentrations of contaminants that are regulated by USEPA in drinking water under the SDWA were compared to MCLs, and concentrations of unregulated contaminants were compared to U.S. Geological Survey (USGS) Health-Based Screening Levels (HBSLs), when available. Of the 337 contaminants analyzed in this study, MCLs are available for 58 contaminants and HBSLs are available for 135 contaminants (see sidebar on page 19). Because regulatory MCLs and non-regulatory HBSLs both are used in this study to provide an initial perspective on the potential significance of detected contaminants to human health, they are henceforth collectively referred to as "human-health benchmarks".

MCLs are legally enforceable USEPA drinking-water standards that set the maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are set as close as feasible to the maximum level of a contaminant at which no known or anticipated adverse effects on human health would occur over a lifetime, taking into account the best available analytical and treatment technologies, cost considerations, expert judgment, and public comments (U.S. Environmental Protection Agency, 2009a). As a result, not all MCLs are based on health-effects data alone.

HBSLs are non-enforceable benchmark concentrations of contaminants in water that were developed by the USGS in collaboration with the USEPA and others using: (1) USEPA Office of Water methodologies for establishing drinking-water guidelines, and (2) the most recent, USEPA peer-reviewed, publicly available human-health toxicity information (Toccalino and others, 2006; Toccalino, 2007). As a result, HBSL values are consistent with existing USEPA drinking-water guideline values, such as Lifetime Health Advisory values and Cancer Risk Concentration values (when they exist), except for unregulated contaminants for which more recent toxicity information has become available (Toccalino, 2007).

Neither an MCL nor an HBSL is available for radon, but USEPA has proposed both an MCL of 300 picocuries per liter (pCi/L) and an Alternative MCL of 4,000 pCi/L for radon in public water systems (U.S. Environmental Protection Agency, 2006a). The lower proposed MCL for radon applies to states and public water systems that do not develop programs to address health risks from radon in indoor air; the higher proposed Alternative MCL applies to states and public water systems that have established such programs (U.S. Environmental Protection Agency, 1999a, 2009e). Except where indicated otherwise in this report, radon activities were compared to the higher proposed Alternative MCL of 4,000 pCi/L.

More than one in five source-water samples from public wells contained one or more contaminants at concentrations greater than human-health benchmarks (p. 20–23).

One or more chemical contaminants were detected at concentrations greater than MCLs or HBSLs in more than one in five (22 percent) of the 932 source-water samples from public wells. Ten contaminants—seven from natural sources and three primarily from man-made sources—individually were detected at concentrations greater than human-health benchmarks in at least 1 percent of samples and collectively accounted for most concentrations greater than benchmarks. Five of these 10 contaminants currently are regulated in drinking water under the SDWA (MCLs are available)—overall, concentrations of at least one contaminant were greater than an MCL in 15 percent of the samples. Eighty percent of the source-water samples contained one or more contaminants at concentrations greater than one-tenth of human-health benchmarks, but most individual contaminant detections were at much lower concentrations, and many were several orders of magnitude less than benchmarks. Public wells yielding water in which contaminant concentrations were greater than benchmarks, as well as those in which concentrations were greater than one-tenth of benchmarks, were distributed throughout the United States and included wells that withdraw water from all principal aquifer rock types included in this study.

Implications:

- Source water from a substantial proportion of public wells—about one of every five sampled—would require treatment or blending with higher-quality water sources to decrease contaminant concentrations to less than human-health benchmarks. Water utilities, however, are not required to treat water for unregulated contaminants, which accounted for about 40 percent of the concentrations greater than benchmarks. Contaminant concentrations greater than benchmarks in source water are potential human-health concerns, but do not necessarily indicate that adverse effects will occur because the benchmarks are conservative (protective) and samples were collected prior to any treatment or blending of water.

- Most public wells sampled—four of every five—contained one or more contaminants at concentrations greater than one-tenth of a benchmark. Contaminant concentrations greater than one-tenth of a benchmark provide an early and conservative indication of contaminant concentrations that may at some time approach or exceed benchmarks and identify contaminants that may warrant additional monitoring. Early attention to potential groundwater contamination is vital because groundwater contamination is difficult and costly to reverse once it occurs.

- The widespread occurrence of contaminants at concentrations greater than one-tenth of benchmarks, including the relatively common occurrence of concentrations greater than benchmarks, indicates the ubiquitous nature of natural and man-made contaminant sources and that all principal aquifer rock types included in this study are vulnerable to contamination. The occurrence of contaminants of primary concern, however, differed among regions and aquifers.

Contaminants from natural sources accounted for about three-quarters of contaminant concentrations greater than human-health benchmarks in source-water samples (p. 24–28).

Naturally occurring trace elements and radionuclides accounted for about three-quarters (74 percent) of all contaminant concentrations greater than human-health benchmarks in source-water samples from public wells. Four trace elements (arsenic, manganese, strontium, and boron) and three radionuclides (radon, radium, and gross alpha-particle radioactivity) each were detected at concentrations greater than MCLs or HBSLs in at least 1 percent of source-water samples. Radon activities were greater than the higher proposed Alternative MCL of 4,000 picocuries per liter (pCi/L) in less than 1 percent of samples, but were greater than the lower proposed MCL of 300 pCi/L in 55 percent of samples. Each of the remaining six trace elements and radionuclides was detected at concentrations greater than human-health benchmarks in 3 to 19 percent of samples. Manganese and boron have undergone USEPA's regulatory determination process under the SDWA, but were not selected for regulation in drinking water. Collectively, concentrations of one or more trace elements or radionuclides were greater than MCLs or HBSLs in 19 percent of samples (when radon activities were compared to 4,000 pCi/L). Trace elements and radionuclides were detected at concentrations greater than benchmarks in samples from both confined and unconfined aquifers, consistent with the fact that these contaminants originate primarily from aquifer materials, rather than from man-made sources at the land surface. Regional patterns of occurrence were apparent for some contaminants, such as arsenic, as a result of the geographic distributions of natural sources.

Implications:

- Naturally occurring trace elements and radionuclides may be present in groundwater at concentrations of potential human-health concern even in undeveloped areas or confined aquifers where contamination usually is not expected.
- Traditional wellhead protection approaches designed to reduce man-made sources of contaminants to groundwater generally are not designed to protect against natural sources of contaminants and, therefore, most occurrences of naturally occurring contaminants at concentrations greater than benchmarks are unlikely to be affected by these approaches.

Contaminants that originate entirely or primarily from man-made sources accounted for about one-quarter of contaminant concentrations greater than human-health benchmarks in source-water samples and were detected in nearly two-thirds of the samples, predominantly in samples from unconfined aquifers (p. 29–31).

Nitrate, pesticide compounds, and volatile organic compounds (VOCs) accounted for about one-quarter (25 percent) of all contaminant concentrations greater than MCLs or HBSLs in source-water samples from public wells. Nitrate, dieldrin, and perchloroethene (PCE) each were detected at concentrations greater than MCLs or HBSLs in 1 to 3 percent of source-water samples. Nitrate is naturally occurring, but most nitrate concentrations greater than 1 milligram per liter as nitrogen (which is one-tenth of the nitrate MCL) originate from man-made sources such as fertilizers, livestock, and wastewater. Dieldrin has undergone USEPA's regulatory determination process under the SDWA, but was not selected for regulation in drinking water. Collectively, pesticide compounds or VOCs were detected in nearly two-thirds (64 percent) of the samples, and concentrations of one or more of these contaminants were greater than human-health benchmarks in 4.5 percent of samples, primarily in the highly populated areas of East-Coast states. Considering all 293 man-made organic contaminants analyzed in this study (including personal-care products and other organic contaminants), 169 (58 percent) were detected in at least one sample. Nitrate, pesticide compounds, and VOCs were detected in a significantly greater proportion of samples from unconfined aquifers than in samples from confined aquifers, and almost all concentrations greater than benchmarks were detected in samples from unconfined aquifers, consistent with the fact that these contaminants originate from man-made sources at the land surface. Contaminant detections represent the influence of both past and current land-use practices and contaminant-use patterns.

Implications:

- The frequent detections of man-made contaminants in samples from aquifers used for public water supply, particularly in samples from unconfined aquifers, indicate the vulnerability of many water-supply aquifers to contamination from human activities at the land surface. This finding underscores the importance of wellhead protection programs designed to reduce groundwater contamination from man-made sources. Reduction of contaminant sources potentially reduces needs for water treatment and blending, and may avoid the loss of some public wells as sources of drinking water.

- The occurrence of man-made contaminants in some samples from confined aquifers indicates that the large pumping rates typical for public wells, combined with the proximity of the wells to developed areas and the possible presence of short-circuiting flow paths to such wells, make even some deep wells that withdraw water from confined aquifers vulnerable to contamination from man-made sources.

- Based only on comparisons of contaminant concentrations to individual human-health benchmarks, contaminants from man-made sources may have less potential human-health significance in public wells than contaminants from natural sources. Human-health benchmarks are not available for many organic contaminants analyzed in this study, however, and the full significance of their occurrence to human health cannot yet be assessed (see below).

- More than 20 years after being banned, dieldrin is still detected at concentrations greater than its benchmark in some source waters because of historical use. Source-water protection strategies that rely on changes in human activities and practices at the land surface to achieve water-quality objectives can take many decades to affect the quality of water in some public wells.

Many organic contaminants detected in source water also were detected in finished water at similar concentrations (p. 32–33).

As many as 272 organic contaminants were analyzed in a subset of 94 paired source- and finished-water samples from public wells (inorganic contaminants were not analyzed in these paired samples). Considering all organic contaminants that were detected in at least 10 percent of source-water samples, concentrations generally were similar in source and finished water, except for concentrations of disinfection by-products (DBPs), which were greater in finished water because these contaminants are by-products that form during the disinfection process. Two of the source-water samples, and none of the finished-water samples, contained at least one organic contaminant at a concentration greater than a human-health benchmark. Comparisons between source and finished water were not intended to characterize treatment efficacy. Disinfection was the primary water treatment used at about three-quarters of the sampled systems, which is about the same proportion as for all groundwater-supplied public water systems nationwide.

Implications:

- The occurrence of organic contaminants in both source and finished water at similar concentrations indicates that commonly used disinfection practices do not reduce concentrations of many organic contaminants. Because disinfection is not designed to treat organic contaminants, and because pesticide compounds or VOCs were detected in 64 percent of the source-water samples (see above), the frequent occurrence of these organic contaminants in finished water is likely, although usually at concentrations less than benchmarks.
- Because concentrations of many man-made organic contaminants were not affected by commonly used treatment processes, protection of source-water quality is an essential component of ensuring high-quality drinking water. Source-water protection can help to reduce potential concerns about the presence of man-made contaminants in source water, particularly unregulated contaminants that do not require treatment in finished water under the SDWA.

Human-health benchmarks are not yet available for many organic contaminants, including some that were frequently detected in source water (p. 34–36).

Human-health benchmarks are not available for 144 (43 percent) of the contaminants analyzed in this study (mostly organic contaminants) because of insufficient toxicity information, including nine contaminants that were detected in 6 to 35 percent of source-water samples from public wells. The nine contaminants are degradates of the herbicides atrazine, alachlor, and metolachlor, a gasoline oxygenate (methyl *tert*-butyl ether), and a solvent (1,1-dichloroethane). Several of these contaminants are on USEPA’s most recent (third) Contaminant Candidate List (CCL), which is a list of unregulated contaminants that are known or anticipated to occur in public water systems and may require regulation under the SDWA in the future. Most herbicide degradates analyzed in this study are not currently regulated by the USEPA in drinking water under the SDWA, but some herbicide degradates are regulated by USEPA under the Federal Insecticide, Fungicide, and Rodenticide Act. Concentrations of the parent herbicides atrazine, alachlor, and metolachlor were less than MCLs or HBSLs in all source-water samples.

Implications:

- The occurrence of contaminants for which human-health benchmarks are not yet available could not be evaluated in the context of potential human-health significance. Continued development of human-health benchmarks is needed to fill this information gap and to help interpret monitoring data, especially for contaminants that frequently occur in water resources.
- Continued monitoring of contaminants for which human-health benchmarks are not yet available is essential for identifying those contaminants for which toxicity assessments are most needed, as well as to track emerging issues. As improved data on toxicity and environmental concentrations become available, human-health benchmarks can be developed, and water-quality assessments can be improved and expanded.

Contaminants usually co-occurred with other contaminants in source and finished water, and mixtures of two or more contaminants at concentrations greater than one-tenth of individual human-health benchmarks were dominated by inorganic contaminants (p. 37–41).

Contaminants detected in source- and finished-water samples from public wells usually co-occurred with other contaminants as mixtures. Although few human-health benchmarks have been established for mixtures of contaminants, concentrations of contaminants in mixtures were compared to individual benchmarks. About 4 percent of source-water samples contained mixtures of two or more contaminants at concentrations greater than individual human-health benchmarks, whereas most samples (84 percent) contained mixtures of two or more contaminants at concentrations greater than one-tenth of individual benchmarks. All of the most common mixtures (those detected in 5 to 33 percent of source-water samples) in which contaminant concentrations were greater than one-tenth of individual benchmarks were composed of one or more trace elements (arsenic, strontium, or uranium were most common), nitrate, and (or) radon (activities greater than 300 pCi/L). When mixtures of organic contaminants were assessed only on the basis of detections and without regard to the availability of human-health benchmarks, three-quarters of the organic-contaminant mixtures contained an herbicide (atrazine or simazine) or an herbicide degradate (deethylatrazine). Two-thirds of these mixtures contained a DBP (chloroform), and 43 percent contained the solvents PCE or trichloroethene. Organic-contaminant mixtures were detected somewhat more frequently in finished water than in source water because of the formation of DBPs in finished water.

Implications:

- The widespread and frequent detections of contaminant mixtures in source water is a matter of increasing concern and attention because the total combined toxicity of contaminants in water may be greater than that of any individual contaminant. Little is known about the potential health effects associated with exposure to multiple contaminants, and more investigation is needed to evaluate the potential toxicity of contaminant mixtures to humans.
- This study identifies which contaminant mixtures may be of most concern in groundwater used for public water supply because of their frequency of occurrence and comparisons of contaminant concentrations to individual human-health benchmarks. This information can help human-health researchers to target and prioritize toxicity assessments of contaminant mixtures.

The most complex mixtures in source water—those with the greatest number of contaminants—were most often detected in samples from unconfined aquifers (p. 42).

Mixtures with the greatest number of contaminants were detected more frequently in source-water samples from public wells that withdraw water from shallower unconfined aquifers than in samples from deeper confined aquifers. For example, about two-thirds of the mixtures containing three contaminants, and nearly all mixtures containing 10 contaminants, were detected in samples from unconfined aquifers. This finding was observed for mixtures that were assessed relative to individual human-health benchmarks and for mixtures of organic contaminants that were assessed without regard to the availability of benchmarks. Generally, as the number of contaminants in mixtures increased, the proportion of samples containing organic contaminants also increased, reflecting the greater vulnerability of unconfined aquifers to contaminants from man-made sources.

Implications:

- The frequent occurrence of complex contaminant mixtures, particularly in source-water samples from unconfined aquifers, reinforces the implication derived from the occurrence of individual contaminants, that multiple contaminant sources and transport pathways may affect the quality of water from public wells.
- Measures to protect groundwater used for public water supply often need to take into consideration multiple sources of man-made contaminants and their co-occurrence with contaminants from natural sources.

Additional Information

For more information on the quality of water in public wells, refer to reports by Toccalino and others (2010) available at http://pubs.usgs.gov/sir/2010/5024/, and by Hopple and others (2009) available at http://pubs.usgs.gov/sir/2009/5200/.

Introduction

Safe drinking water is essential to public health, and the quality of the Nation's drinking-water supply is an issue of growing national importance (U.S. General Accounting Office, 1997). In 2008, about 105 million people in the United States—more than one-third of the Nation's population—obtained their drinking water from about 140,000 public water systems that derive all or part of their source-water supply from groundwater (U.S. Environmental Protection Agency, 2008c; U.S. Census Bureau, 2009). Public wells are a primary source of drinking water in large areas of the country, including much of the southwestern, southern, and central United States (fig. 1).

The quality of *finished* drinking water (after treatment and before distribution) from the Nation's public water systems is regulated by the U.S. Environmental Protection Agency (USEPA) under the Safe Drinking Water Act (SDWA) (U.S. Environmental Protection Agency, 2004c). The SDWA defines a public water system as one that serves piped drinking water to at least 25 people or 15 service connections for at least 60 days a year (U.S. Environmental Protection Agency, 2003f). Public water systems range from very small, privately owned systems such as those that supply some mobile-home parks, to large, publicly owned systems that serve millions of people (U.S. Environmental Protection Agency, 2002a). Most (nearly 90 percent) of the public wells sampled in this study were part of community water systems that serve the same people year-round (U.S. Environmental Protection Agency, 2003f), and about half of the sampled public wells were part of large and very large public water systems (table 1).

The SDWA, originally passed by Congress in 1974 and amended in 1986 and 1996, requires many actions to protect drinking water and its sources—rivers, lakes, reservoirs, springs, and groundwater. For example, the SDWA authorizes the USEPA to set national health-based standards for drinking water to protect against both naturally occurring and man-made contaminants that may be detected in drinking water (U.S. Environmental Protection Agency, 2004c). USEPA oversees the states, localities, and water suppliers who implement the drinking-water standards.

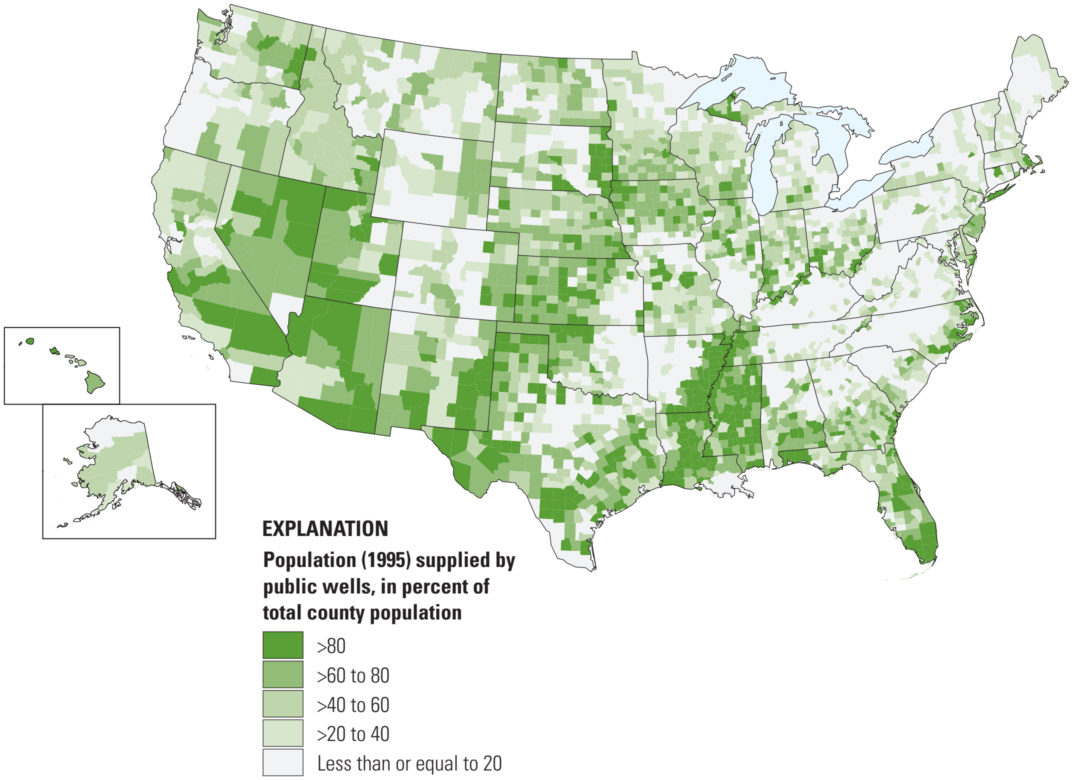


Figure 1. Nationwide, about 105 million people rely on public wells for drinking water. In many parts of the United States, public wells supply drinking water for large percentages of the population. Water-use data are from Solley and others (1998). >, greater than.

