The Chemical Quality of Self-Supplied Domestic Well Water in the United States

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Abstract

Existing water quality data collected from domestic wells were summarized to develop the first national-scale retrospective of self-supplied drinking water sources. The contaminants evaluated represent a range of inorganic and organic compounds, and although the data set was not originally designed to be a statistical representation of national occurrence, it encompasses large parts of the United States including at least some wells sampled in every state and Puerto Rico. Inorganic contaminants were detected in many of the wells, and concentrations exceeded the U.S. EPA maximum contaminant levels (MCLs; federal drinking water standards used to regulate public drinking water quality) more often than organic contaminants. Of the inorganic constituents evaluated, arsenic concentrations exceeded the MCL (10 µg/L) in ~11% of the 7580 wells evaluated, nitrate exceeded the MCL (10 mg/L) in ~8% of the 3465 wells evaluated, uranium-238 exceeded the MCL (30 µg/L) in ~4% of the wells, and radon-222 exceeded 300 and 4000 pCi/L (potential drinking water standards currently under review by the U.S. EPA) in ~75% and 9% of the wells, respectively. The MCLs for total mercury and fluoride were each exceeded in <1% of the wells evaluated. The MCL was exceeded in <1% of all wells for all anthropogenically derived organic contaminants evaluated and was not exceeded for many contaminants. In addition, 10 contaminants evaluated do not currently have an MCL. Atrazine, however, was detected in 24% of the wells evaluated and was the most frequently detected organic contaminant of the 28 organic contaminants evaluated in this study. Simazine and metolachlor each were detected in ~9% of all wells and tied for second in frequency of detection for organic contaminants. The third and fourth most frequently detected organic contaminants were methyl *tert*-butyl ether (MTBE) (6%) and chloroform (5%), respectively. Because the water quality of domestic wells is not federally regulated or nationally monitored, this study provides a unique, previously nonexistent, perspective on the quality of the self-supplied drinking water resources used by ~45 million Americans in the United States.

Introduction

Approximately 225 million Americans drink water that has been delivered to their homes by public water purveyors (Hutson et al. 2003). The quality of public drinking water is regulated and monitored under various provisions of the Safe Drinking Water Act (the main federal law that ensures the quality of public drinking water in the United States). However, ~45 million other Americans use household (hereafter called "domestic") wells to supply their own drinking water (Hutson et al. 2003), which is not regulated or monitored on a national basis.

Between 1995 and 2000, the self-supplied domestic population remained at 16% of the total population of the United States; however, self-supplied domestic withdrawals increased ~10% and the self-supplied domestic population increased almost 7% (Hutson et al. 2003). More than

90,000 new domestic wells are installed each year across the United States (Centers for Disease Control and Prevention [CDC] 1998). Although the water quality and safety of public supplies of drinking water are the responsibilities of local, regional, and federal government agencies and public water purveyors, the water quality and safety of self-supplied drinking water is largely the responsibility of individual homeowners.

Most self-supplied water is not monitored or tested for the range of potential water contaminants that are routinely monitored in public water systems nationwide, and therefore, scientists, public health, and other officials do not have nationally consistent data and information about the quality of water being consumed by tens of millions of Americans. The few exceptions include bacteriological and nitrate tests that are commonly required by local health ordinances in order to sell or purchase a new home and some limited local or statewide monitoring programs (Job 2002). For example, New Jersey (through the Private Well Testing Act) requires statewide private well testing for

a range of potential contaminants, but the testing is limited to regulations associated with the sale of a house (New Jersey Department of Environmental Protection 2004). As a result, most Americans deriving their drinking water from domestic wells have little or no nationally consistent information on the quality of their drinking water.

Assessments of ambient ground water quality are more common than those focused on domestic wells alone, and typically include many different types of wells such as public supply wells, monitoring wells, and domestic wells. For example, the USGS National Water Quality Assessment (NAWQA) Program's objective to assess the ambient ground water quality of the United States typically includes a subset of domestic wells as part of individual study unit sampling designs (Gilliom et al. 2001). National-scale monitoring efforts specifically designed to assess the potential range of different contaminant groups in water withdrawn from domestic wells in the United States do not exist. Moran et al. (2002), however, completed a retrospective analysis of existing data from the NAWQA Program on 55 targeted volatile organic compounds (VOCs) from 1926 domestic wells collected across the United States from 1986 to 1999. Although the original objectives of the data were broader than specific assessments of domestic well water quality, the study by Moran et al. (2002) is the only documented national-scale assessment of a group of water quality constituents in domestic well water that are regulated in public water supplies.

