Quality of Ground Water from Private Domestic Wells

Find out details about the recently released USGS report on ground water wells.

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This article highlights major findings from two USGS reports: DeSimone (2009) and DeSimone and others (2009). These reports can be accessed at http://water.usgs.gov/nawqa. This article is followed by a summary of treatment considerations and options for owners of private domestic wells, written by Cliff Treyens of the National Ground Water Association.

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey sampled ground water from about 2100 private domestic wells across the United States from 1991 to 2004. The sampled wells were located in 48 states and in 30 of the nation's 62 principal aquifers used for water supply (Figure 1).

Domestic wells are an important water supply to characterize because more than 43 million people—about 15% of the nation's population—rely on these wells for drinking water. The quality and safety of water from domestic wells are not regulated by the Safe Drinking Water Act or, in many cases, by state laws. Rather, individual homeowners are responsible for maintaining their domestic well systems and for any routine monitoring.

In this study, samples were collected from wells prior to most in-home plumbing or treatment and thus do not necessarily represent water from the tap. As many as 219 properties (such as pH) and major ions, nutrients, radionuclides, trace elements, pesticides, volatile organic compounds, and microbial contaminants were measured.

Measured properties and constituents are referred to in this article and in the USGS study as "contaminants," regardless of the measured concentration or potential for adverse health effects. This terminology follows the definitions of the Safe Drinking Water Act, which states that a contaminant is "any physical, chemical, biological, or radiological substance or matter in water." However, the presence of a contaminant in water does not necessarily mean that there is a health concern.

Contaminant concentrations are placed in a human-health context through comparisons to human-health benchmarks, including the U.S. Environmental Protection Agency's maximum contaminant levels (MCLs) for contaminants regulated in drinking water (which includes proposed MCLs for radon), and USGS health-based screening levels (HBSLs) for unregulated contaminants.

The EPA MCLs and most state standards are enforceable regulations for public water systems, but are not used to regulate contaminant concentrations in domestic wells. HBSLs are nonenforceable guidelines for unregulated contaminants developed by the USGS in