Table 1. About one-half of the public wells sampled in this study were part of large and very large public water systems that each serve more than 10,000 people.

[System size classifications are from the U.S. Environmental Protection Agency (2010b)]

System size	Number of people served	Percentage of public wells sampled in this study
Very small	25 to 500	11
Small	501 to 3,300	21
Medium	3,301 to 10,000	13
Large	10,001 to 100,000	31
Very large	More than 100,000	18
Unknown	Unknown	6

Many studies have demonstrated the presence of naturally occurring and man-made contaminants in finished drinking water (U.S. Environmental Protection Agency, 2001a, 2002b, 2003e) and in untreated source water (Gilliom and others, 2006; Zogorski and others, 2006; Ayotte and others, 2007) from public wells, providing valuable information about various aspects of public-well water quality (see sidebar on page 13). The objectives of this study by the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) were to evaluate (1) the occurrence of contaminants in source water from public wells and their potential significance to human health, (2) whether contaminants that occur in source water also occur in finished water after treatment, and (3) the occurrence and characteristics of contaminant mixtures. In addressing these objectives, this study differs from most previous studies in several ways:

- The quality of the source water that supplies groundwater to public water systems is evaluated, whereas many previous studies examined only the quality of finished drinking water delivered to consumers (Westrick and others, 1984; Longtin, 1988; U.S. Environmental Protection Agency, 2001a, 2003e). An evaluation of contaminant occurrence in source water provides background information regarding the presence of a contaminant in the environment.
- The occurrence of a diverse suite of organic contaminants in source water and in finished water (before and after treatment) is compared in a limited subset of public-well samples. Many of these organic contaminants are not regulated in drinking water under the SDWA.
- Specific sites or areas with known water-quality problems are not sampled, whereas some previous studies include, and in some instances, focus on areas of known contamination (Westrick and others, 1984; Focazio and others, 2001).
- More contaminants and contaminant groups are assessed than in previous public-well studies (Longtin, 1988; Westrick, 1990; Grady and Casey, 2001), including many inorganic and organic contaminants.
- Contaminants evaluated include some that are regulated in drinking water and many that are not, whereas studies of SDWA compliance data commonly focus only on regulated contaminants (U.S. Environmental Protection Agency, 1999b, 2003e, 2008c). Many unregulated contaminants analyzed in this study are not included in other source-water and finished-water monitoring programs such as the Unregulated Contaminant Monitoring program (U.S. Environmental Protection Agency, 2010c).
- Analytical reporting levels used in this study typically are 2-fold to more than 1,000-fold lower than in many previous studies (U.S. Environmental Protection Agency, 2001a, 2002b, 2003e) (see sidebar on page 17). Contaminant occurrence documented at these low reporting levels can help to identify emerging issues and to track changes in concentrations over time (Gilliom and others, 2006).
- More human-health benchmarks are available for comparisons with contaminant concentrations in this study than in pre-2005 studies that considered the occurrence of unregulated contaminants in drinking water. The USGS, in collaboration with USEPA and others, has developed Health-Based Screening Levels (HBSLs) for many contaminants that are not regulated in drinking water under the SDWA. HBSLs supplement USEPA human-health benchmarks and provide a basis for a more comprehensive evaluation of contaminant-occurrence data in the context of human health (Toccalino, 2007).
- The co-occurrence of contaminants as mixtures and the potential significance of such mixtures to human health is assessed. Data from this study enhance previous studies of contaminant mixtures by examining the co-occurrence of a larger number of contaminants in source and finished water from public wells, and by assessing the occurrence of mixtures relative to individual human-health benchmarks.
- Contaminant occurrence is examined by regional aquifers, providing a framework for understanding water-quality conditions within similar hydrogeologic and geographic regions. The nationally consistent sampling and analysis design used by the USGS NAWQA Program enables comparisons of water-quality conditions among geographic areas and across the United States.

The water-quality findings from this assessment of public wells, together with the accumulation of findings from previous studies, provide a foundation for improving our understanding and management of this critical source of drinking water.

Results are Consistent with Previous National-Scale Studies

This study complements and expands upon findings reported in previous national-scale studies of public wells in several ways, as described in the Introduction, but findings from this study generally confirm and reinforce previous conclusions about many contaminants. A detailed comparison to findings reported in previous public-well studies is included in Toccalino and others (2010).

Detection frequencies and the percentages of samples with contaminant concentrations greater than benchmarks determined in this study generally were similar to those observed in previous national-scale U.S. Geological Survey (USGS) studies of specific contaminant groups (Gilliom and others, 2006; Zogorski and others, 2006). These similarities occur because one-quarter to one-third of the public wells sampled in this study also were included in some of the previous USGS studies and because of similarities in study designs.

Those contaminants that were most and least frequently detected in this study also generally were most and least frequently detected in several previous national-scale U.S. Environmental Protection Agency (USEPA) monitoring studies (Westrick and others, 1984; Longtin, 1988; U.S. Environmental Protection Agency, 1999b, 2001a, 2003e, 2008c). Many individual contaminants were detected more frequently in this study than were reported in the USEPA monitoring studies because of factors such as differences in analytical reporting levels and sampling points. USGS uses lower analytical reporting levels (see sidebar on page 17) than those used in most USEPA monitoring reports. USGS also typically collects untreated source-water samples whereas USEPA typically collects treated finished-water samples. In this study and in USEPA monitoring studies, many regulated contaminants were detected at concentrations greater than one-tenth of Maximum Contaminant Levels (MCLs), but concentrations greater than MCLs were not common—the same few contaminants generally were most frequently detected at concentrations greater than MCLs.

The results from this study and from a recent national-scale USGS study of domestic wells (DeSimone and others, 2009) also were compared. Overall, the quality of water from domestic and public wells in the United States is similar. In both this study and the domestic-well study (DeSimone and others, 2009), about one in five samples contained one or more contaminants at concentrations greater than human-health benchmarks, naturally occurring trace elements and radionuclides were the contaminants that were detected most frequently at concentrations greater than benchmarks, and contaminant mixtures were common. Notable differences between samples from public and domestic wells were that pesticide compounds and volatile organic compounds (VOCs) were detected more frequently at concentrations greater than human-health benchmarks in public-well samples, whereas nitrate was detected more than twice as frequently at concentrations greater than the MCL in domestic-well samples. The detection frequencies of some individual organic contaminants—mostly VOCS—were 2-fold to 6-fold greater in samples from public wells than from domestic wells, likely because of the proximity of public wells to developed areas and the higher pumping rates used for public wells than for domestic wells.

NAWQA's Approach to Assessing the Quality of Water from Public Wells

Source-water samples from public wells were collected before any treatment or blending. These are examples of pumps and plumbing configurations used by public water systems.

(Top photograph by Roland Tollett, U.S. Geological Survey. Bottom photograph by U.S. Geological Survey.)

This report presents a national assessment of the quality of source (untreated) water from 932 public wells and a comparison of source and finished (treated) water for a subset of 94 wells. The wells are located in selected parts of 41 states and withdraw water from parts of 30 regionally extensive aquifers used for water supply (fig. 2); these aquifers constitute about one-half of the principal aquifers in the United States (U.S. Geological Survey, 2009a). Each well was sampled once during the period of 1993–2007, and all samples were collected and analyzed following a nationally consistent study design (Gilliom and others, 1995; Lapham and others, 2005).

This report combines and summarizes the major findings from two detailed USGS public-well assessments (Hopple and others, 2009; Toccalino and others, 2010). In the study by Toccalino and others (2010), as many as six water-quality properties and 212 chemical contaminants were analyzed in source-water samples collected from 932 public wells during 1993–2007 (Appendix 1). Source-water samples were collected at the wellhead (the point at which the groundwater exits the well, at the land surface) before any treatment or blending that potentially could alter contaminant concentrations. As a result, the quality of the sampled source water does not necessarily reflect the quality of finished water ingested by the people served by these wells.

In the study by Hopple and others (2009), as many as 272 organic contaminants were analyzed in source-water samples collected from 221 public wells during 2002–2005, and in both source and finished (treated) water from a subset of 94 wells. These 221 public wells are a subset of the 932 wells included in the study by Toccalino and others (2010). Finished-water samples were collected after the water passed through all treatment processes, but prior to distribution (Hopple and others, 2009). About one-half of the 272 organic contaminants (147 pesticide and volatile organic compounds) included in the study by Hopple and others (2009) also were included in the study by Toccalino and others (2010) and are listed in Appendix 1, whereas the remaining organic contaminants (125) were unique to the Hopple study and are listed in Appendix 2.

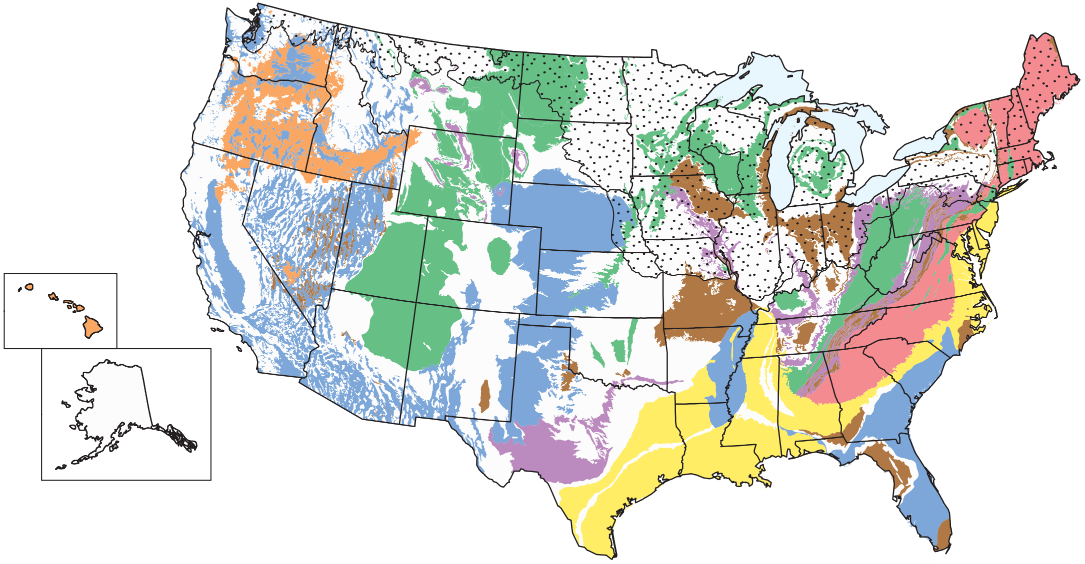
All together, as many as six water-quality properties and 337 chemical contaminants were assessed as part of the combined analysis described in this report. The numbers of individual contaminants in each contaminant group included in this study, along with the numbers of samples collected for each contaminant group, are summarized in table 2.

Several additional aspects of the study design and data characteristics, as well as the approach to data analysis and interpretation, need to be considered when interpreting the findings in this report.

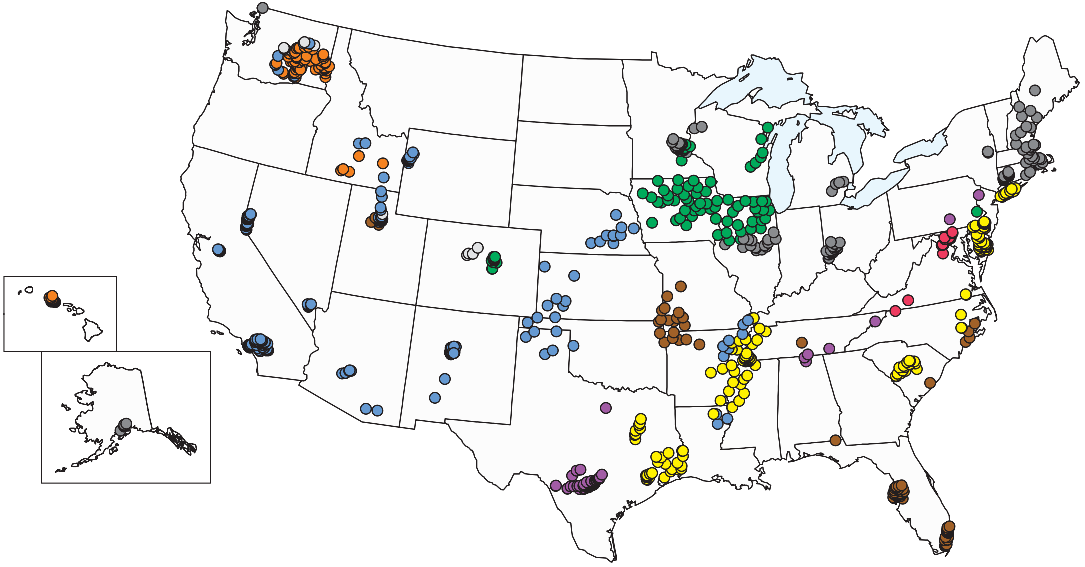
- Principal aquifers are regionally extensive aquifers or aquifer systems that have the potential to be used as sources of potable water (Miller, 2000; U.S. Geological Survey, 2009b). Principal aquifers were grouped into eight rock-type categories by following the classifications used in the National Atlas (Miller, 2000; U.S. Geological Survey, 2003, 2009a) (fig. 2). Aquifers within these rock-type categories are likely to share general characteristics of groundwater flow and, in some cases, overall geochemistry (Miller, 2000). Water-quality conditions, however, can vary substantially within principal aquifers, indicating the diversity of natural systems and human influences.

- The aquifer type for each public well was coded as unconfined, confined, or mixed using data from a variety of sources including well owners, well-construction logs, and other records from state or local jurisdictions (U.S. Geological Survey, 2006) (see sidebar on page 18).

A. Principal aquifer rock types of the United States



B. Principal aquifer rock types for 932 public wells



EXPLANATION

Principal aquifer rock type (Figure *2A*)

🟦 Unconsolidated sand and gravel aquifers (non-glacial origin)
▨ Glacial sand and gravel aquifers
🟨 Semi-consolidated sand and gravel aquifers
🟩 Sandstone aquifers
🟪 Sandstone and carbonate-rock aquifers
🟫 Carbonate-rock aquifers
🟧 Basaltic and other volcanic-rock aquifers
🟥 Crystalline-rock aquifers
⬜ Other aquifers

Number of public wells (Figure *2B*)

🔵 284
⚫ 118
🟡 172
🟢 94
🟣 66
🟤 81
🟠 89
🔴 17
⚪ 11

Figure 2. Source-water samples were collected from 932 public wells that are located in parts of 41 states and withdraw water from parts of about one-half of the regionally extensive aquifers used for water supply in the United States. Map (*A*) shows the areal extent, by rock type, of all principal aquifers in the United States, and map (*B*) shows the locations and the principal aquifer rock types associated with the public wells sampled in this study.

Table 2. Water-quality properties, inorganic contaminants, and organic contaminants were analyzed in source-water samples from 932 public wells.

Contaminant or contaminant group	Number of contaminants in group	Number of source-water samples analyzed [1]
Contaminants analyzed in source-water samples evaluated by Toccalino and others (2010)—Appendix 1		
Water-quality properties [2]	6	802 to 896
Major ions	9	787 to 810
Trace elements	23	[3] 598 to 809
Nutrients	8	201 to 817
Radionuclides		
Radon	1	506
Radionuclides other than radon	3	84 to 191
Organic contaminants		
Pesticide compounds	83	[4] 507 to 898
Volatile organic compounds	85	758 to 832
Additional organic contaminants analyzed in a subset of source-water samples evaluated by Hopple and others (2009)—Appendix 2		
Personal-care and domestic-use products	21	[5] 203 to 217
Other organic contaminants		
Other pesticide compounds	60	[6] 200 to 221
Herbicide and herbicide degradates	18	43 to 73
Other volatile organic compounds	9	119 to 217
Manufacturing additives, pavement- and combustion-derived compounds, plant- or animal-derived biochemicals	17	202 to 217

[1] The number of samples analyzed for individual contaminants varies because of factors such as differences in study designs.

[2] Alkalinity, dissolved oxygen, pH, specific conductance, temperature, and total dissolved solids.

[3] Five trace elements were analyzed in 437 to 503 samples.

[4] Four pesticide compounds were analyzed in 159 to 165 samples.

[5] Three personal-care and domestic-use products were analyzed in 118 to 187 samples.

[6] Hexazinone was analyzed in 113 samples.

- NAWQA studies were designed as integrated water-resource assessments of critical and regionally extensive hydrologic systems of the Nation, but were not designed as a statistically representative sampling of all public wells nationwide. Within the sampled hydrogeologic settings, however, the public wells were randomly selected to represent typical aquifer conditions.
- Because each public well was sampled once, percentages of samples presented in this study are the same as percentages of wells.
- Trends within the 15-year study period (1993–2007) were not assessed, but changes in contaminant occurrence over time were not expected to be large compared to geographic variability because of the relatively slow movement of groundwater. The occurrence of some contaminants, however, particularly in unconfined aquifers, may have changed over time in some wells because of variability in contaminant sources and because pumping and other human activities can enhance the mobility of contaminants (Jurgens and others, 2009).
- Contaminant concentrations were compared to Maximum Contaminant Levels (MCLs) or to HBSLs when available, to provide an initial perspective on the potential signficance of detected contaminants to human health (see sidebars on pages 4 and 19). Detections of contaminants do not necessarily indicate a concern for human health; samples were analyzed using methods with detection levels that often are 100-fold to 1,000-fold lower than MCLs or HBSLs (see sidebar on page 17).
- The occurrence and composition of unique contaminant mixtures were assessed in various subsets of samples. Unique mixtures are specific combinations of two, three, or more contaminants, regardless of the presence of other contaminants.

- Detailed analysis of mixtures focused on a subset of 383 source-water samples in which most contaminants—major ions, trace elements, nutrients, radon, pesticide compounds, and volatile organic compounds (VOCs)—were analyzed. Mixtures of contaminants were identified in three categories: (1) contaminants each detected at concentrations greater than individual human-health benchmarks; in this category, radon activities were compared to the higher proposed Alternative MCL (4,000 picocuries per liter, or pCi/L); (2) contaminants each detected at concentrations greater than one-tenth of individual benchmarks; radon activities were compared to the lower proposed MCL (300 pCi/L); and (3) same as the second category, but with additional consideration for man-made organic contaminants detected at any concentration.
- Mixtures of man-made organic contaminants also were evaluated in a subset of 814 source-water samples, and in a subset of 94 paired samples of source and finished water, regardless of the availability of human-health benchmarks or the concentrations relative to benchmarks.

Data used in this report previously have been selectively included in national-scale NAWQA assessments of specific contaminant groups (trace elements, radionuclides, nutrients, pesticide compounds, and VOCs) and have been used in detailed investigations of water-quality conditions in individual NAWQA assessment areas and principal aquifers. Publications from these previous assessments are available online at http://water.usgs.gov/nawqa/.

Importance of Low-Level Detections

Recent advances in laboratory analytical methods have given scientists increasingly refined tools to detect a wide range of contaminants in the environment at progressively lower concentrations. U.S. Geological Survey (USGS) analytical methods were designed to detect concentrations as low as technically and economically feasible. The analytical methods used in this study have detection levels that are commonly 100-fold to 1,000-fold lower than human-health benchmarks for water quality. Detections of contaminants, therefore, do not necessarily indicate a concern for human health, but rather identify the environmental presence of a wide variety of contaminants, many of which are not commonly monitored in water resources, and help to characterize aquifer vulnerability, regardless of well depth or aquifer characteristics. Trends in contaminant concentrations were not assessed in this study, but low-level detections can be used in other studies to track changes in contaminant occurrence and concentrations over time. The reporting levels for the analytical methods used by the U.S. Environmental Protection Agency, water utilities, or commercial laboratories for the analysis of finished-water samples for compliance monitoring typically are higher than reporting levels for analytical methods used by USGS. As a result, contaminant detection frequencies in USGS reports may be greater than detection frequencies in annual water-quality reports (consumer confidence reports) provided by water utilities.

U.S. Geological Survey chemist at the National Water-Quality Laboratory in Lakewood, Colorado. (Photograph by U.S. Geological Survey.)

Aquifer Types and Well Depth

An aquifer is a saturated, permeable geologic formation that can transmit substantial quantities of water, such as to wells (Freeze and Cherry, 1979). The amount of groundwater that can flow through a geologic formation primarily depends on the permeability (the size and arrangement of the connected spaces in the materials that comprise the formation) and the hydraulic gradient. Permeable geologic materials—such as gravel, sand, sandstone, and fractured rock—have large or many connected spaces through which groundwater can readily flow. Relatively impermeable materials—such as clay or shale—have spaces that are not well connected or are so small that the flow of groundwater is restricted (Heath, 1983).

A confined aquifer is one that is located beneath a relatively impermeable (confining) layer, and an unconfined aquifer is one in which the water table forms the upper boundary (Heath, 1983) (fig. 3). Confined aquifers tend to be deeper than unconfined aquifers, which commonly are near the land surface (Freeze and Cherry, 1979). Accordingly, of the public wells sampled in this study, the 397 wells that withdraw water from confined aquifers generally were deeper than the 502 wells that withdraw water from unconfined aquifers (Toccalino and others, 2010).

The susceptibility of an aquifer to contamination from activities at the land surface can be directly related to the degree of aquifer isolation from the land surface by the confining layers (Lindsey and others, 2009). In general, an aquifer tends to be less susceptible to contamination if it has a deep water table (for an unconfined aquifer), a thick, low-permeability layer, such as clay-rich material, between the aquifer and the land surface (for a confined aquifer), and no highly permeable fractures that can act as conduits for fluid flow. By contrast, an aquifer tends to be more susceptible to contamination if it has a shallow water table, no low-permeability protecting layer, and features that facilitate the movement of water, such as fractures and nearby wellbores (Younger, 2007). The vulnerability of an aquifer to contamination depends on (1) intrinsic susceptibility (the physical aquifer properties that affect groundwater flow), as discussed above, and (2) the presence of contaminant sources and additional factors that affect contaminant fate and transport (Focazio and others, 2002).

In general, deep wells are presumed to be less vulnerable than shallower wells to contaminants that originate at the land surface (Zogorski and others, 2006). Large withdrawal rates from public wells, however, combined with proximity to developed areas and the possible presence of short-circuiting flow paths, make even deep wells vulnerable to contamination. Short-circuiting flow paths can be natural (such as fractures in a confining layer) or man-made (such as wells) and can allow water and contaminants to bypass substantial portions of aquifers that would otherwise restrict their movement to deep public wells (Landon and others, 2009). Deep public wells, which are commonly pumped for sustained periods at high rates, can intercept groundwater flowing along extensive flow paths with long residence times (Zogorski and others, 2006).

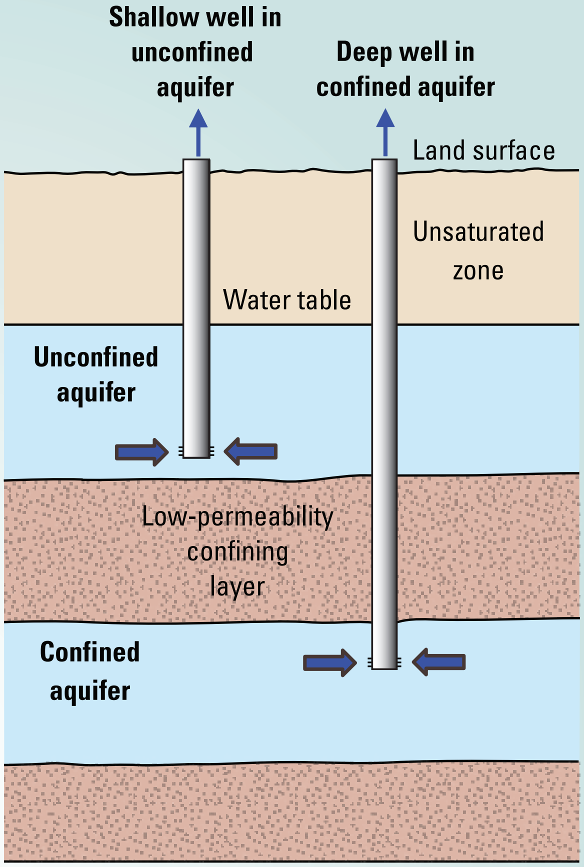


Figure 3. Samples were collected from 502 public wells that withdraw water from unconfined aquifers and 397 public wells that withdraw water from confined aquifers (33 sampled wells withdraw water from mixed or unknown aquifer types). Unconfined aquifers tend to be shallower, and more vulnerable to contamination from human activities at the land surface, than confined aquifers. This simplified diagram was modified from Alley and others (1999).

Groundwater that flows over long distances to public wells may include water that drains from a variety of land-use settings and may contain degradation products from parent compounds and contaminants with substantial historical use (Gilliom and others, 2006). Additionally, public wells in some hydrogeologic settings may intercept water with a wide range of ages, including relatively young water flowing along short flow paths that make such wells vulnerable to contaminants in recently recharged groundwater (McMahon and others, 2008).

Evaluating Results in the Context of Human Health

Contaminant concentrations in untreated source water from public wells were compared to Maximum Contaminant Levels (MCLs) or Health-Based Screening Levels (HBSLs) to provide an initial perspective on the potential significance of detected contaminants to human health and to help prioritize further investigations (see sidebar on page 4). Such comparisons are not designed to evaluate specific effects of contaminants on human health, and are not a substitute for comprehensive risk assessments, which generally include many additional factors such as multiple avenues of exposure (Toccalino and others, 2006).

Contaminant concentrations greater than human-health benchmarks in source water are of potential human-health concern, but do not necessarily indicate that adverse effects will occur, because (1) the benchmarks are conservative (protective) (Toccalino and others, 2006; Toccalino, 2007), and (2) source-water samples were collected prior to any treatment or blending that could alter contaminant concentrations in finished drinking water. In this study, contaminant concentrations greater than MCLs do not represent MCL violations because MCLs appy to finished water and the majority of the samples were collected from source waters. None of the source-water or finished-water samples were collected for regulatory compliance purposes; further, compliance with some MCLs is based on running annual average concentrations, not on concentrations detected in single samples as collected in this study.

Exposure to individual contaminants detected at concentrations less than benchmarks is unlikely to result in adverse human-health effects because the benchmarks typically are concentrations in drinking water that are not anticipated to cause adverse effects from a lifetime of exposure (Toccalino, 2007; U.S. Environmental Protection Agency, 2009a). The occurrence of contaminants for which human-health benchmarks are not yet available were not evaluated in the context of potential human-health significance in this study.

Human-health benchmark values used in this report were current as of September 2009. MCL values were obtained from the U.S. Environmental Protection Agency (USEPA) (2006a), and HBSL values were obtained from the HBSL website (Toccalino and others, 2008). USEPA updated their drinking-water standards and guidelines document in late 2009 (U.S. Environmental Protection Agency, 2009a), but data from the updated USEPA report were not available in time for inclusion in this report. MCLs or HBSLs were available for 193 of the 337 contaminants analyzed in this study (fig. 4).

Concentrations greater than one-tenth of benchmarks were used in this study to provide an early and conservative indication of contaminants that may approach concentrations of potential human-health concern, either individually or in mixtures, and to identify contaminants that may warrant additional monitoring (Toccalino and others, 2010). Various federal and state agencies use the criteria of one-tenth (or one-half) of a human-health benchmark for a variety of purposes; examples include: (1) reporting contaminant occurrence in groundwater (U.S. Environmental Protection Agency, 1999b; New Jersey Department of Environmental Protection, 2003), (2) reporting pesticide detections in water to USEPA under the Federal Insecticide, Fungicide, and Rodenticide Act (Nebraska Department of Agriculture, 1997; U.S. Environmental Protection Agency, 1998), (3) ranking the susceptibility of wells to contamination (New Jersey Department of Environmental Protection, 2003, 2004), and (4) identifying contaminants of potential human-health concern for risk assessment evaluations (U.S. Environmental Protection Agency, 1993, 1994).

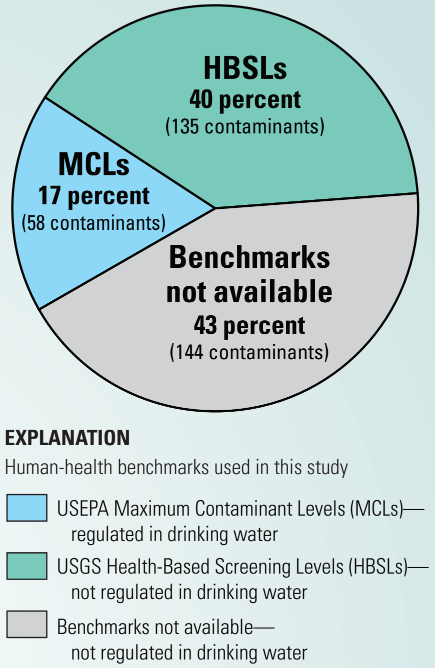


Figure 4. Human-health benchmarks were available for 57 percent of the contaminants analyzed in this study. Most (83 percent) of the 337 contaminants analyzed in this study are not regulated by the U.S. Environmental Protection Agency in drinking water under the Safe Drinking Water Act (SDWA); MCLs are not available for unregulated contaminants. Contaminants that are not regulated in drinking water under the SDWA may be regulated in other contexts and under other statutes.

Major Findings

More than one in five source-water samples from public wells contained one or more contaminants at concentrations greater than human-health benchmarks

One or more chemical contaminants were detected at concentrations greater than human-health benchmarks in more than one in five (22 percent) of the 932 source-water samples from public wells (fig. 5). Concentrations of at least one chemical contaminant were greater than an MCL in 15 percent of the source-water samples when radon activities were compared to the proposed Alternative MCL of 4,000 pCi/L. Concentrations of at least one contaminant were greater than an HBSL in 10 percent of the source-water samples, and contaminant concentrations were greater than both MCLs and HBSLs in some samples. MCLs or HBSLs were not available for 144 (43 percent) of the contaminants analyzed in this study (fig. 4). Collectively, contaminants regulated in drinking water accounted for 60 percent of concentrations greater than human-health benchmarks, and unregulated contaminants accounted for 40 percent of concentrations greater than benchmarks.

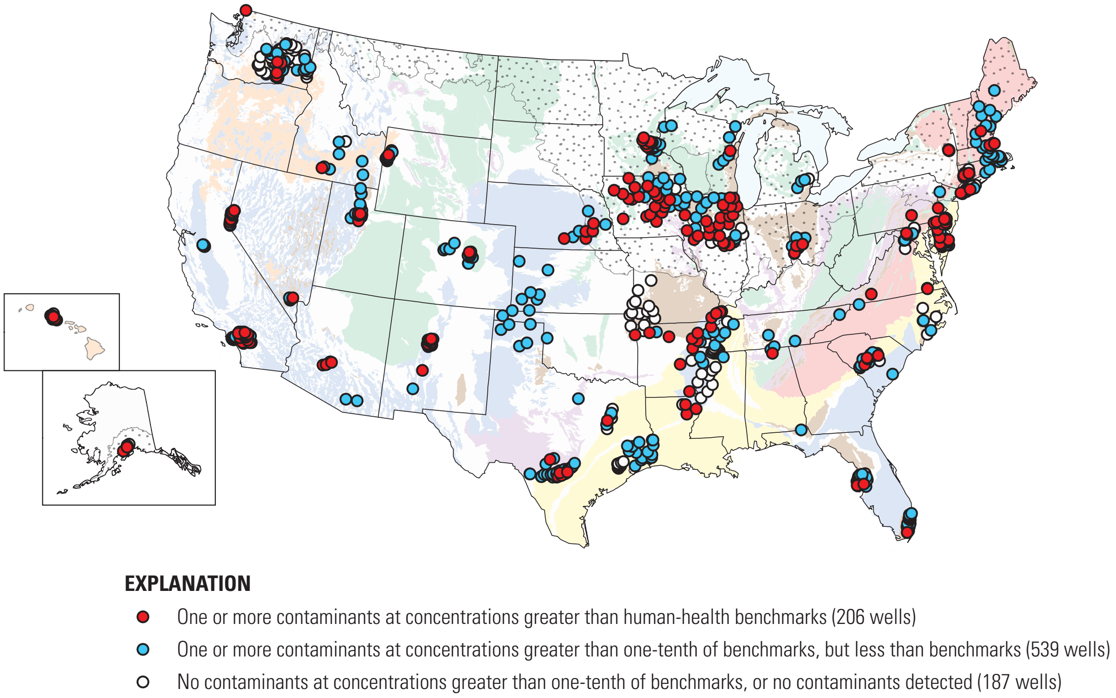
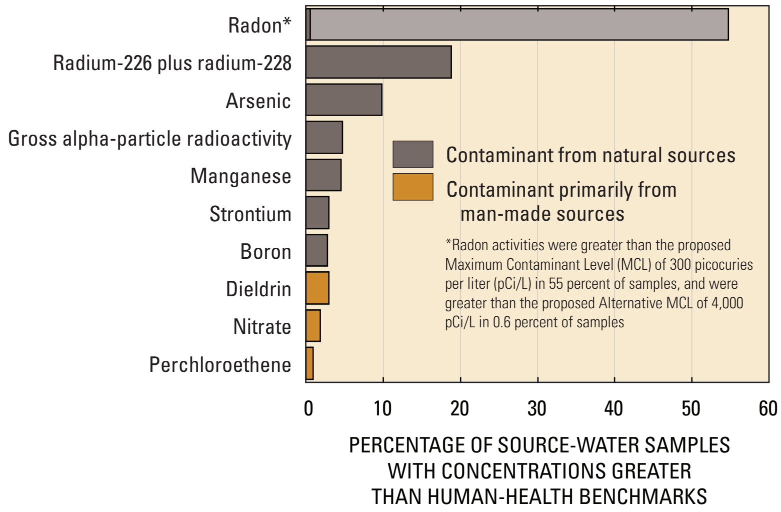


Figure 5. Twenty-two percent of 932 source-water samples from public wells contained one or more chemical contaminants at concentrations greater than Maximum Contaminant Levels or Health-Based Screening Levels. A total of 80 percent of samples (206 plus 539 wells) contained one or more contaminants at concentrations greater than one-tenth of human-health benchmarks. Public wells yielding water in which contaminant concentrations were greater than benchmarks, as well as those in which concentrations were greater than one-tenth of benchmarks, were distributed throughout the United States and included wells that withdraw water from every principal aquifer rock type included in this study. (See fig. 2*A* for explanation of principal aquifer rock types.)

A total of 23 contaminants were detected at concentrations greater than MCLs or HBSLs in at least one source-water sample from public wells. Ten of these contaminants—seven from natural sources and three primarily from man-made sources—individually were detected at concentrations greater than human-health benchmarks in at least 1 percent of samples (fig. 6) and collectively accounted for most concentrations greater than benchmarks. Contaminant concentrations greater than human-health benchmarks in source water are of potential human-health concern, but do not necessarily indicate that adverse effects will occur (see sidebar on page 19). The potential health effects associated with the ingestion of water containing any of these 10 contaminants at concentrations greater than benchmarks include an increased risk of cancer (for six of the contaminants); various neurological, developmental, and reproductive effects; liver problems; and "blue-baby syndrome" (table 3).

Five of the 10 contaminants that were detected at concentrations greater than benchmarks in at least 1 percent of source-water samples (radium, arsenic, gross alpha-particle radioactivity, nitrate, and perchloroethene (PCE)) are regulated in drinking water by the USEPA under the SDWA, and therefore managed, in finished drinking water (fig. 6); radon has proposed MCLs. Manganese, boron, and dieldrin have undergone USEPA's regulatory determination process under the SDWA, but after evaluating available occurrence, exposure, and health-effects information, USEPA determined that no regulatory action was appropriate for these contaminants because they infrequently occur at health levels of concern in public water systems, and regulating these contaminants in drinking water would not "present a meaningful opportunity for health risk reduction" (U.S. Environmental Protection Agency, 2003a, 2008b). Strontium is listed on USEPA's most recent (third) Contaminant Candidate List (CCL) (U.S. Environmental Protection Agency, 2010a).

A total of 80 percent of source-water samples contained at least one contaminant at concentrations greater than one-tenth of human-health benchmarks. Most individual contaminant detections, however, were less than one-tenth of human-health benchmarks, and many detections were several orders of magnitude less than benchmarks. Public wells yielding water in which contaminant concentrations were greater than benchmarks, as well as those in which concentrations were greater than one-tenth of benchmarks, were distributed throughout the United States and include wells that withdraw water from all principal aquifer rock types included in this study (fig. 5).



*Radon activities were greater than the proposed Maximum Contaminant Level (MCL) of 300 picocuries per liter (pCi/L) in 55 percent of samples, and were greater than the proposed Alternative MCL of 4,000 pCi/L in 0.6 percent of samples

Figure 6. Ten contaminants, including seven from natural sources and three from primarily man-made sources, each were detected at concentrations greater than human-health benchmarks in at least 1 percent of source-water samples from public wells. Radium, arsenic, gross alpha-particle radioactivity, nitrate, and perchloroethene are regulated in drinking water under the Safe Drinking Water Act.

Table 3. The potential health effects associated with the 10 contaminants that each were detected at concentrations greater than developmental, and reproductive effects; liver problems; and "blue-baby syndrome". Contaminants are listed in decreasing percentage

[pCi/L, picocuries per liter; AMCL, Alternative Maximum Contaminant Level; MCL, Maximum Contaminant Level; µg/L, micrograms per liter; HBSL,

Contaminant	Contaminant type	Human-health benchmark [1]		Potential health effects from ingestion of water with contaminant concentration greater than the human-health benchmark [2]
		Value	Type	
Radon-222	Radionuclide	4,000 (300) pCi/L	Proposed AMCL (proposed MCL)	Increased risk of lung cancer [a,b]
Radium-226 plus radium-228	Radionuclide	5 pCi/L	MCL	Increased risk of cancer
Arsenic	Trace element	10 µg/L	MCL	Skin damage or problems with circulatory system, and may have increased risk of getting cancer
Gross alpha-particle radioactivity	Radionuclide	15 pCi/L	MCL [5]	Increased risk of cancer
Manganese [6]	Trace element	300 µg/L	HBSL	Neurological effects [c,d,e]
Strontium [7]	Trace element	4,000 µg/L	HBSL	Abnormal bone development [f,g]
Dieldrin [6]	Pesticide compound, insecticide	0.002 µg/L	HBSL low [8]	Liver and central nervous system problems, increased risk of cancer [d,h,i,j]
Boron [6]	Trace element	1,000 µg/L	HBSL	Reproductive and developmental effects [d,k,l]
Nitrate	Nutrient	10 mg/L as N	MCL	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die—symptoms include shortness of breath and "blue-baby syndrome"
Perchloroethene	Volatile organic compound, solvent	5 µg/L	MCL [9]	Liver problems, increased risk of cancer

[1] Human-health benchmark values were current as of September 2009. MCL values were obtained from the USEPA (2006a) and HBSL values were obtained from the HBSL website (Toccalino and others, 2008).

[2] Unless otherwise indicated, references for potential health effects and sources of contaminant are from the USEPA (2003f, 2009b). MCLs and HBSLs generally are contaminant concentrations at which adverse effects are not expected over a lifetime of exposure.

[3] Radon activities greater than the proposed AMCL of 4,000 pCi/L were counted.

[4] Radon activities greater than the proposed MCL of 300 pCi/L were counted.

[5] The MCL for gross alpha-particle radioactivity excludes alpha-particle radioactivity from radon and uranium (U.S. Environmental Protection Agency, 2000). Gross alpha-particle radioactivity values for public-well samples in this study were not corrected for radon or uranium.