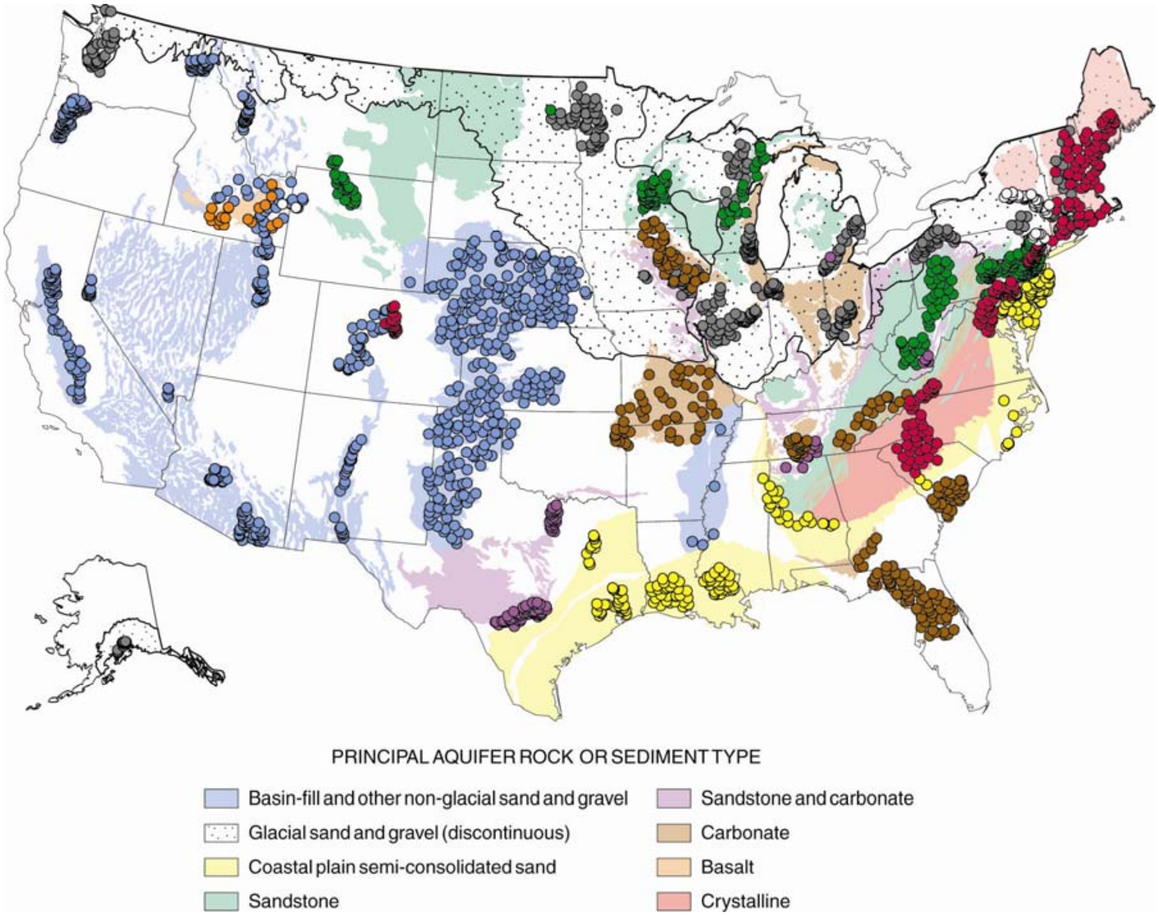

Figure 1. Domestic wells sampled in this study are located in 48 states and parts of 30 of the 62 principal aquifers of the United States. Domestic wells are categorized by principal aquifer rock type: *blue*—basin-fill and other non-glacial sand and gravel aquifers; *grey*—glacial aquifers; *yellow*—coastal plain aquifers; *green*—sandstone aquifers; *purple*—sandstone and carbonate aquifers; *brown*—carbonate aquifers; *orange*—basalt aquifers; *red*—crystalline-rock aquifers.

collaboration with the EPA and others, using EPA methods and the most current EPA peer-reviewed, publicly available health-risk assessments and toxicity information. Because HBSLs are calculated using EPA toxicity information and methods, HBSLs are equivalent to existing EPA lifetime health advisory and cancer risk concentrations (when they exist), except for unregulated contaminants for which more recent toxicity information has become available.

Comparisons of measured concentrations to MCLs and HBSLs serve as a "screening-level assessment" that provides an initial perspective on the potential significance of contaminant occurrences to human health and on priorities for future monitoring and research. Such assessments are not designed to evaluate specific effects of contaminants on human health, nor are they a substitute for comprehensive risk assessment that generally includes multiple exposure pathways and many additional factors.

Recent advances in laboratory analytical methods have given USGS scientists the tools to detect a variety of contaminants at low concentrations, often 100 to 1000 times lower than drinking water standards and other human-health benchmarks. Low-level detections do not necessarily indicate a concern for human health, but rather help identify the environmental presence of contaminants (some of which may not be commonly monitored) and help track changes in contaminant occurrence and concentrations over time.

Results of this study generally are consistent with previous studies of domestic wells but also more fully characterize a comprehensive suite of individual contaminants and contaminant mixtures than previously reported. This study also describes contaminant occurrence for regional aquifers, providing a framework for understanding water-quality conditions within units of similar hydrogeology—although contaminant occurrence can vary over short distances and with depth within these aquifers because of variability in contaminant sources, aquifer characteristics, and geochemical conditions.

Selected portions of the principal aquifers were included in the study design, which focused on NAWQA ground water assessment areas that were sampled during 1991-2004, and the findings are not statistically representative of all domestic wells across the U.S.

Major Findings

More than one in five of sampled domestic wells contained one or more contaminants at a concentration greater than an EPA MCL or other human-health benchmark.

Benchmarks used are EPA MCLs for contaminants regulated in public water systems and USGS HBSLs for unregulated contaminants. Although no individual contaminant exceeded a human-health benchmark in more than 7% of sampled wells, 23% of wells contained one or more different contaminant greater than either an MCL or HBSL. Of the sampled wells, 13% had one or more different contaminant greater than an MCL.

Contaminants most frequently found at concentrations greater than human-health benchmarks were inorganic chemicals, mostly derived from natural sources.

These included radon, arsenic and several other trace elements, nitrate, and fluoride (Table 1). Each of these contaminants was individually greater than its benchmark in about 1% to 7% of sampled wells (using the higher of two proposed MCLs for radon—4000 picocuries per liter, pCi/L).

Except for nitrate, these contaminants originate in ground water primarily from geologic sources. Marked regional patterns among principal aquifers were noted in the occurrence of many naturally occurring contaminants. Radon, for example, was found at relatively high concentrations in crystalline-rock aquifers in the Northeast, in the central and southern Appalachians, and in central Colorado. The occurrence of radon in ground water is controlled in large part by the presence of uranium-bearing rocks.

Nitrate was the most common contaminant derived from man-made sources that was found at concentrations greater than human-health benchmarks.