[6] Manganese, dieldrin, and boron have undergone USEPA's regulatory determination process under the Safe Drinking Water Act, but were not selected for regulation in drinking water (U.S. Environmental Protection Agency, 2003a, 2008b).

[7] Strontium is listed on USEPA's most recent (third) Contaminant Candidate List (U.S. Environmental Protection Agency, 2010a).

[8] Low end of HBSL range corresponding to a 10^{-6} (one in one million) cancer risk. The HBSL range corresponds to a 10^{-6} to 10^{-4} cancer risk range.

[9] The MCL for perchloroethene is under review by the USEPA.

human-health benchmarks in at least 1 percent of source-water samples include an increased risk of cancer; various neurological, of source-water samples from public wells with concentrations greater than human-health benchmarks.

Health-Based Screening Level; mg/L as N, milligrams per liter as nitrogen; USEPA, U.S. Environmental Protection Agency]

Sources of contaminant in drinking water [2]	Number of public wells sampled	Percentage of samples with		Principal aquifer rock types most often associated with concentrations greater than benchmarks
		Concentrations greater than benchmark	Concentrations greater than one-tenth of benchmark	
Radioactive decay of uranium in aquifer materials [a,b]	506	[3] 0.6, [4] 55	[4] 55	Unconsolidated sand and gravel (non-glacial)
Erosion of natural deposits	191	19	62	Sandstone—not all rock types were sampled
Erosion of natural deposits; runoff from orchards; runoff from industrial wastes	638	10	42	Unconsolidated sand and gravel (non-glacial)
Erosion of natural deposits of certain radioactive minerals	84	5	54	Semi-consolidated sand and gravel—not all rock types were sampled
Aquifer materials; some industrial wastes [c,d]	808	5	20	Glacial sand and gravel and unconsolidated sand and gravel (non-glacial)
Aquifer materials; some industrial wastes [f]	503	3	49	Sandstone aquifers
Historical agricultural applications and insecticidal use; waste sites; all uses banned in 1987 [i,j]	896	3	3	Semi-consolidated sand and gravel
Aquifer materials; sewage or septic-system effluent; fertilizer application; some industrial wastes [d,k]	501	3	28	Sandstone
Runoff from fertilizer use; leaching from septic tanks; sewage; erosion of natural deposits	806	2	45	Unconsolidated sand and gravel (non-glacial)
Discharge from factories and dry cleaners	829	1	3	Semi-consolidated sand and gravel

[a] National Research Council (1999).

[b] U.S. Environmental Protection Agency (1999a).

[c] Agency for Toxic Substances and Disease Registry (2008).

[d] World Health Organization (2004).

[e] U.S. Environmental Protection Agency (1995).

[f] Agency for Toxic Substances and Disease Registry (2004).

[g] U.S. Environmental Protection Agency (1992).

[h] U.S. Environmental Protection Agency (1987).

[i] Agency for Toxic Substances and Disease Registry (2002b).

[j] U.S. Environmental Protection Agency (2003c).

[k] U.S. Environmental Protection Agency (2008d).

[l] U.S. Environmental Protection Agency (2004a).

Contaminants from natural sources accounted for about three-quarters of contaminant concentrations greater than human-health benchmarks in source-water samples

Naturally occurring trace elements and radionuclides accounted for about three-quarters (74 percent) of all contaminant concentrations greater than human-health benchmarks in source-water samples from public wells. Four trace elements (arsenic, manganese, strontium, and boron) and three radionuclides (radon, radium, and gross alpha-particle radioactivity) each were detected at concentrations greater than benchmarks in at least 1 percent of source-water samples (fig. 6). Radon activities were greater than the higher proposed Alternative MCL of 4,000 pCi/L in less than 1 percent of samples, but were greater than the lower proposed MCL of 300 pCi/L in 55 percent of samples. Each of the remaining six trace elements and radionuclides was detected at concentrations greater than benchmarks in 3 to 19 percent of source-water samples (fig. 6).

Overall, concentrations of one or more trace elements were greater than human-health benchmarks in 16 percent of source-water samples (fig. 7), and were greater than one-tenth of benchmarks in a total of 73 percent of samples (Toccalino and others, 2010). One or more radionuclide activities were greater than benchmarks in 8 percent of samples when radon activities were compared to the higher proposed Alternative MCL of 4,000 pCi/L (fig. 7), and were greater than one-tenth of benchmarks in a total of 68 percent of samples (Toccalino and others, 2010). All together, concentrations of one or more trace elements or radionuclides were greater than MCLs or HBSLs in 19 percent of samples when radon activities were compared to 4,000 pCi/L.

Many trace elements and radionuclides were detected at concentrations greater than benchmarks in samples from both confined and unconfined aquifers (fig. 7), consistent with the fact that these naturally occurring contaminants originate primarily from aquifer materials, rather than from man-made sources at the land surface.

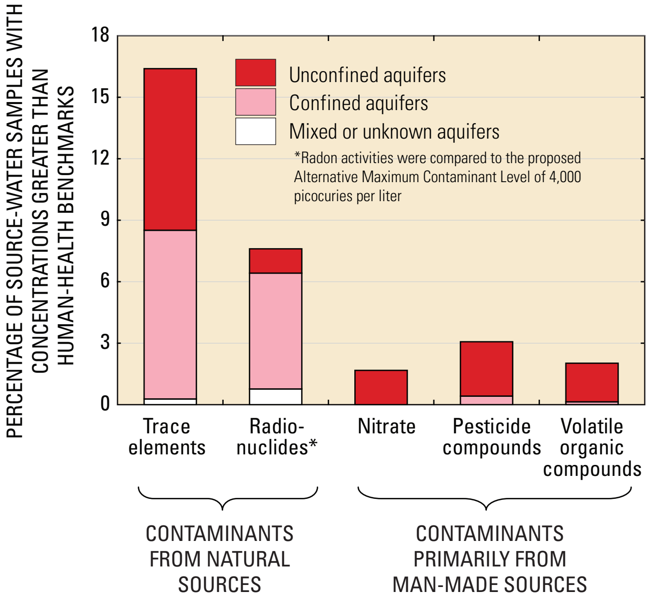
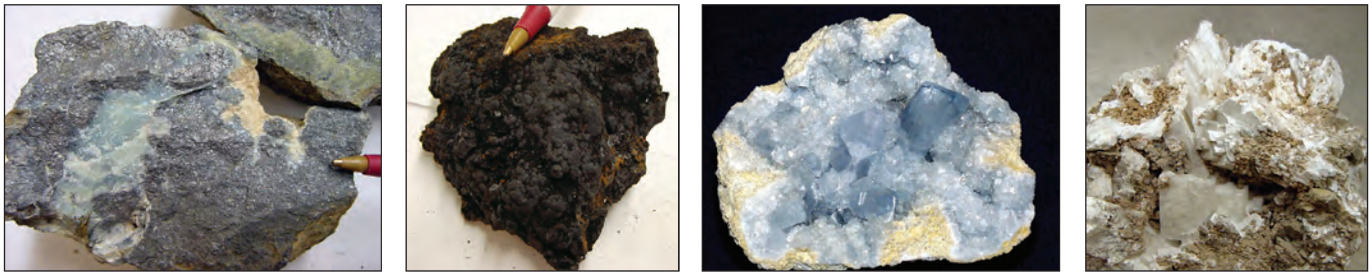


Figure 7. Contaminants from natural sources were detected more frequently at concentrations greater than human-health benchmarks in source-water samples from public wells than were man-made contaminants. Trace elements and radionuclides were detected at concentrations greater than benchmarks in samples from both unconfined and confined aquifers, consistent with the fact that these contaminants originate primarily from aquifer materials. By contrast, man-made contaminants were detected at concentrations greater than human-health benchmarks mainly in samples from unconfined aquifers, consistent with the fact that these contaminants originate from human activities at the land surface.

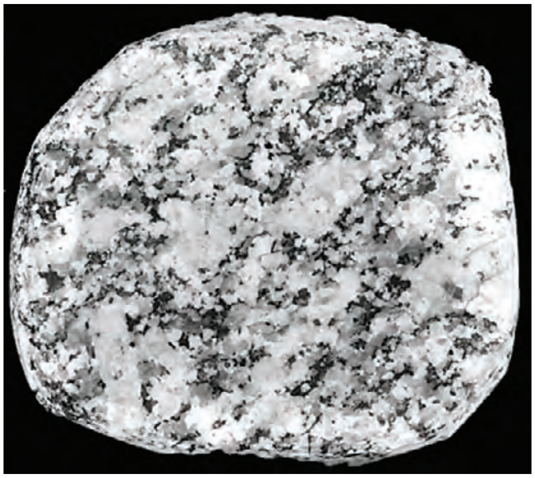


Trace elements in groundwater originate primarily from the dissolution and weathering of the rocks and minerals that make up aquifers and soils. Example sources, from left to right, include arsenopyrite, a sulfide mineral containing arsenic; pyrolusite, a manganese oxide; celestite, a strontium sulfate; and borax, a sodium borate compound.

(Arsenopyrite, pyrolusite, and borax photographs by Andrew Young, Brigham Young University. Celestite photograph by Mary Sutherland, James Madison University.)

The concentrations of naturally occurring inorganic contaminants in groundwater reflect, in large part, their abundance in aquifer materials, the length of time that the water is in contact with aquifer materials, and physical and geochemical conditions, such as pH and dissolved oxygen concentrations, that govern their solubility and mobility (Freeze and Cherry, 1979; Hem, 1985). The chemical characteristics of water in natural systems, therefore, vary from place to place and with the types of soils, rocks, and aquifer materials through which the groundwater moves. Human activities such as mining and industrial discharges also can have a strong influence on the occurrence of many trace elements in water (Hem, 1985). Man-made sources of radionuclides include nuclear facilities and power plants, and institutional and industrial facilities, such as hospitals and laboratories (U.S. Environmental Protection Agency, 2000). In areas where development has occurred (such as increased irrigation and pumping associated with agricultural and urban development), associated changes in groundwater flow and aquifer chemistry can enhance the mobility of natural contaminants in aquifers, resulting in increased concentrations in groundwater withdrawn from public wells (Jurgens and others, 2009).

The occurrences of radon and arsenic, the radionuclide and trace element detected at concentrations greater than benchmarks in the highest percentages of samples, are described below. Detailed descriptions of the occurrences of the remaining eight contaminants detected at concentrations greater than human-health benchmarks in at least 1 percent of the public-well samples are included in Toccalino and others (2010).



Radon is formed as part of the normal radioactive decay chain of uranium. Most rocks contain some uranium, but some types of rocks—such as granite shown here—have higher than average uranium contents. These include some volcanic rocks, dark shales, sedimentary rocks that contain phosphate, and granites. (Photograph from U.S. Geological Survey Photographic Library.)

Radon

Radon is a naturally occurring radioactive gas that is soluble in groundwater. Radon activities in groundwater can reflect the distribution of uranium-bearing rocks, from which radon originates (Ayotte and others, 2007). In this study, radon activities were positively correlated with uranium concentrations in most principal aquifer rock types. Radon dissolved in water was detected in nearly all (98 percent) of 506 source-water samples analyzed for radon in this study.

USEPA classifies radon as a human carcinogen (U.S. Environmental Protection Agency, 2006a). Radon contributes to lung-cancer deaths through exposure to radon and its decay products in indoor air. Because radon is a gas, many uses of water, such as showering, readily release radon from the water into indoor air. Ingestion of radon in drinking water may contribute to adverse effects in the gastrointestinal tract and other organs (National Research Council, 1999).

USEPA has proposed an MCL of 300 pCi/L and an Alternative MCL of 4,000 pCi/L for radon in public water systems (U.S. Environmental Protection Agency, 2006a). Some states also have set their own standards or guidelines for radon in drinking water, including New Hampshire (2,000 pCi/L), Maine (4,000 pCi/L), Connecticut (5,000 pCi/L), and Massachusetts (10,000 pCi/L) (New Hampshire Department of Environmental Services, 2008; Maine Center for Disease Control and Prevention, 2006; Connecticut Department of Public Health, 2005; Commonwealth of Massachusetts, 2009). States may set radon guidelines higher than USEPA's proposed MCL or Alternative MCL because USEPA's proposed benchmarks for radon are not final, and are therefore not yet legally enforceable. Under the SDWA, individual states may set and enforce drinking-water standards that are more stringent than USEPA's national standards (U.S. Code, 1996).

Radon activities were greater than the proposed Alternative MCL of 4,000 pCi/L in less than 1 percent of source-water samples from public wells (3 samples), but 55 percent of samples contained radon activities greater than the proposed MCL of 300 pCi/L (table 3 and fig. 6). Public wells yielding water with radon activities greater than 300 pCi/L were geographically distributed across the United States and included wells that withdraw water from every principal aquifer rock type (fig. 8). Radon activities generally were lowest in public wells in the central United States and in a few smaller sampled areas, such as eastern North Carolina, where radon either was not detected or activities were less than 300 pCi/L (fig. 8).

High radon activities in water withdrawn from crystalline-rock aquifers, particularly in the northeastern United States, have been reported in several previous studies. For example, Ayotte and others (2007) and DeSimone (2009) each calculated a median radon activity of greater than 2,000 pCi/L in groundwater from observation, domestic, and public wells that withdraw water from crystalline-rock aquifers, primarily in the northeastern United States. In this study, radon was analyzed in only two samples from crystalline-rock aquifers, so substantive comparisons to previous studies could not be made, but radon activities were greater than 2,000 pCi/L in each of those two samples.

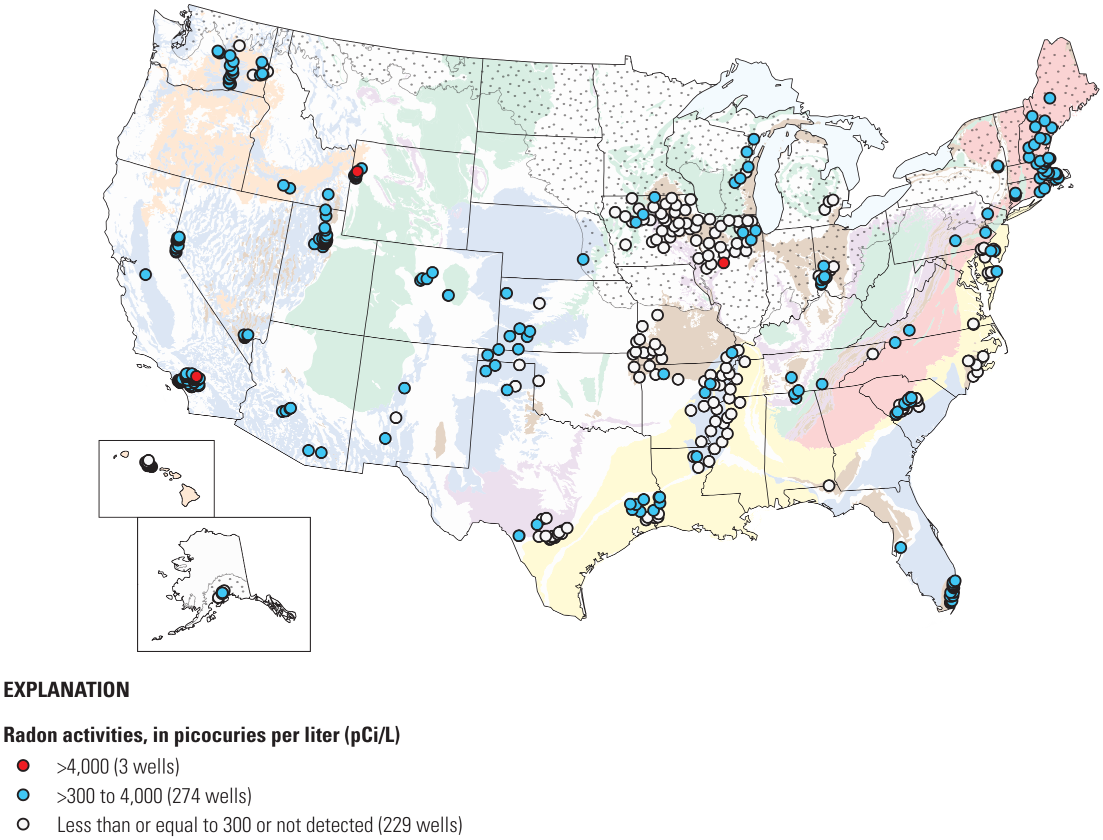


Figure 8. Radon activities were greater than the proposed Maximum Contaminant Level (MCL) of 300 pCi/L in 55 percent of source-water samples from public wells. These wells are distributed throughout the United States, and include wells that withdraw water from every principal aquifer rock type sampled. Radon activities greater than the proposed Alternative MCL of 4,000 pCi/L were detected in only 3 samples. Radon was analyzed in 506 source-water samples. (See fig. 2*A* for explanation of principal aquifer rock types; >, greater than.)

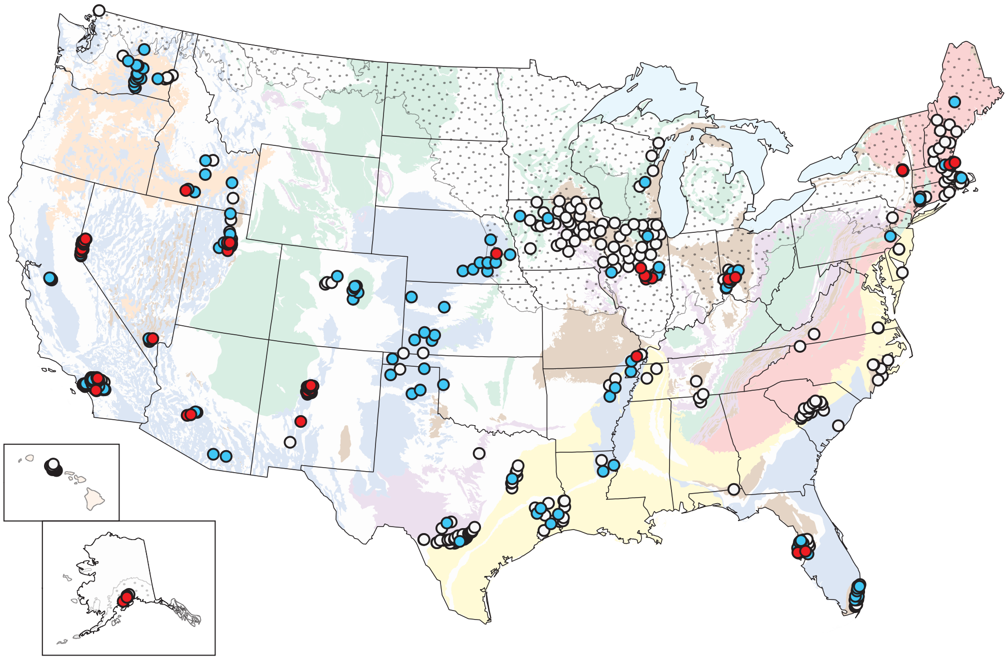
Arsenic

Arsenic is a naturally occurring nonmetallic trace element in rocks and soils, as well as waters in contact with them (Hem, 1985; Focazio and others, 2000). Man-made sources of arsenic include agricultural pesticides, wood preservatives, contaminants from mining activities, and livestock feed additives (Welch and others, 2000; Nordstrom, 2002). Arsenic was detected in 70 percent of 638 source-water samples analyzed for arsenic in this study.

Recognized as a toxic element for centuries, arsenic is of human-health concern because it can contribute to a wide variety of adverse health effects, including several types of cancers (National Research Council, 2001). Concentrations of arsenic were greater than the MCL of 10 micrograms per liter (µg/L) in 10 percent of the source-water samples (table 3). Seven to 10 percent of groundwater samples in previous national-scale studies (Focazio and others, 2000; Welch and others, 2000; DeSimone, 2009) contained arsenic at concentrations greater than 10 µg/L, which is consistent with the findings from this study, even though the earlier studies included more water samples from different types of wells.

Almost all of the source-water samples with arsenic concentrations greater than the MCL were from public wells that withdraw water from unconsolidated sand and gravel aquifers (non-glacial origin) and from glacial sand and gravel aquifers. Although public wells yielding water with arsenic concentrations greater than the MCL were distributed across the United States and withdraw water from both unconfined and confined aquifers, about three-quarters of these wells were in the western United States (fig. 9). Arsenic concentrations were lowest in samples from public wells in the north-central and the southeastern areas of the United States (except for Florida). Previous national-scale studies also have reported arsenic concentrations in groundwater to generally be highest in the western United States (Focazio and others, 2000; Welch and others, 2000; Ryker, 2001) and lowest in the southeastern United States (Welch and others, 2000). Regional-scale studies, however, have noted arsenic concentrations in groundwater greater than 10 µg/L in other areas of the country, such as eastern New England (Ayotte and others, 2003). A total of 42 percent of source-water samples from public wells contained arsenic concentrations greater than one-tenth of the MCL (table 3); these public wells were widely distributed across the United States (fig. 9).

The mobility and solubility of arsenic in groundwater is increased by low concentrations of dissolved oxygen, high pH (greater than 8.5), and the presence of substances such as organic carbon and iron oxides (Welch and others, 2000; Nordstrom, 2002; Kelly and others, 2005). Arsenic concentrations greater than the MCL in groundwater are associated with factors such as the release of arsenic from iron oxide, on which arsenic may be adsorbed (Welch and others, 2000), and old groundwater recharged before 1953 (Thomas, 2007). Additionally, sulfide minerals are both a source and sink for arsenic, and geothermal waters with high evaporation rates also are associated with arsenic concentrations greater than 10 µg/L in groundwater, particularly in the western United States (Welch and others, 2000).



EXPLANATION

Arsenic concentration, in micrograms per liter

🔴 >10 (63 wells)

🔵 >1 to 10 (206 wells)

○ Less than or equal to 1 or not detected (369 wells)

Figure 9. Arsenic concentrations were greater than the Maximum Contaminant Level (MCL) of 10 micrograms per liter in 10 percent of source-water samples from public wells. Most of these wells withdraw water from sand and gravel aquifers (glacial and non-glacial origin) in several western states. A total of 42 percent of samples (63 plus 206 wells) contained arsenic at concentrations greater than one-tenth of the MCL. Arsenic was analyzed in 638 source-water samples. (See fig. 2*A* for explanation of principal aquifer rock types; >, greater than.)

Contaminants that originate entirely or primarily from man-made sources accounted for about one-quarter of contaminant concentrations greater than human-health benchmarks in source-water samples and were detected in nearly two-thirds of the samples, predominantly in samples from unconfined aquifers

Nitrate, pesticide compounds, and VOCs accounted for about one-quarter (25 percent) of all contaminant concentrations greater than MCLs or HBSLs in source-water samples from public wells. Nitrate (a nutrient), dieldrin (an insecticide), and PCE (a solvent), each were detected at concentrations greater than MCLs or HBSLs in 1 to 3 percent of source-water samples (table 3 and fig. 6). Nitrate occurs naturally, but nitrate concentrations greater than 1 milligram per liter as nitrogen (which is one-tenth of the nitrate MCL) are considered indicative of man-made sources such as fertilizers, livestock, and wastewater in many parts of the United States (Nolan and Hitt, 2003). Dieldrin and PCE originate from man-made sources.

Nitrate was detected at concentrations greater than the MCL in 2 percent of the source-water samples from public wells, and at concentrations greater than one-tenth of the MCL in a total of 45 percent of samples (table 3). All samples with nitrate concentrations greater than the MCL were collected from unconfined aquifers (fig. 7), consistent with the fact that nitrate originates from man-made sources at the land surface. Most samples with nitrate concentrations greater than the MCL were collected from public wells that withdraw water from unconsolidated sand and gravel aquifers, which is consistent with previous studies that indicate that aquifers with high effective porosities—such as those consisting of unconsolidated sand and gravel—are most vulnerable to nitrate contamination (Mueller and others, 1995; Nolan and Hitt, 2006; Lindsey and others, 2009).

Only 7 of the 168 pesticide compounds or VOCs analyzed in most source-water samples (Appendix 1) were detected at concentrations greater than human-health benchmarks in at least one public-well sample. These organic contaminants included dieldrin, *alpha*-hexachlorocyclohexane, PCE, trichloroethene (TCE), dibromochloropropane, ethylene dibromide, and acrylonitrile. All together, one or more pesticide compounds were detected at concentrations greater than MCLs or HBSLs in 3 percent of source-water samples from public wells, and one or more VOCs were detected at concentrations greater than MCLs or HBSLs in 2 percent of samples (fig. 7). These findings are consistent with recent national assessments that reported that pesticide and VOC concentrations were greater than human-health benchmarks in 2 and 1.5 percent of public-well samples, respectively (Gilliom and others, 2006; Zogorski and others, 2006).

Detections of dieldrin accounted for almost all concentrations of pesticide compounds greater than human-health benchmarks. Dieldrin, a highly persistent insecticide compound, originates from historical applications of dieldrin and aldrin, which degrades to dieldrin in the environment (table 3). By 1974, all except a few uses of dieldrin were banned in the United States (U.S. Environmental Protection Agency, 1980), and the USEPA banned all uses in 1987 (Agency for Toxic Substances and Disease Registry, 2002a). As a result, detections of dieldrin reflect pesticide use practices that are no longer allowed, and show that source-water protection strategies that rely on changes in human activities and practices at the land surface to achieve water-quality objectives can take years to centuries to affect the quality of water in some public wells (McMahon and others, 2008).

Perchloroethene (PCE) is the most commonly used solvent at commercial dry cleaners.
(Photograph from iStock Photos.)

Although nitrate occurs naturally in groundwater, concentrations often are increased by human activities in agricultural and urban areas. Sources of nitrate to groundwater include fertilizers, livestock, and wastewater.
(Photograph from iStock Photos.)

Dieldrin is an insecticide that is no longer used in the United States. Historically, dieldrin was used to control insects on some crops, and to control locusts, mosquitoes, and termites.
(Photograph from iStock Photos.)

Collectively, concentrations of one or more pesticide compounds or VOCs were greater than human-health benchmarks in 4.5 percent of source-water samples and were greater than one-tenth of benchmarks in a total of 10 percent of samples (fig. 10). Almost all (86 to 94 percent) of the pesticide compound and VOC concentrations greater than human-health benchmarks were detected in samples from public wells that withdraw water from unconfined aquifers, consistent with the fact that these contaminants originate at the land surface (fig. 7).

About two-thirds of the source-water samples with concentrations of pesticide compounds or VOCs greater than benchmarks were from public wells in the highly populated areas of states bordering the East Coast, primarily in semi-consolidated sand and gravel aquifers that underlie the Coastal Plains (fig. 10). Public wells yielding water with concentrations of pesticide compounds or VOCs greater than one-tenth of benchmarks were distributed throughout the United States, but nearly three-quarters of these public wells withdraw water from unconsolidated and semi-consolidated sand and gravel aquifers. Most samples collected from public wells in the central and west-central United States contained concentrations of pesticide compounds or VOCs less than one-tenth of benchmarks, or human-health benchmarks were not available for detected organic contaminants (fig. 10).

The occurrence of pesticide compounds and VOCs in groundwater is influenced by their sources and pathways in the hydrologic system; and their volatility, mobility and persistence in soils and groundwater (Gilliom and others, 2006; Zogorski and others, 2006). Pesticides are released into the environment primarily through their application to agricultural lands, such as croplands, and to non-agricultural

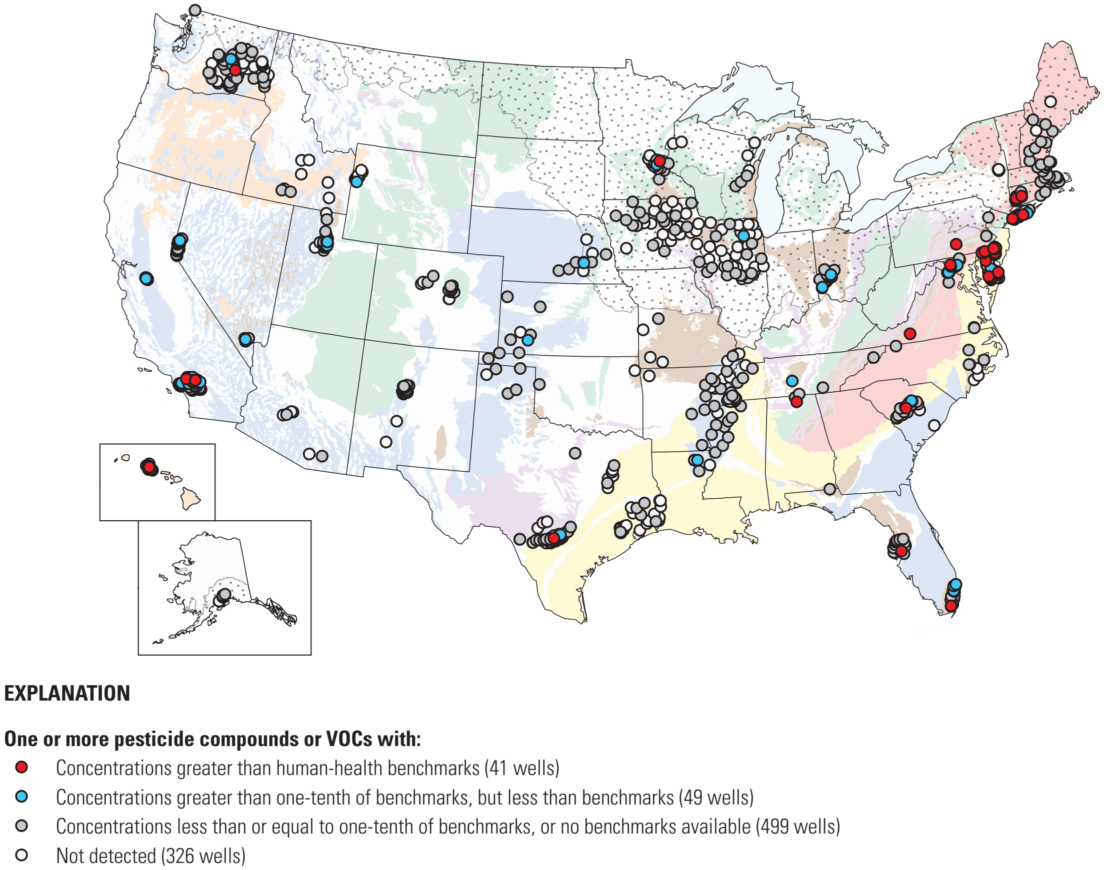


Figure 10. Concentrations of one or more pesticide compounds or volatile organic compounds (VOCs) were greater than human-health benchmarks in 4.5 percent of source-water samples from public wells. About two-thirds of these wells withdraw water from semi-consolidated sand and gravel aquifers in the highly populated areas of East-Coast states. A total of 10 percent of samples (41 plus 49 wells) contained one or more pesticide compounds or VOCs at concentrations greater than one-tenth of benchmarks. Pesticide compounds and VOCs were analyzed in 915 source-water samples. (See fig. 2*A* for explanation of principal aquifer rock types.)

lands, such as lawns, golf courses, and commercial areas (Gilliom and others, 2006). For some pesticides, USEPA may modify pesticide labels and resulting use patterns to mitigate exposures to those pesticides in areas expected to be most vulnerable. USEPA makes these decisions based on their assessments of potential exposure to pesticides in drinking water by using modeling tools and monitoring data (Elizabeth Behl, U.S. Environmental Protection Agency, written commun., December 2009), such as those data included in this study. VOCs are a broad class of organic contaminants that have numerous uses in industry, commerce, households, and military sites (Zogorski and others, 2006), and consequently have several transport pathways into groundwater.

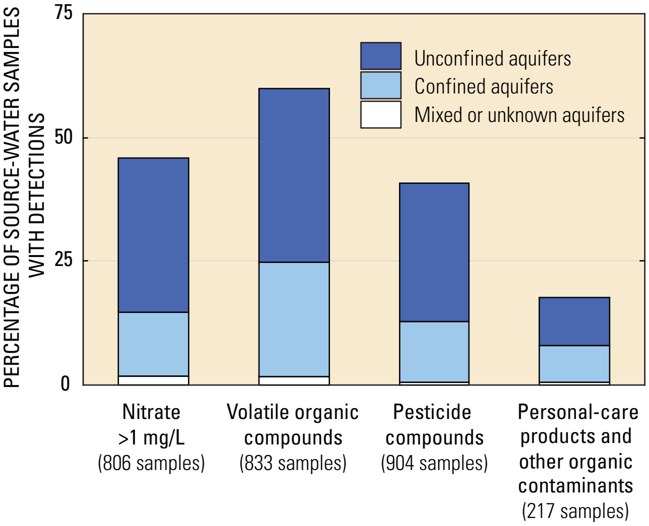


Figure 11. The frequent detections of man-made contaminants in source-water samples from public wells, particularly those wells that withdraw water from unconfined aquifers, indicate the susceptibility of aquifers to contamination from human activities at the land surface. Nitrate concentrations greater than 1 milligram per liter (>1 mg/L) as nitrogen typically originate from man-made sources.

Sources of man-made organic contaminants, such as pesticide compounds and volatile organic compounds (VOCs), are various and widespread. More than a billion pounds of pesticides are applied each year in the United States to control weeds, insects, and other pests in agricultural and urban areas. VOCs are used in many industrial, commercial, and domestic activities, and sources to groundwater include landfills, leaking storage tanks and spills, leaking water and sewer lines, and vehicular exhaust.

(Photograph by Jeff Vanuga, Natural Resources Conservation Service, U.S. Department of Agriculture.)

(Photograph from EGDigital, iStock photos.)

Collectively, one or more man-made pesticide compounds or VOCs were detected in nearly two-thirds (64 percent) of the source-water samples; pesticide compounds and VOCs each were detected in 41 and 60 percent of samples, respectively (fig. 11). About two-thirds of the samples in which nitrate or pesticide compounds were detected were from public wells that withdraw water from unconfined aquifers and one-third of the samples were from public wells that withdraw water from confined aquifers (fig. 11). This finding is consistent with previous studies that show that shallow groundwater—particularly from unconfined aquifers—is more vulnerable to contamination from human activities at the land surface than deep groundwater from confined aquifers (U.S. Geological Survey, 1999) (see sidebar on page 18). Fifty-nine percent of the samples in which VOCs were detected were from unconfined aquifers. Nitrate, pesticide compounds, and VOCs were detected in a significantly greater proportion of samples from unconfined aquifers than in samples from confined aquifers. Other organic contaminants, such as personal-care and domestic-use products, were detected in 18 percent of samples, about one-half of which were from unconfined aquifers (fig. 11).

A total of 293 organic contaminants were analyzed in this study; 169 (58 percent) were detected in at least one source-water sample from public wells, and 124 (42 percent) were not detected in any sample (Appendixes 1 and 2). Chloroform, a disinfection by-product (DBP), was the most frequently detected organic contaminant in source-water samples from public wells—it was detected in 46 percent of all source-water samples. Chloroform also was reported as the most frequently detected VOC in the Nation's public wells in other studies (Westrick and others, 1984; Squillace and others, 1999; U.S. Environmental Protection Agency, 2002b; Zogorski and others, 2006). Chloroform is used as a solvent, is a by-product of chlorination of drinking water and wastewater, and may be introduced into groundwater through artificial recharge of aquifers using chlorinated water (Zogorski and others, 2006).

Other frequently detected VOCs—in 11 to 22 percent of source-water samples—included solvents such as PCE, TCE, and 1,1,1-trichloroethane, the gasoline oxygenate methyl-*tert*-butyl ether (MTBE), and bromodichloromethane, another DBP. Deethylatrazine, a degradation product of atrazine, was the most frequently detected pesticide compound in source water, and was detected in 30 percent of samples. The herbicides atrazine, simazine, and prometon also were frequently detected—in 11 to 27 percent of all source-water samples.

Many organic contaminants detected in source water also were detected in finished water at similar concentrations

As many as 272 organic contaminants were analyzed in a subset of 94 paired source- and finished-water samples from public wells; inorganic contaminants were not analyzed in these paired samples. Public water systems typically are required to monitor finished water for about 90 contaminants that are regulated in drinking water under the SDWA (U.S. Environmental Protection Agency, 2009a), but generally do not monitor finished water for many of the 272 organic contaminants assessed by Hopple and others (2009). The extent to which contaminants detected in source water also were detected in finished water was assessed in this study, but the efficacy of water treatment used at the public water systems was not evaluated.

Disinfection was the primary water treatment used at about three-quarters of the sampled systems (J.A. Hopple, U.S. Geological Survey, written commun., January 2010), which is about the same proportion as for all groundwater-supplied public water systems nationwide. Nationally, about three-quarters (71 percent) of groundwater-supplied public water systems use disinfection only or disinfection plus chemical addition, such as the addition of fluoride (U.S. Environmental Protection Agency, 2002a). Disinfection destroys harmful organisms, but disinfection is not designed to treat organic contaminants, and may chemically transform them into different organic contaminants. Public water systems that are not in compliance with the SDWA (systems not meeting MCLs) using disinfection alone must use additional treatment—such as granular activated carbon and aeration—or change or blend their sources of water (U.S. Environmental Protection Agency, 2004b, 2004c).

Forty-five organic contaminants (excluding DBPs) were detected in both source- and corresponding finished-water samples. DBPs were excluded from this analysis because, during water treatment, DBPs can form when disinfectants, such as chlorine, react with organic matter in the water (Richardson and others, 2002). As a result, DBP concentrations were greater in finished water than in source water, as is generally expected. Twenty-two of the 45 contaminants—including pesticides, pesticide degradates, and VOCs—each were detected in more than 10 percent of source-water samples. Concentrations of these 22 frequently detected contaminants generally were similar in source and finished water, especially for nonblended finished water (fig. 12). These results are consistent with previous analyses by the USEPA Office of Pesticide Programs, which reported that pesticides detected in source waters often are detected in treated finished waters at similar concentrations (U.S. Environmental Protection Agency, 2001b). As expected, the variability in concentrations between source water and finished water generally was greater for finished water that was blended with water from other wells before distribution (fig. 12).


(Photograph from iStock Photos.)

When contaminant concentrations (including DBPs) were compared to human-health benchmarks, two of the source-water samples contained PCE, TCE, and (or) 1,1-dichloroethene at concentrations greater than MCLs (Hopple and others, 2009). None of the finished-water samples contained any

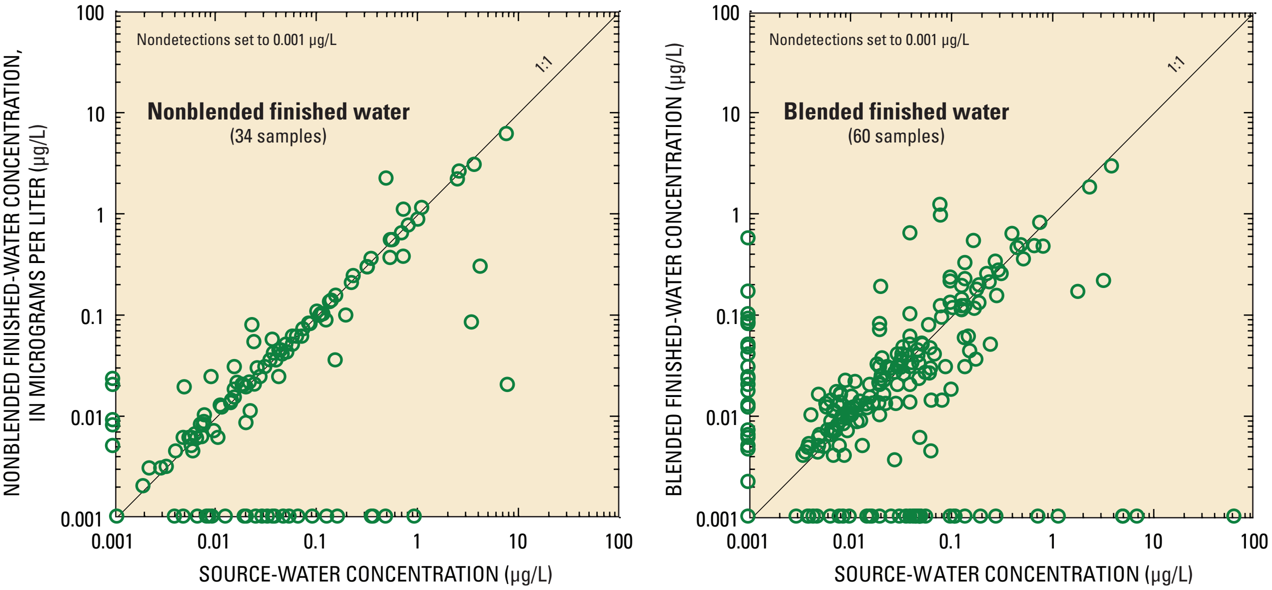


Figure 12. When an organic contaminant was detected in both source and finished water, concentrations generally were similar, especially for nonblended finished water. As expected, the variability in concentrations between source water and finished water (scatter around the 1:1 line) was greater for blended finished water, which includes water from other wells that were not sampled. Data are shown for 22 organic contaminants that each were detected in more than 10 percent of source-water samples; data for disinfection by-products are not shown. Data are from 94 public wells from which source and finished water were sampled.

organic contaminants at concentrations greater than benchmarks. At least one contaminant was detected at concentrations greater than one-tenth of benchmarks in 9 source-water samples (primarily solvents), and in 11 finished-water samples (primarily DBPs). Dieldrin was not detected in any sample from 48 paired source- and finished-water samples (Hopple and others, 2009).