Nitrate was measured at concentrations greater than the EPA MCL of 10 milligrams per liter as nitrogen in about 4% of sampled wells. Nitrate occurs naturally in ground water, but elevated concentrations usually originate from man-made sources such as fertilizer and septic system effluent. A separate analysis of 436 additional domestic wells in areas of relatively intense agriculture showed that nitrate concentrations were greater than the MCL in nearly 25% of the wells.

Table 1. Eight inorganic contaminants were found at concentrations greater than human-health benchmarks in 1% or more of domestic wells sampled in this study. Except for nitrate, these contaminants are derived primarily from natural sources.

[**Human-health benchmarks**: MCLs are U.S. Environmental Protection Agency Maximum Contaminant Levels for public water supplies and HBSLs are U.S. Geological Survey health-based screening levels. **Sources of contaminant in drinking water**: modified from U.S. Environmental Protection Agency (2008)[1] and from references cited in DeSimone and others (2009). pCi/L, picocurie per liter; ug/L, microgram per liter; mg/L, milligram per liter.]

Contami-nant	Human-health benchmark		Sources of contaminant in drinking water	Number of wells sampled	Frequency of concentrations greater than benchmark (percent of wells)	Principal aquifers with concentrations most frequently greater than human-health benchmarks
	Value	Type				
Arsenic	10 ug/L	MCL	Aquifer materials; pesticide application	1774	6.8%	Crystalline-rock aquifers in New England; basin-fill aquifers in the western and south-central U.S., and basaltic-rock aquifer in Idaho (more than 10% of wells > 10 ug/L).
Boron	1,000 ug/L	HBSL	Aquifer materials; sewage or septic-system effluent; fertilizer application; some industrial wastes	535	1.3%	Some basin-fill and sandstone aquifers in the western and south-central U.S.
Fluoride	4 mg/L	MCL	Water additive which promotes strong teeth; aquifer materials; discharge from fertilizer and aluminum factories	2157	1.2%	Some basin-fill and sandstone aquifers in the western and south-central U.S. (about 4% of wells > 4 mg/L).
Manganese	300 ug/L	HBSL	Aquifer materials; some industrial wastes	2159	5.2%	Glacial aquifers; some sandstone aquifers in central Appalachian region; some coastal plain aquifers in Southeast (about 8% to 60% of wells > 300 ug/L). In all aquifers, in wells with low dissolved oxygen.
Nitrate	10 mg/L as N	MCL	Fertilizer use; manure; sewage and septic-system effluent; aquifer materials	2132	4.4%	Some basin-fill aquifers in the Southwest and California; glacial aquifers in the upper Midwest; some coastal-plain and crystalline-rock aquifers in the central Appalachian region (more than 10% of wells > 10 mg/L as N). Generally, in areas of agricultural land use.
Radon	4,000 pCi/L 300 pCi/L	Proposed MCLs[2]	Radioactive decay of uranium in aquifer materials	1958	4.4% 65%	Crystalline rock aquifers in the Northeast, central and southern Appalachians, and central Colorado (about 30% of wells > 4,000 pCi/L).
Strontium	4,000 ug/L	HBSL	Aquifer materials	488	7.3%	Some basin-fill and sandstone/carbonate-rock aquifers in the Southwest and south-central U.S.
Uranium	30 ug/L	MCL	Aquifer materials	1725	1.7%	Basin-fill aquifers in the West; crystalline-rock aquifers in the Rocky Mountains and in the Northeast (about 3% to 26% of wells > 30 ug/L).

[1] U.S. Environmental Protection Agency, 2008, Drinking water contaminants: accessed November 25, 2008 at *www.epa.gov/safewater/contaminants/index.html*.

[2] U.S. Environmental Protection Agency, 1999, Proposed radon in drinking water rule: Washington, DC, U.S. Environmental Protection Agency, Office of Water, EPA 815-F-99-006, 6 p., accessed October 26, 2005 at *www.epa.gov/safewater/radon/proposal.html*

Few man-made organic contaminants exceeded human-health benchmarks. Only seven of 168 organic compounds analyzed—two insecticides, one herbicide, two solvents, and two fumigants— were found at concentrations greater than human-health benchmarks, each in less than 0.5% of the sampled wells. Diverse organic compounds (including herbicides, insecticides, solvents, disinfection byproducts, gasoline hydrocarbons and oxygenates, refrigerants, and fumigants) were detected in 60% of the sampled wells at lower concentrations. This indicates that a variety of contaminant sources (including agricultural, domestic, and industrial) can affect the quality of water from domestic wells.

About half of the sampled wells had at least one property or contaminant at a level outside the range of values recommended by the EPA for non-health-related, cosmetic, or aesthetic purposes.