Some contaminants were detected at lower concentrations in finished water than in source water, or were detected in source water only (fig. 12). The solvents 1,1,1-trichloroethane, PCE, and TCE are examples of such contaminants (Hopple and others, 2009). There are several possible explanations for these results, including a decrease in concentrations in finished water as a result of blending source water from several wells, the transformation or removal of contaminants during water treatment, volatilization, accidental introduction of contaminants at the wellhead sample collection point, or analytical variability for concentrations near the detection level.

Conversely, some contaminants were detected at lower concentrations in source water than in finished water, or were detected in finished water only (fig. 12). Examples of such contaminants include xylenes (gasoline hydrocarbons), methyl isobutyl ketone (a solvent), and several herbicides or herbicide degradates (Hopple and others, 2009). Determining the possible sources of contaminants that were detected only in finished water is beyond the scope of this study. Blending of the finished water with water from other wells prior to distribution, however, appears to account for many of these detections in finished water only (fig. 12). Maintenance and chemical use at public water systems also can possibly explain some unmatched detections.

Human-health benchmarks are not yet available for many organic contaminants, including some that were frequently detected in source water

MCLs or HBSLs were not available for 144 (43 percent) of the contaminants analyzed in this study (fig. 4) and, therefore, the occurrence of these contaminants could not be evaluated in the context of human health. Most contaminants for which human-health benchmarks were not available are organic contaminants (Appendixes 1 and 2).

The SDWA directs USEPA to regulate contaminants in drinking water that present the greatest public-health concern. As part of determining whether drinking-water regulations are needed, the SDWA requires USEPA to publish a list of unregulated contaminants called the CCL every 5 years. The CCL includes contaminants that currently are not subject to any proposed or promulgated national primary drinking water regulations, which are known or anticipated to occur in public water systems, and which may require regulation under the SDWA in the future. Following the publication of each CCL, USEPA decides whether to regulate at least five contaminants from the CCL in drinking water (called regulatory determinations) on the basis of the contaminant's potential for adverse human-health effects and occurrence in public water systems, and a meaningful opportunity to protect public health (U.S. Environmental Protection Agency, 2010a). The USEPA uses USGS data on the occurrence of unregulated contaminants in water resources as part of both the CCL and regulatory determination processes.

Nine unregulated contaminants for which human-health benchmarks are not available were detected in 6 to 35 percent of source-water samples from public wells (fig. 13). Of these contaminants, the gasoline oxygenate MTBE, the solvent 1,1-dichloroethane, and the herbicide degradates alachlor ethane sulfonic acid, alachlor oxanilic acid, metolachlor ethane sulfonic acid, and metolachlor oxanilic acid are listed on the most recent (third) CCL (U.S. Environmental Protection Agency, 2010a). Deethylatrazine and deisopropylatrazine are degradates of atrazine, and are not listed on the third CCL. Most herbicide degradates analyzed in this study are not currently regulated by the USEPA in drinking water under the SDWA, but some herbicide degradates are regulated by USEPA under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (see sidebar on page 36). FIFRA requires USEPA to register pesticides sold or used in the United States to ensure that pesticides will not cause unreasonable risks to the environment or human health when used according to the label directions (U.S. Environmental Protection Agency, 2009d).

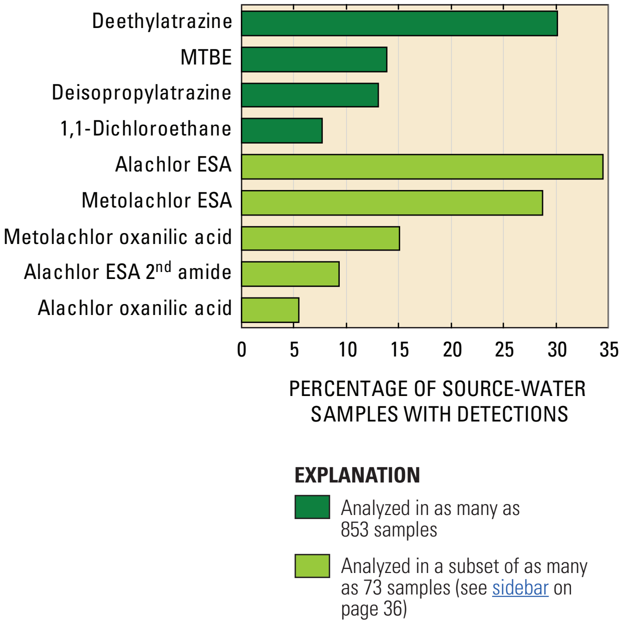


Figure 13. Degradates of the herbicides atrazine, alachlor, and metolachlor; a gasoline oxygenate (methyl *tert*-butyl ether or MTBE); and a solvent (1,1-dichloroethane) were the most frequently detected organic contaminants in source-water samples from public wells for which human-health benchmarks are not available. Concentrations of the parent herbicides atrazine, alachlor, and metolachlor were less than human-health benchmarks in all source-water samples. ESA, ethane sulfonic acid.

Atrazine and deethylatrazine were the most frequently detected pesticide compounds of those that were analyzed in most of the source-water samples from public wells. Because deethylatrazine is a degradation product of atrazine, it tended to occur in the same source-water samples as atrazine. Atrazine has been one of the most heavily used herbicides in the United States for nearly 20 years, on the basis of total pounds applied (Thelin and Stone, 2010). Most of the agricultural use of atrazine has been associated with corn production, but it also has had some nonagricultural use. Atrazine is highly soluble, mobile, and moderately persistent in water (Gilliom and others, 2006). Atrazine, but none of its degradation products, is regulated by USEPA in drinking water under the SDWA (U.S. Environmental Protection Agency, 2006a). Atrazine concentrations were less than the MCL in all source-water samples; concentrations were greater than one-tenth of the MCL in 4 samples (Toccalino and others, 2010).

The degradates of alachlor and metolachlor were analyzed using a separate analytical method in a subset of 43 to 73 source-water samples from selected areas where the parent herbicides likely were used (see sidebar on page 36). These degradates were detected in 6 to 35 percent of the samples (fig. 13). Alachlor and metolachlor are used on corn and other crops (Gilliom and others, 2006), and in the Corn-Belt region of the United States, more than four times as many pounds of metolachlor than alachlor have been applied annually since 1996 (Sullivan and others, 2009). Alachlor is regulated in drinking water under the SDWA, but metolachlor and the degradates of alachlor and metolachlor are not (U.S. Environmental Protection Agency, 2006a). Alachlor concentrations were less than the MCL in all source-water samples; concentrations were greater than one-tenth of the MCL in one sample. All metolachlor detections were less than one-tenth of the HBSL (Toccalino and others, 2010).

Atrazine, alachlor, and metolachlor are herbicides used to control weeds in corn fields, although each also has other uses.

(Photograph from iStock Photos.)

Herbicide Degradates were Frequently Detected in Source Water

Herbicide degradates are formed by the transformation or breakdown of a parent herbicide by chemical, photochemical, or biologically mediated reactions. Eight herbicides and 23 of their degradation products were assessed in a subset of as many as 73 source-water samples from public wells (Hopple and others, 2009). The only herbicides detected in more than one sample were from two classes of herbicides, the chloroacetanilides (acetochlor, alachlor, and metolachlor) and the triazines (atrazine and simazine). Degradates of these herbicides were analyzed because the parent herbicides likely were used in the areas that were sampled, and because degradates may have similar or greater persistence than their parent herbicides (Thurman and others, 1992; Kalkhoff and others, 1998).

Herbicide degradates may have less, similar, or greater toxicity than parent compounds (Hladik and others, 2005). For example, in U.S. Environmental Protection Agency (USEPA) risk assessments, the toxicities of the chlorotriazine degradates of atrazine, including deethylatrazine, are considered to be equivalent to that of the parent compound (U.S. Environmental Protection Agency, 2003d, 2006b). By contrast, some chloroacetanilide degradates have been shown to be less toxic than their parent herbicides (Heydens and others, 2000). For many pesticide degradates, however, the toxicity to humans is not well understood.

Summed concentrations of the chloroacetanilide degradates generally were substantially greater than the parent herbicide concentrations (fig. 14). Summed concentrations of the atrazine degradates generally were similar to or greater than the concentrations of the atrazine parent compound. In some samples, herbicide degradates—but not the parent compounds—were detected, pointing to the importance of monitoring for both parent and degradate compounds. Total degradate concentrations can be similar to or greater than parent-compound concentrations when conditions in groundwater favor transformations to degradates that are chemically persistent. Groundwater moves relatively slowly through aquifer materials, providing time for microbial or chemical transformations to occur (Gilliom and others, 2006).

As part of the Federal Insecticide, Fungicide, and Rodenticide Act reregistration of atrazine in 2003, the USEPA developed Drinking Water Levels of Comparison (DWLOCs) for the sum of the concentrations of atrazine and its three chlorinated degradates (deethylatrazine, deisopropylatrazine, and deethyldeisopropyl atrazine), referred to as total chlorotriazines (TCT), in public water systems (U.S. Environmental Protection Agency, 2003d). DWLOCs are the maximum concentrations in drinking water that, when considered together with other dietary exposure, do not exceed a level of concern.

The USEPA no longer uses the DWLOC approach for dietary risk assessments (Elizabeth Behl, U.S. Environmental Protection Agency, written commun., December 2009), and is in the process of re-evaluating the potential human-health effects of atrazine (U.S. Environmental Protection Agency, 2009c). Although this re-evaluation of atrazine will change future assessments, TCT concentrations in source-water samples from public wells in this study were compared to the DWLOC of 12.5 micrograms per liter as a preliminary assessment. This DWLOC for TCT is a 90-day moving average that applies when source-water samples are collected from a water system less frequently than weekly during the high-use season (U.S. Environmental Protection Agency, 2003d). None of 73 source-water samples analyzed in this study contained summed TCT concentrations greater than one-tenth of the DWLOC.

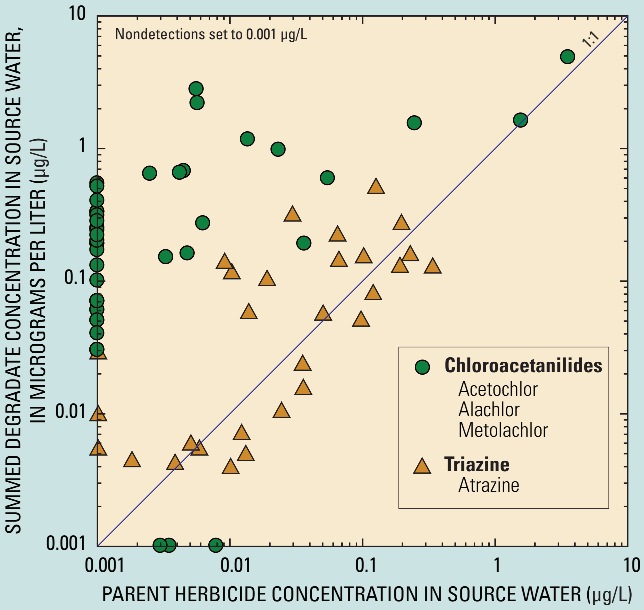


Figure 14. Summed concentrations of herbicide degradates generally were similar or greater than concentrations of parent compounds for two classes of herbicides, the chloroacetanilides and the triazines. Symbols above the 1:1 line indicate that concentrations of summed degradates were greater than concentrations of parent herbicides. Herbicide degradates were analyzed in a subset of as many as 73 source-water samples from public wells.

Contaminants usually co-occurred with other contaminants in source and finished water, and mixtures of two or more contaminants at concentrations greater than one-tenth of individual human-health benchmarks were dominated by inorganic contaminants

Analysis of individual contaminants, as described above, is needed to identify those that occur at concentrations of potential human-health concern, and to assess where and why they occur. Most people, however, are exposed to mixtures of man-made organic and naturally occurring inorganic contaminants at concentrations less than those known to cause adverse effects (Carpenter and others, 2002). Although few human-health benchmarks have been established for mixtures of contaminants, concentrations of the contaminants in mixtures were compared to individual benchmarks in this study. Little is known about the potential health effects associated with exposure to multiple contaminants at the low concentrations typically detected in the environment, yet toxicologic interactions that can result in adverse effects are possible at these concentrations (Hasegawa and others, 1994; Yang, 1994).

Identifying and characterizing all possible contaminant mixtures in drinking water and assessing their toxicity is not practical (Squillace and others, 2002; Ryker and Small, 2008). Many contaminant combinations are possible, and which combinations are potential concerns because of their combined toxicity often is unknown. Evaluating the toxicity of mixtures to humans is complicated by the possibility of multiple types of interactions between the contaminants (such as additive, synergistic, antagonist, or no interactions), and because many individual contaminants can affect multiple organs and functions in the body (Carpenter and others, 2002). Findings from this study, however, can help to identify which contaminant mixtures may be of most concern because of their frequency of occurrence in groundwater withdrawn by public wells and comparisons to individual human-health benchmarks.

Occurrence and Distribution of Mixtures

Although 22 percent of source-water samples from public wells contained at least one contaminant at concentrations greater than human-health benchmarks, mixtures of two or more contaminants in which the concentration of each contaminant was greater than its individual benchmark, were detected less frequently—in 4 percent of source-water samples (fig. 15). On the other hand, 84 percent of source-water samples contained two or more contaminants in which the concentration of each contaminant was greater than one-tenth of its individual benchmark. Mixtures that also considered detections of any pesticide compound or VOC (without regard to the availability of benchmarks or concentrations relative to individual benchmarks) were detected in 92 percent of samples (fig. 15).

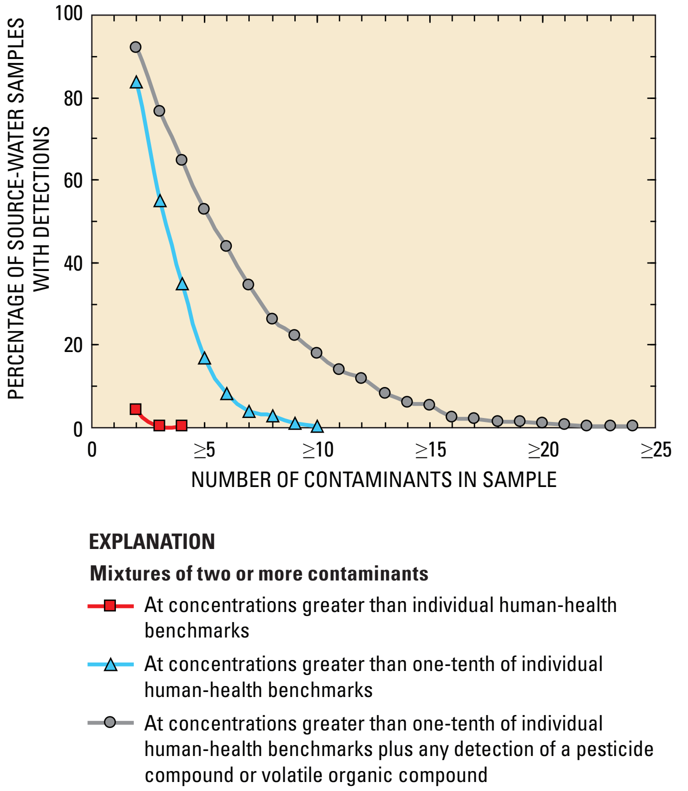


Figure 15. Mixtures of two or more contaminants were detected at concentrations greater than one-tenth of individual human-health benchmarks in 84 percent of samples, and mixtures of five or more contaminants were detected at such concentrations in 17 percent of samples. Little is known about the potential health effects associated with exposure to contaminant mixtures. Data are from 383 source-water samples from public wells in which major ions, trace elements, nitrate, radon, pesticide compounds, and volatile organic compounds were analyzed. ≥, greater than or equal to.

Mixtures with the largest number of contaminants (5 to 10) detected at concentrations greater than one-tenth of individual human-health benchmarks were distributed among a number of sampled areas throughout the United States, but were most common in public wells sampled in parts of the western United States. About three-quarters of the public wells with five or more contaminants detected at concentrations greater than one-tenth of individual benchmarks withdraw water from unconsolidated sand and gravel aquifers in the western United States, mostly in California, Utah, Nevada, and Arizona (fig. 16).

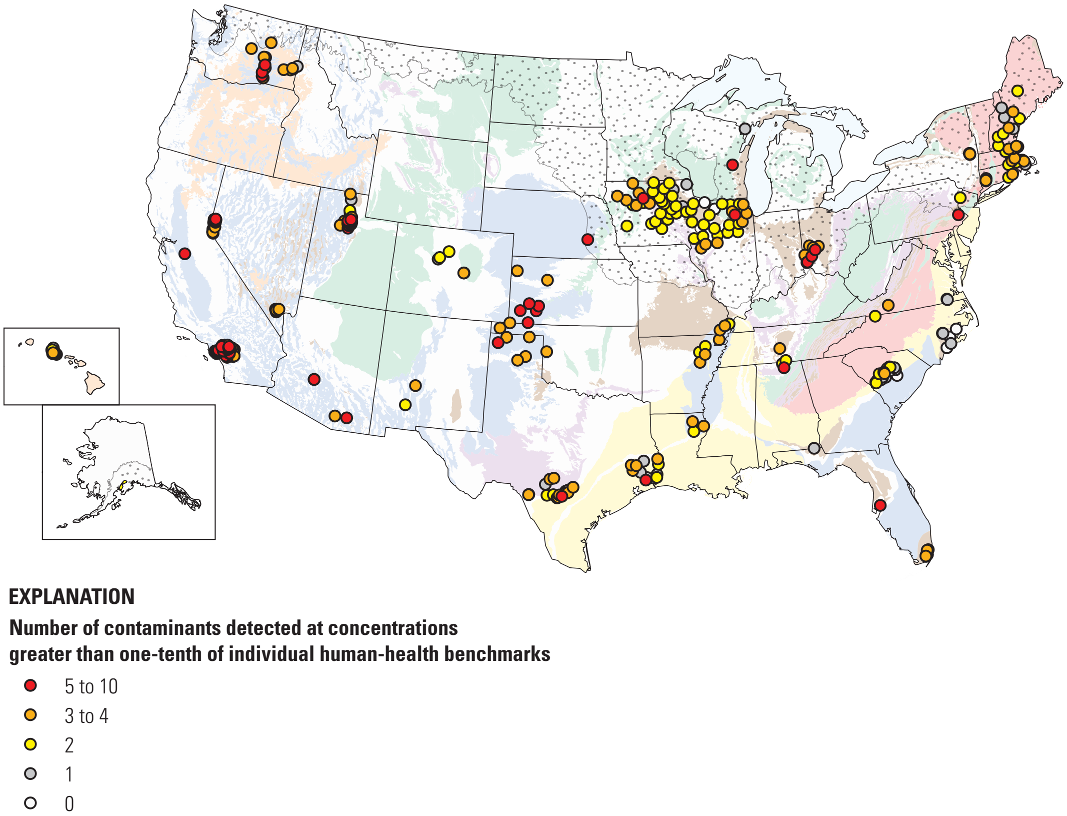


Figure 16. Mixtures with the largest number of contaminants (5 to 10) detected at concentrations greater than one-tenth of individual human-health benchmarks were distributed among a number of sampled areas throughout the United States. Such mixtures were most common, however, in samples collected from public wells that withdraw water from unconsolidated sand and gravel aquifers in parts of the western United States. Data are from 383 source-water samples from public wells in which major ions, trace elements, nitrate, radon, pesticide compounds, and volatile organic compounds were analyzed. Radon activities were compared to the proposed MCL of 300 picocuries per liter. (See fig. 2*A* for explanation of principal aquifer rock types.)