Levels of pH and concentrations of dissolved solids, iron, and manganese were compared to EPA secondary maximum contaminant levels (SMCLs), which are non-enforceable guidelines regarding aesthetic quality or other nonhealth effects, and were outside SMCL ranges in 15% to 21% of wells. Fluoride concentrations were greater than the fluoride SMCL in 4% of wells.

Regional patterns were apparent. For example, low pH values occurred in wells that tap crystalline-rock and coastal-plain sand aquifers, mostly in the East, that have relatively little capacity to neutralize acids. High dissolved solids were found in basin-fill, sandstone/carbonate, and sandstone aquifers underlying parts of the western and south-central United States, which can result from easily weathered rocks and sediments, dry climate, and heavy irrigation.

Microbial contaminants were detected in as many as one-third of sampled wells.

Total coliform bacteria, a broad group of bacteria from soil, water, and animal feces, were detected in about 34% of sampled wells. *Escherichia coli* was detected in about 8% of sampled wells. *E. coli* is typically not harmful itself, but is an indicator of fecal contamination and, therefore, the possible presence of pathogens. The approximately 400 wells sampled for microbial contaminants were a subset of the 2100 study wells and were clustered in a few geographic areas.

Contaminants usually co-occurred with other contaminants as mixtures.

Of the sampled wells, 4% contained mixtures of two or more contaminants at individual concentrations greater than health benchmarks (using the higher of two proposed MCLs for radon—4000 pCi/L). Nearly 75% of sampled wells contained mixtures of two or more contaminants with concentrations greater than one-tenth of their individual benchmarks. Concentrations greater than one-tenth of benchmarks were used to identify contaminants that were approaching levels of potential health concern. The most common mixtures of contaminants at these levels were composed of frequently detected inorganic contaminants including nitrate, arsenic, radon, and uranium. Nitrate and (or) radon at concentrations greater than one-tenth of their benchmarks co-occurred with the organic compounds atrazine, deethylatrazine, or chloroform in 10% to 15% of sampled wells. The combination of nitrate and atrazine may have greater potential for health effects than either contaminant alone, but there are no health benchmarks for this mixture.

Implications and Future Needs

Overall, more than one in five domestic wells had one or more contaminants at a concentration greater than a human-health benchmark, which suggests a substantial potential for adverse effects on human health. However, findings show that the potential for effects is not evenly distributed across the nation. Many contaminants in domestic wells follow distinct geographic patterns related to geology, geochemical conditions, land use, or other influences. The greatest potential for successfully addressing water-quality concerns for domestic wells is with targeted approaches in specific areas where concentrations are highest in relation to human-health benchmarks, and high proportions of the population depend on domestic wells. Notably, traditional wellhead protection approaches to preventing contamination generally are not effective for contaminants that occur naturally in an aquifer.

Findings from this study underscore the continuing need to improve assessment and scientific understanding of the water quality of domestic wells. Several specific needs are highlighted as follows.

- Improved information is needed on the number of people consuming water from domestic wells in specific regions and aquifers, and on water quality conditions in the particular aquifer zones that are tapped by wells. Such information is essential for evaluating the potential human health implications and possible mitigation approaches.

- Continued public education and testing of domestic wells are needed because homeowners are not required to monitor private wells and may not be aware of contaminants in their source of drinking water. In particular, homeowners may not be aware that many contaminants known to be of concern are primarily from natural sources in some areas, or that contaminants from man-made sources may be present in ground water from current or previous land uses or activities.

- Continued water-quality assessment and research are needed to more fully understand natural and man-made factors and transport mechanisms associated with the movement of contaminants to domestic wells. This is particularly important because of the complex and often localized nature of ground water flow and quality.

- Finally, refined information on the water quality of domestic wells, as with other drinking water sources, will need to be integrated with more comprehensive risk assessment to place the potential concerns about specific contaminants and mixtures of contaminants in a broader human-health context. The total combined toxicity of contaminant mixtures can be greater than that of any single contaminant. Continued research is needed because most human-health benchmarks are based on toxicity data for individual compounds and the potential for additive or synergistic effects of mixtures of contaminants at low levels is not well understood.

This article is based on technical findings presented in USGS Scientific Investigations Report 2008-5227 "Quality of Water from Domestic Wells in Principal Aquifers of the United States, 1991-2004" and in a companion USGS report, Circular 1332. These reports, along with data and downloadable graphics, can be obtained online at http://water.usgs.gov/nawqa. Questions regarding the reports should be directed to Leslie DeSimone in the USGS Massachusetts–Rhode Island Water Science Center at (508) 490-5023 or ldesimon@usgs.gov.