Composition of Mixtures

The most common contaminants in unique mixtures—specific combinations of contaminants regardless of others that may be present—were those that were most frequently detected individually. Twenty-one unique mixtures of contaminants at concentrations greater than individual benchmarks were identified, and each of these mixtures was detected in less than 1 percent of the source-water samples. These mixtures most commonly were composed of solvents (primarily PCE and TCE), trace elements (such as arsenic and strontium), and nitrate, indicating a mix of naturally occurring and man-made contaminants (table 4).

Sixty-eight unique mixtures of contaminants at concentrations greater than one-tenth of individual benchmarks each were detected in at least 5 percent of the source-water samples. All of these mixtures were composed of a trace element (arsenic, strontium, or uranium were most common), radon, and (or) nitrate. The most common unique mixture of contaminants at concentrations greater than one-tenth of individual benchmarks was nitrate and radon, which was detected in 32 percent of samples (table 4).

When the unique mixtures of contaminants at concentrations greater than one-tenth of individual benchmarks were expanded to include all detections of pesticide compounds or VOCs, regardless of their concentrations relative to benchmarks or the availability of benchmarks, 125 unique mixtures each were detected in at least 10 percent of source-water samples. Nitrate and radon were among the most common inorganic contaminants in these unique mixtures, but consideration of all pesticide or VOC detections added herbicides and herbicide degradates, such as atrazine and deethylatrazine; DBPs, such as chloroform; and solvents, such as PCE to the most common contaminants in the mixtures. The most common unique mixture in this category was nitrate and chloroform, which was detected in 34 percent of samples (table 4).

Mixtures of man-made pesticide compounds and VOCs also were evaluated separately from other contaminant groups because there are no natural sources for most of these contaminants and because the occurrence and toxicity of such mixtures are not well understood. Mixtures of pesticide compounds and VOCs were assessed without regard to the availability of benchmarks or the concentrations relative to individual benchmarks. Twenty-three unique mixtures of organic contaminants each were detected in at least 10 percent of the source-water samples (table 5).

Three-quarters of the organic mixtures contained an herbicide (atrazine or simazine) or an herbicide degradate (deethylatrazine). The most common unique mixture of organic contaminants was atrazine and deethylatrazine (a degradation product of atrazine), which was detected in 25 percent of samples. The common co-occurrence of atrazine and deethylatrazine also was reported in previous regional- and national-scale studies (Ayers and others, 2000; Squillace and others, 2002; Gilliom and others, 2006; DeSimone, 2009). Two-thirds of the organic mixtures contained chloroform (a DBP), and 43 percent contained a solvent (PCE or TCE) (table 5). The most frequently detected mixtures of VOCs in other national assessments of public wells and public water systems also included DBPs and solvents (Grady, 2002; Zogorski and others, 2006).

An analysis of mixtures of organic contaminants in paired samples from the subset of 94 public wells for which source and finished water were compared showed similar numbers of organic contaminants in source- and finished-water samples. Mixtures were detected in a somewhat larger percentage of finished-water samples than source-water samples because of the formation of DBPs in finished water. This finding was observed regardless of the complexity of (number of contaminants detected in) the mixtures (Hopple and others, 2009). Several recent studies have begun to evaluate DBP mixtures in drinking water because of widespread exposures to these complex mixtures and because epidemiologic and toxicologic studies of DBPs have raised concerns for human health (Teuschler and Simmons, 2003; U.S. Environmental Protection Agency, 2003b; Simmons and others, 2004; Teuschler and others, 2004).

Table 4. Unique mixtures of contaminants at concentrations greater than individual human-health benchmarks each were infrequently detected in source-water samples from public wells. The most common unique mixtures of contaminants at concentrations greater than one-tenth of individual benchmarks were composed of nitrate, naturally occurring trace elements, or radon. When detections of pesticide compounds or volatile organic compounds were included in the mixtures, herbicides, disinfection-by products, and solvents were common contaminants in the mixtures.

[Data are from 383 source-water samples from public wells in which major ions, trace elements, nitrate, radon, pesticide compounds, and volatile organic compounds were analyzed]

Composition of the 10 most common unique mixtures detected in source-water samples from public wells by selected mixture criteria			Detection frequency of unique mixtures (percent of samples)
Mixtures of contaminants at concentrations greater than individual human-health benchmarks [1]			
Boron	Strontium		0.8
Arsenic	Manganese		0.8
Nitrate	Perchloroethene		0.5
Arsenic	Molybdenum		0.5
Boron	Radon		0.4
Nitrate	Strontium		0.4
Arsenic	Strontium		0.4
Perchloroethene	Dieldrin		0.3
Nitrate	Perchloroethene	Trichloroethene	0.3
Nitrate	Perchloroethene	Dibromochloropropane	0.3
Mixtures of contaminants at concentrations greater than one-tenth of individual human-health benchmarks [2]			
Nitrate	Radon		32
Arsenic	Radon		29
Boron	Strontium		27
Strontium	Radon		22
Uranium	Radon		20
Nitrate	Strontium		19
Nitrate	Arsenic		19
Nitrate	Uranium		18
Nitrate	Arsenic	Radon	16
Arsenic	Uranium		16
Mixtures of contaminants at concentrations greater than one-tenth of individual human-health benchmarks, plus the detection of any pesticide compound or volatile organic compound regardless of the availability of benchmarks [2]			
Nitrate	Chloroform		34
Chloroform	Radon		34
Nitrate	Radon		32
Arsenic	Radon		29
Nitrate	Deethylatrazine		27
Boron	Strontium		27
Deethylatrazine	Atrazine		26
Nitrate	Atrazine		24
Nitrate	Chloroform	Radon	24
Nitrate	Deethylatrazine	Atrazine	23

[1] Radon activities were compared to the proposed Alternative Maximum Contaminant Level of 4,000 picocuries per liter (pCi/L).

[2] Radon activities were compared to the proposed Maximum Contaminant Level of 300 pCi/L, which is about one-tenth of the proposed Alternative Maximum Contaminant Level.

Table 5. The most common unique mixtures of pesticide compounds and volatile organic compounds in source-water samples from public wells contained herbicides (atrazine or simazine), an herbicide degradate (deethylatrazine), a disinfection by-product (chloroform), and (or) solvents (perchloroethene or trichloroethene). These mixtures of organic contaminants were assessed without regard to the availability of human-health benchmarks.

[Data are from 814 source-water samples from public wells in which pesticide compounds and volatile organic compounds were analyzed]

Composition of the most common unique mixtures of organic contaminants detected in source-water samples from public wells				Detection frequency of unique mixtures (percent of samples)
Deethylatrazine	Atrazine			25
Deethylatrazine	Chloroform			24
Chloroform	Atrazine			21
Deethylatrazine	Chloroform	Atrazine		20
Chloroform	Perchloroethene			20
Deethylatrazine	Perchloroethene			14
Simazine	Chloroform			13
Simazine	Deethylatrazine			13
Deethylatrazine	Chloroform	Perchloroethene		13
Perchloroethene	Atrazine			13
Simazine	Atrazine			13
Simazine	Deethylatrazine	Atrazine		13
Chloroform	Methyl *tert*-butyl ether			13
Deethylatrazine	Perchloroethene	Atrazine		12
Chloroform	Perchloroethene	Atrazine		12
Chloroform	Trichloroethene			12
Deethylatrazine	Chloroform	Perchloroethene	Atrazine	12
Simazine	Deethylatrazine	Chloroform		12
Simazine	Chloroform	Atrazine		11
Chloroform	1,1,1-Trichloroethane			11
Simazine	Deethylatrazine	Chloroform	Atrazine	11
Chloroform	Bromodichloromethane			11
Perchloroethene	Trichloroethene			11

The most complex mixtures in source water—those with the greatest number of contaminants—were most often detected in samples from unconfined aquifers

The most complex mixtures of contaminants in source-water samples from public wells—those mixtures with the greatest number of contaminants—were detected more often in samples from shallower unconfined aquifers than in samples from deeper confined aquifers. For mixtures of contaminants at concentrations greater than one-tenth of individual human-health benchmarks, the proportion of samples from the more vulnerable unconfined aquifers increased as the complexity of the mixtures increased (fig. 17).

About one-half of the samples containing two or more contaminants at concentrations greater than one-tenth of individual benchmarks were from unconfined aquifers, and about one-half were from confined aquifers. This finding was expected because simple mixtures containing two or three contaminants were dominated by inorganic contaminants (table 4), which occur in both confined and unconfined aquifers. By contrast, about two-thirds of samples containing four to six contaminants at concentrations greater than one-tenth of benchmarks, and more than three-quarters of samples containing seven to 10 contaminants at concentrations greater than one-tenth of benchmarks, were from unconfined aquifers (fig. 17). Generally, as the number of contaminants in mixtures increased, the proportion of samples containing organic contaminants also increased, reflecting the greater vulnerability of unconfined aquifers to contaminants from man-made sources (fig 11).

Similarly, mixtures of pesticide compounds and (or) VOCs that were evaluated without regard to the availability of benchmarks or the concentrations relative to benchmarks were frequently detected and complex. One-half of the source-water samples from public wells contained mixtures of two or more pesticide compounds or VOCs, and 27 percent of the samples contained five or more pesticide compounds or VOCs (fig. 18). For mixtures of pesticide compounds and VOCs, the proportion of samples from the more vulnerable unconfined aquifers also increased as the complexity of the mixtures increased. About two-thirds of the samples containing mixtures of two or more pesticide compounds or VOCs were from unconfined aquifers, whereas 90 percent of the samples containing mixtures of 10 or more pesticide compounds or VOCs were from unconfined aquifers (fig. 18).

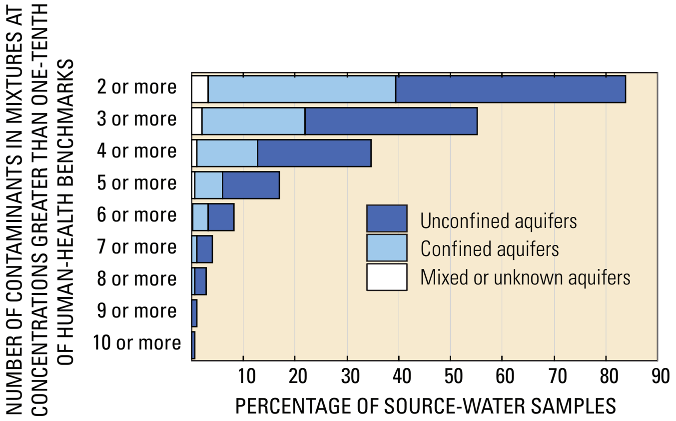


Figure 17. As the complexity of mixtures of contaminants at concentrations greater than one-tenth of individual human-health benchmarks increased, the proportion of samples from more vulnerable unconfined aquifers also increased. Data are from 383 source-water samples from public wells in which major ions, trace elements, nitrate, radon, pesticide compounds, and volatile organic compounds were analyzed. Radon activities were compared to the proposed MCL of 300 picocuries per liter.

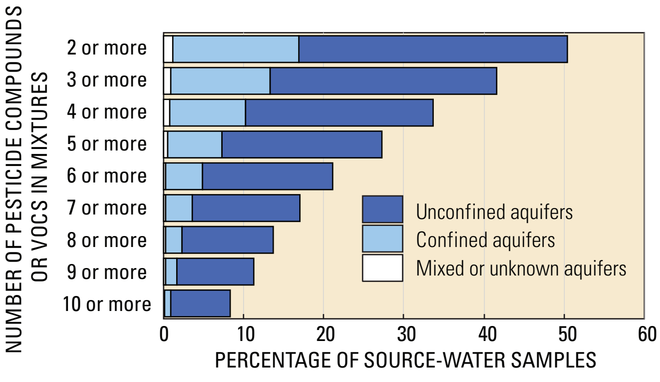


Figure 18. Mixtures of pesticide compounds and volatile organic compounds (VOCs) were detected more often in samples from shallower unconfined aquifers than from deeper confined aquifers. As the complexity of these mixtures increased, the proportion of samples from more vulnerable unconfined aquifers also increased. Data are from 814 source-water samples from public wells in which pesticide compounds and VOCs were analyzed.

More Information for People Served by Public Water Utilities

The best source of specific information about drinking-water quality for people served by public water systems is their water supplier. Water suppliers that serve the same people year-round are required by the U.S. Environmental Protection Agency (USEPA) to provide their customers an annual water-quality report (also called a consumer confidence report, or CCR). CCRs may be obtained directly from water utilities and some are available online at http://www.epa.gov/safewater/ccr/index.html. Each CCR provides consumers with fundamental information about their drinking water, including (1) the source of the water, (2) a brief summary of the susceptibility of the local drinking-water source to contamination, (3) the concentrations of any contaminants detected in local drinking water, as well as their Maximum Contaminant Levels, and (4) resources for additional information. Many other agencies and organizations also provide consumers and homeowners with information about their drinking-water quality, including: USEPA's Safe Drinking Water Hotline (http://www.epa.gov/safewater/hotline), the U.S. Centers for Disease Control and Prevention (ToxFAQs provide summaries about chemical exposure and the effects of exposure on human health at http://www.atsdr.cdc.gov/toxfaqs/index.asp), local and state environmental and public-health agencies, and non-governmental organizations such as the American Water Works Association (http://www.awwa.org or http://www.drinktap.org) and the National Ground Water Association (http://www.ngwa.org).

NAWQA Reports and Data are Readily Available

The U.S. Geological Survey (USGS) promotes public access to scientific information and strives to communicate and disseminate reliable, timely, and relevant information about water resources. USGS Circulars from the National Water-Quality Assessment (NAWQA) Program, along with hundreds of other publications that describe individual study-unit and national-scale assessments, are available on the NAWQA Web site at http://water.usgs.gov/nawqa. The Web site also includes maps and water-quality data. The large NAWQA database on national water-quality conditions at http://water.usgs.gov/nawqa/data can be used for a wide range of analyses at national, regional, state, and local scales.

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Appendix 1. As many as six water-quality properties and 212 chemical contaminants were analyzed in source-water samples from 932 public wells during 1993–2007. Data are from Toccalino and others (2010).

[CAS, Chemical Abstract Service; MCL, Maximum Contaminant Level; HBSL, Health-Based Screening Level; –, not available; N, nitrogen; P, phosphorus; AMCL, Alternative Maximum Contaminant Level. Property or contaminant column: **bold text**, contaminant was detected in at least one source-water sample; ***bold italic text***, property or contaminant was detected in at least 10 percent of source-water samples; unbolded text, contaminant was not detected in any source-water sample]

Property or contaminant	CAS registry number(s) [1]	Number of samples	Availability of MCL or HBSL values [2]
Water-quality properties			
Alkalinity	–	840	–
Dissolved oxygen	–	865	–
pH	–	878	–
Specific conductance	–	896	–
Temperature	–	893	–
Total dissolved solids	–	802	–
Major ions			
Bromide	24959-67-9	787	–
Calcium	7740-70-2	809	–
Chloride	16887-00-6	809	–
Fluoride	16984-48-8	808	MCL
Magnesium	7439-95-4	809	–
Potassium	7440-09-7	810	–
Silica	7631-86-9	809	–
Sodium	7440-23-5	809	–
Sulfate	14808-79-8	810	–
Trace elements			
Aluminum	7429-90-5	598	–
Antimony	7440-36-0	619	MCL
Arsenic	7440-38-2	638	MCL
Barium	7440-39-3	630	MCL
Beryllium	7440-41-7	622	MCL
Boron	7440-42-8	501	HBSL
Cadmium	7440-43-9	631	MCL
Chromium	7440-47-3	626	MCL
Cobalt	7440-48-4	627	–
Copper	7440-50-8	625	MCL
Iron	7439-89-6	809	–
Lead	7439-92-1	630	MCL
Lithium	7439-93-2	458	–
Manganese	7439-96-5	808	HBSL
Molybdenum	7439-98-7	628	HBSL
Trace elements—Continued			
Nickel	7440-02-0	629	HBSL
Selenium	7782-49-2	632	MCL
Silver	7440-22-4	606	HBSL
Strontium	7440-24-6	503	HBSL
Thallium	7440-28-0	437	MCL
Uranium	7440-61-1	650	MCL
Vanadium	7440-62-2	457	–
Zinc	7440-66-6	613	HBSL
Nutrients and dissolved organic carbon			
Ammonia as N	7664-41-7	806	–
Ammonia plus organic nitrogen as N	17778-88-0	603	–
Dissolved organic carbon	–	817	–
Nitrate plus nitrite as N	–	806	MCL
Nitrite as N	14797-65-0	807	MCL
Orthophosphate as P	14265-44-2	804	–
Phosphorus, dissolved as P	7723-14-0	454	–
Total nitrogen as N (nitrate + nitrite + ammonia + organic N)	–	201	–
Radionuclides			
Gross alpha-particle radioactivity	12587-46-1	84	MCL
Gross beta-particle radioactivity	12587-47-2	86	MCL
Radium-226 plus radium-228	13982-63-3, 15262-20-1	191	MCL
Radon-222	14859-67-7	506	Proposed MCL and AMCL
Pesticide compounds			
Acetochlor	34256-82-1	800	HBSL
Acifluorfen	50594-66-6	590	HBSL

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Property or contaminant	CAS registry number(s) [1]	Number of samples	Availability of MCL or HBSL values [2]
Pesticide compounds—Continued			
Alachlor	15972-60-8	869	MCL
Aldicarb	116-06-3	584	HBSL
Aldicarb sulfone	1646-88-4	569	HBSL
Aldicarb sulfoxide	1646-87-3	569	HBSL
Atrazine	1912-24-9	853	MCL
Azinphos-methyl (Guthion)	86-50-0	894	HBSL
Benfluralin	1861-40-1	896	HBSL
Bentazon	25057-89-0	589	HBSL
Bromacil	314-40-9	590	HBSL
Bromoxynil	1689-84-5	590	HBSL
Butylate	2008-41-5	511	HBSL
Carbaryl	63-25-2	898	HBSL
Carbofuran	1563-66-2	644	MCL
Chloramben methyl ester	7286-84-2	580	–
Chlorothalonil	1897-45-6	507	HBSL
Chlorpyrifos	2921-88-2	898	HBSL
Clopyralid	1702-17-6	586	–
Cyanazine	21725-46-2	634	HBSL
2,4-D (2,4-Dichlorophenoxyacetic acid)	94-75-7	590	MCL
Dacthal (DCPA)	1861-32-1	898	HBSL
Dacthal monoacid	887-54-7	590	–
2,4-DB (4-(2,4-Dichlorophenoxy) butyric acid)	94-82-6	580	HBSL
***p,p'*-DDE (1-Chloro-4-[2,2-dichloro-1-(4-chlorophenyl)ethenyl] benzene)**	72-55-9	512	HBSL
Deethylatrazine	6190-65-4	853	–
Diazinon	333-41-5	897	HBSL
Dicamba	1918-00-9	584	HBSL
Dichlobenil	1194-65-6	159	HBSL
Dichlorprop	120-36-5	590	HBSL
Dieldrin	60-57-1	896	HBSL
2,6-Diethylaniline	579-66-8	898	–
Dinoseb	88-85-7	590	MCL
Disulfoton	298-04-4	647	HBSL
Diuron	330-54-1	587	HBSL
DNOC (2-Methyl-4,6-dinitrophenol)	534-52-1	165	–
EPTC (Eptam)	759-94-4	646	HBSL
Ethalfluralin	55283-68-6	512	HBSL
Ethoprop (Ethoprophos)	13194-48-4	647	HBSL
Fenuron	101-42-8	587	–
Fluometuron	2164-17-2	590	HBSL
Fonofos	944-22-9	898	HBSL
***alpha*-HCH (*alpha*-Hexachlorocyclohexane)**	319-84-6	512	HBSL
***gamma*-HCH (Lindane)**	58-89-9	512	MCL
3-Hydroxycarbofuran	16655-82-6	580	–
Linuron	330-55-2	512	HBSL
Malathion	121-75-5	898	HBSL
MCPA (4-Chloro-2-methylphenoxy acetic acid)	94-74-6	582	HBSL
MCPB (4-(2-Methyl-4-chlorophenoxy)butyric acid)	94-81-5	590	HBSL
Methiocarb	2032-65-7	579	HBSL
Methomyl	16752-77-5	569	HBSL
Metolachlor	51218-45-2	870	HBSL
Metribuzin	21087-64-9	898	HBSL
Molinate	2212-67-1	635	HBSL
Napropamide	15299-99-7	511	HBSL
Neburon	555-37-3	584	–
Norflurazon	27314-13-2	585	HBSL
Oryzalin	19044-88-3	582	HBSL

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[CAS, Chemical Abstract Service; MCL, Maximum Contaminant Level; HBSL, Health-Based Screening Level; –, not available; N, nitrogen; P, phosphorus; AMCL, Alternative Maximum Contaminant Level. Property or contaminant column: **bold text**, contaminant was detected in at least one source-water sample; ***bold italic text***, property or contaminant was detected in at least 10 percent of source-water samples; unbolded text, contaminant was not detected in any source-water sample]

Property or contaminant	CAS registry number(s) [1]	Number of samples	Availability of MCL or HBSL values [2]
Pesticide compounds—Continued			
Oxamyl	23135-22-0	569	MCL
Parathion (Ethyl parathion)	56-38-2	512	HBSL
Parathion-methyl (Methyl parathion)	298-00-0	889	HBSL
Pebulate	1114-71-2	512	HBSL
Pendimethalin	40487-42-1	898	HBSL
cis-Permethrin	54774-45-7	898	HBSL
Phorate	298-02-2	898	HBSL
Picloram	1918-02-1	585	MCL
Prometon	1610-18-0	885	HBSL
Pronamide (Propyzamide)	23950-58-5	898	HBSL
Propachlor	1918-16-7	512	HBSL
Propanil	709-98-8	647	HBSL
Propargite	2312-35-8	644	HBSL
Propham	122-42-9	589	HBSL
Propoxur (Baygon)	114-26-1	586	HBSL
Simazine	122-34-9	884	MCL
2,4,5-T (2-(2,4,5-Trichlorophenoxy)acetic acid)	93-76-5	165	HBSL
Tebuthiuron	34014-18-1	859	HBSL
Terbacil	5902-51-2	508	HBSL
Terbufos	13071-79-9	898	HBSL
Thiobencarb	28249-77-6	647	HBSL
2,4,5-TP (Silvex)	93-72-1	165	MCL
Triallate	2303-17-5	512	HBSL
Triclopyr	55335-06-3	590	HBSL
Trifluralin	1582-09-8	898	HBSL
Volatile organic compounds			
Acetone	67-64-1	771	HBSL
Acrylonitrile	107-13-1	771	HBSL
tert-Amyl methyl ether (Methyl _tert_-pentyl ether)	994-05-8	771	–
Benzene	71-43-2	831	MCL
Bromobenzene	108-86-1	832	–
Bromochloromethane	74-97-5	832	HBSL
Bromodichloromethane	75-27-4	831	MCL
Volatile organic compounds—Continued			
Bromoform (Tribromomethane)	75-25-2	832	MCL
Bromomethane (Methyl bromide)	74-83-9	832	HBSL
_n_-Butylbenzene	104-51-8	831	–
sec-Butylbenzene	135-98-8	831	–
tert-Butylbenzene	98-06-6	832	–
Carbon disulfide	75-15-0	765	HBSL
Carbon tetrachloride (Tetrachloromethane)	56-23-5	832	MCL
Chlorobenzene (Monochlorobenzene)	108-90-7	832	MCL
Chloroethane	75-00-3	830	–
Chloroform (Trichloromethane)	67-66-3	831	MCL
Chloromethane (Methyl chloride)	74-87-3	806	HBSL
3-Chloropropene	107-05-1	771	–
2-Chlorotoluene (*o*-) (1-Chloro-2-methylbenzene)	95-49-8	832	HBSL
4-Chlorotoluene (*p*-)	106-43-4	832	HBSL
Dibromochloromethane	124-48-1	832	MCL
Dibromochloropropane (DBCP)	96-12-8	832	MCL
Dibromomethane	74-95-3	832	–
1,2-Dichlorobenzene (_o_-)	95-50-1	831	MCL
1,3-Dichlorobenzene (_m_-)	541-73-1	832	HBSL
1,4-Dichlorobenzene (_p_-)	106-46-7	831	MCL
trans-1,4-Dichloro-2-butene	110-57-6	771	–
Dichlorodifluoromethane	75-71-8	832	HBSL
1,1-Dichloroethane	75-34-3	832	–
1,2-Dichloroethane	107-06-2	825	MCL
1,1-Dichloroethene	75-35-4	832	MCL
cis-1,2-Dichloroethene	156-59-2	832	MCL
trans-1,2-Dichloroethene	156-60-5	832	MCL
1,2-Dichloropropane	78-87-5	830	MCL
1,3-Dichloropropane	142-28-9	832	–
2,2-Dichloropropane	594-20-7	832	–

Appendix 1. As many as six water-quality properties and 212 chemical contaminants were analyzed in source-water samples from 932 public wells during 1993–2007. Data are from Toccalino and others (2010).—Continued

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Property or contaminant	CAS registry number(s) [1]	Number of samples	Availability of MCL or HBSL values [2]
Volatile organic compounds—Continued			
1,1-Dichloropropene	563-58-6	832	–
cis-1,3-Dichloropropene	10061-01-5	832	HBSL
trans-1,3-Dichloropropene	10061-02-6	832	HBSL
Diethyl ether (Ethyl ether)	60-29-7	771	HBSL
Diisopropyl ether	108-20-3	758	–
Ethyl methacrylate	97-63-2	771	–
Ethyl *tert*-butyl ether (*tert*-Butyl ethyl ether)	637-92-3	771	–
Ethylbenzene	100-41-4	830	MCL
Ethylene dibromide (1,2-Dibromoethane)	106-93-4	832	MCL
2-Ethyltoluene (1-Ethyl-2-methylbenzene)	611-14-3	770	–
Hexachlorobutadiene	87-68-3	831	HBSL
Hexachloroethane	67-72-1	771	HBSL
Iodomethane (Methyl iodide)	74-88-4	771	–
Isopropylbenzene	98-82-8	830	HBSL
***n*-Isopropyltoluene (1-Methyl-4-isopropylbenzene)**	99-87-6	831	–
Methyl acrylate	96-33-3	771	–
Methyl acrylonitrile (Methacrylonitrile)	126-98-7	771	HBSL
Methyl butyl ketone (2-Hexanone)	591-78-6	771	–
Methyl ethyl ketone (Ethyl methyl ketone)	78-93-3	769	HBSL
Methyl isobutyl ketone (4-Methyl-2-pentanone)	108-10-1	769	–
Methyl methacrylate	80-62-6	771	HBSL
Methyl tert-butyl ether	1634-04-4	832	–
Methylene chloride (Dichloromethane)	75-09-2	832	MCL
Volatile organic compounds—Continued			
Naphthalene	91-20-3	831	HBSL
Perchloroethene (Tetrachloroethene)	127-18-4	829	MCL
***n*-Propylbenzene**	103-65-1	831	–
Styrene	100-42-5	829	MCL
1,1,1.2-Tetrachloroethane	630-20-6	832	HBSL
1,1,2,2-Tetrachloroethane	79-34-5	832	HBSL
Tetrahydrofuran	109-99-9	771	–
1,2,3,4-Tetramethylbenzene	488-23-3	770	–
1,2,3,5-Tetramethylbenzene	527-53-7	770	–
Toluene	108-88-3	818	MCL
1,2,3-Trichlorobenzene	87-61-6	832	–
1,2,4-Trichlorobenzene	120-82-1	831	MCL
1,1,1-Trichloroethane	71-55-6	832	MCL
1,1,2-Trichloroethane	79-00-5	829	MCL
Trichloroethene	79-01-6	832	MCL
Trichlorofluoromethane	75-69-4	832	HBSL
1,2,3-Trichloropropane	96-18-4	832	HBSL
Trichlorotrifluoroethane (1,1,2-Trichloro-1,2,2-trifluoroethane)	76-13-1	832	HBSL
1,2,3-Trimethylbenzene	526-73-8	770	–
1,2,4-Trimethylbenzene	95-63-6	828	–
1,3,5-Trimethylbenzene	108-67-8	831	–
Vinyl bromide (Bromoethene)	593-60-2	771	–
Vinyl chloride (Chloroethene)	75-01-4	832	MCL
***o*-Xylene**	95-47-6	769	MCL
***m*- and *p*- Xylenes**	108-38-3, 106-42-3	769	MCL

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[1] This study contains CAS Registry Numbers®, which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client Services$^{\text{SM}}$.

[2] MCL or HBSL values were current as of September 2009. MCL values were obtained from U.S. Environmental Protection Agency (2006a) and HBSL values were obtained from the HBSL website (Toccalino and others, 2008). See Toccalino and others (2010) for additional information about these benchmarks.

Appendix 2. As many as 125 additional organic contaminants were analyzed in source-water samples from a subset of 221 public wells during 2002–2005. Data are from Hopple and others (2009).

[CAS, Chemical Abstract Service; MCL, Maximum Contaminant Level; HBSL, Health-Based Screening Level; –, not available. Contaminant column: **bold text**, contaminant was detected in at least one source-water sample; ***bold italic text***, contaminant was detected in at least 10 percent of source-water samples; unbolded text, contaminant was not detected in any source-water sample]

Contaminant	CAS registry number[1]	Number of samples	Availability of MCL or HBSL values [2]
Personal-care and domestic-use products			
Acetophenone	98-86-2	187	HBSL
Acetyl hexamethyl tetrahydronaphthalene (AHTN)	21145-77-7	217	–
3-*tert*-Butyl-4-hydroxy anisole (BHA)	25013-16-5	217	–
Caffeine	58-08-2	168	–
Camphor	76-22-2	217	–
Cotinine	486-56-6	118	–
4-Cumylphenol	599-64-4	217	–
Hexahydrohexamethylcyclopentabenzopyran (HHCB)	1222-05-5	217	–
Indole	120-72-9	217	–
Isoborneol	124-76-5	217	–
Isoquinoline	119-65-3	217	–
d-Limonene	5989-27-5	217	–
Menthol	89-78-1	203	–
Methyl salicylate	119-36-8	217	HBSL
Nonylphenol, diethoxy- (total)	26027-38-2	217	–
4-*n*-Octylphenol	1806-26-4	217	–
4-*tert*-Octylphenol	140-66-9	217	–
Octylphenol, diethoxy-	–	217	–
Octylphenol, monoethoxy-	–	217	–
Triclosan	3380-34-5	217	–
Triethyl citrate (ethyl citrate)	77-93-0	217	–
Other pesticide compounds			
Azinphos-methyl-oxon	961-22-8	221	–
Bendiocarb	22781-23-3	215	HBSL
Benomyl	17804-35-2	215	HBSL
Bensulfuron-methyl	83055-99-6	215	HBSL
Other pesticide compounds—Continued			
Chlorimuron-ethyl	90982-32-4	215	HBSL
2-Chloro-2,6-diethylacetanilide	6967-29-9	221	–
4-Chloro-2-methylphenol	1570-64-5	221	–
3(4-Chlorophenyl)-1-methyl urea	5352-88-5	215	–
Chlorpyrofos, oxygen analog	5598-15-2	221	–
Cycloate	1134-23-2	215	HBSL
Cyfluthrin	68359-37-5	221	HBSL
Cypermethrin	52315-07-8	221	HBSL
2,4-D methyl ester	1928-38-7	215	–
Deethyldeisopropyl atrazine	3397-62-4	213	–
Deisopropylatrazine	1007-28-9	215	–
Desulfinylfipronil	–	221	–
Desulfinylfipronil amide	–	221	–
Diazinon, oxygen analog	962-58-3	221	–
3,4-Dichloroaniline	95-76-1	221	–
Dichlorvos	62-73-7	221	HBSL
Dicrotophos	141-66-2	221	HBSL
Dimethoate	60-51-5	221	HBSL
Diphenamid	957-51-7	215	HBSL
Ethion	563-12-2	221	HBSL
Ethion monoxon	17356-42-2	221	–
2-Ethyl-6-methylaniline	24549-06-2	221	–
Fenamiphos	22224-92-6	221	HBSL
Fenamiphos sulfone	31972-44-8	221	–
Fenamiphos sulfoxide	31972-43-7	200	–
Fipronil	120068-37-3	221	–
Fipronil sulfide	120067-83-6	221	–
Fipronil sulfone	120068-36-2	221	–
Flumetsulam	98967-40-9	215	HBSL

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Contaminant	CAS registry number[1]	Number of samples	Availability of MCL or HBSL values[2]
Other pesticide compounds—Continued			
Fonofos, oxygen analog	944-21-8	206	–
Hexazinone	51235-04-2	113	HBSL
2-Hydroxy atrazine	2163-68-0	215	HBSL
Imazaquin	81335-37-7	215	HBSL
Imazethapyr	81335-77-5	215	HBSL
Imidacloprid	138261-41-3	215	HBSL
Iprodione	36734-19-7	221	HBSL
Isofenphos	25311-71-1	221	HBSL
3-Ketocarbofuran	16709-30-1	213	–
Malaoxon	1634-78-2	221	–
Metalaxyl	57837-19-1	221	HBSL
Methidathion	950-37-8	221	HBSL
Metsulfuron methyl	74223-64-6	214	HBSL
Myclobutanil	88671-89-0	221	HBSL
1-Naphthol	90-15-3	221	–
Nicosulfuron	111991-09-4	215	HBSL
Paraoxon-methyl	950-35-6	221	–
Pentachlorophenol	87-86-5	211	MCL
Phorate oxon	2600-69-3	221	–
Phosmet	732-11-6	211	HBSL
Phosmet oxon	3735-33-9	201	–
Prometryn	7287-19-6	221	HBSL
Propiconazole	60207-90-1	215	HBSL
Siduron	1982-49-6	215	HBSL
Sulfometuron-methyl	74222-97-2	215	HBSL
Terbufos-O-analogue sulfone	56070-15-6	221	–
Terbuthylazine	5915-41-3	221	HBSL
Other herbicide and herbicide degradates			
Acetochlor ethane sulfonic acid	187022-11-3	73	–
Acetochlor oxanilic acid	184992-44-4	73	–
Other herbicide and herbicide degradates—Continued			
Acetochlor sulfynilacetic acid	–	73	–
Acetochlor/Metolachlor 2nd Amide ESA	–	43	–
Alachlor ESA 2nd amide	–	43	–
Alachlor ethane sulfonic acid	142363-53-9	58	–
Alachlor oxanilic acid	171262-17-2	73	–
Alachlor sulfynilacetic acid	140939-16-8	73	–
Dimethenamid	87674-68-8	43	–
Dimethenamid ethane sulfonic acid	205939-58-8	73	–
Dimethenamid oxanilic acid	–	73	–
Flufenacet	142459-58-3	43	–
Flufenacet ethane sulfonic acid	–	73	–
Flufenacet oxanilic acid	–	73	–
Metolachlor ethane sulfonic acid	171118-09-5	73	–
Metolachlor oxanilic acid	152019-73-3	73	–
Propachlor ethane sulfonic acid	–	73	–
Propachlor oxanilic acid	–	73	–
Other volatile organic compounds			
Anthraquinone	84-65-1	217	–
tert-Butyl alcohol	75-65-0	119	–
Carbazole	86-74-8	217	–
***p*-Cresol**	106-44-5	217	–
2,6-Dimethylnaphthalene	581-42-0	217	–
Methyl acetate	79-20-9	119	–
2-Methyl-2-butanol	75-85-4	119	–
1-Methylnaphthalene	90-12-0	217	–
2-Methylnaphthalene	91-57-6	217	HBSL

Appendix 2. As many as 125 additional organic contaminants were analyzed in source-water samples from a subset of 221 public wells during 2002–2005. Data are from Hopple and others (2009).—Continued

[CAS, Chemical Abstract Service; MCL, Maximum Contaminant Level; HBSL, Health-Based Screening Level; –, not available. Contaminant column: **bold text**, contaminant was detected in at least one source-water sample; ***bold italic text***, contaminant was detected in at least 10 percent of source-water samples; unbolded text, contaminant was not detected in any source-water sample]

Contaminant	CAS registry number[1]	Number of samples	Availability of MCL or HBSL values [2]
Manufacturing additives, pavement- and combustion-derived compounds, plant- or animal-derived biochemicals			
Anthracene	120-12-7	217	HBSL
Benzo[a]pyrene	50-32-8	217	MCL
Bisphenol A	80-05-7	212	HBSL
Cholesterol	57-88-5	217	–
3-*beta*-Coprostanol	360-68-9	217	–
Fluoranthene	206-44-0	217	HBSL
5-Methyl-1H-benzotriazole	136-85-6	215	–
3-Methyl-1(H)-indole (Skatole)	83-34-1	217	–
Phenanthrene	85-01-8	217	–
Manufacturing additives, pavement- and combustion-derived compounds, plant- or animal-derived biochemicals—Continued			
Pyrene	129-00-0	216	HBSL
***beta*-Sitosterol**	83-46-5	217	–
***beta*-Stigmastanol**	19466-47-8	217	–
Tri(2-butoxyethyl)phosphate	78-51-3	203	–
Tri(2-chloroethyl)phosphate	115-96-8	217	–
Tributyl phosphate	126-73-8	217	–
Triphenyl phosphate	115-86-6	202	–
Tris(dichlorisopropyl) phosphate	13674-87-8	217	–

[1] This study contains CAS Registry Numbers®, which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client Services℠.

[2] MCL or HBSL values were current as of September 2009. MCL values were obtained from U.S. Environmental Protection Agency (2006a) and HBSL values were obtained from the HBSL website (Toccalino and others, 2008). See Hopple and others (2009) for additional information about these benchmarks.

Abbreviations, Acronyms, and Units of Measure

CCL	Contaminant Candidate List
CCR	consumer confidence report
DBP	disinfection by-product
DWLOC	Drinking Water Level of Comparison
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
HBSL	Health-Based Screening Level
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
MTBE	methyl *tert*-butyl ether
NAWQA	National Water-Quality Assessment Program (USGS)
PCE	perchloroethene
pCi/L	picocuries per liter
SDWA	Safe Drinking Water Act
TCE	trichloroethene
TCT	total chlorotriazines
µg/L	micrograms per liter
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	volatile organic compound

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For more information concerning the research in this report, contact:
Chief, National Water-Quality Assessment Program
U.S. Geological Survey
413 National Center
12201 Sunrise Valley Drive
Reston, VA 20192

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