There have been several studies on local, state, and regional scales that have assessed domestic well water quality. Typically, those studies have focused on one contaminant or a group of related compounds and were not designed to assess general water quality conditions. For example, the CDC completed an analysis of atrazine, nitrate, coliform, and *Escherichia coli* bacteria in 5520 domestic wells throughout nine Midwestern states in 1994 (CDC 1998). As aforementioned, some limited bacteriological tests are routinely performed on water from domestic wells; however, the CDC study included chemical contaminants that are known or suspected to be associated with water resources impacted by agricultural land uses in the targeted areas. The study was initiated after the Midwest floods of 1993 contaminated many wells with coliform or *E. coli* bacteria. A study of domestic well water in Pennsylvania showed that bacterial contamination is influenced by well construction characteristics (Zimmerman et al. 2001). In a study of arsenic occurrence, Montgomery et al. (2003) analyzed water samples collected from 353 domestic wells in southeastern New Hampshire. The study included a spatially random design to ensure the collection of representative water samples from the geologic formations in the study area. Among the findings, an estimated 41,000 people in Hillsborough, Rockingham, and Strafford counties were shown to use private bedrock wells, containing water with concentrations of arsenic that exceeded the MCL of 10 µg/L. Based on the results submitted to the State of New Jersey (New Jersey Department of Environmental Protection 2004) during the first 6 months of the Private Well Testing Act, 92% of the 5179 wells passed all the required primary (health based)

standards, with the exception of lead. Of the remaining 8% (417 wells), the most common constituents that exceeded their respective MCLs were nitrate (189 wells), followed by fecal coliform (92 wells), and VOCs (71 wells). For those wells in the counties where arsenic and mercury testing are required, water from 72 wells exceeded the standard for arsenic and water from 14 wells exceeded the standard for total mercury. There are other examples of local-, state-, and regional-scale studies of domestic well water quality but most remain unpublished assessments by local health or other state agencies. For example, the State of Florida maintains a domestic well testing program for a range of chemical contaminants (Vincent, R., written communication, 2004).

Therefore, because of the general lack of nationally consistent programs across the United States to monitor and evaluate the water quality of domestic wells this study is a starting point to provide perspective on a national scale. The data evaluated and summarized could also help to support development of hypotheses and related studies concerning the local, regional, and national sources, occurrence, and fate and transport of the targeted contaminants.

Approach

The contaminants evaluated in this study include a cross section of various organic and inorganic chemicals with natural as well as anthropogenic sources for which the U.S. EPA has developed federal drinking water standards, or that are known or suspected to occur in water resources. Microbial contaminants, although important components of domestic well water quality, are not within the scope of this report. All analyses were performed following consistent national protocols by USGS laboratories.

Targeted Contaminants

Thirteen pesticides, 15 VOCs, 2 radionuclides, and 6 other inorganic water contaminants were analyzed for this study. The selection of these constituents was largely based on the following four criteria: (1) a U.S. EPA MCL exists for the contaminant; (2) previous studies have shown that the contaminant frequently occurs in ambient water resources; (3) a variety of organic and inorganic contaminants that are associated with anthropogenic as well as natural sources are included; and/or (4) the contaminant is often analyzed by the USGS. There are many other contaminants that have been assigned federal drinking water standards but were not evaluated in this study. The 36 constituents evaluated provide a comprehensive representation of chemical drinking water contaminants and contaminant sources. The number of wells with data for each constituent varies for each constituent or group of constituents because not all water samples were analyzed for all constituents. For example, arsenic was analyzed in water samples from 7580 domestic wells, the largest number of wells for any of the 36 constituents evaluated in this study other than fluoride (15,495 wells).

Spatial and Temporal Considerations

The most recent analysis of raw (untreated) water was used for each well regardless of how many times the well had been sampled. This approach provides a snapshot of water quality conditions in the studied wells for the time period of interest for this study (1986 to 2001). This approach, however, does not capture the variability that could be encountered in a given well or set of wells if sampled over time, nor does it provide a current picture in cases where water quality has changed since sampling. Consequently, temporal assessments are not possible with the data evaluated in this study.

The contaminant data assembled and evaluated for this study were retrieved from existing data stored in the USGS National Water Information System (NWIS; http://waterdata.usgs.gov/nwis), which includes water data collected for various objectives including local, state, and national program needs (e.g., the USGS Cooperative Water Program, NAWQA Program, National Research Program, and the Toxic Substances Hydrology Program). The criteria used to select wells evaluated for this study included availability of ancillary data for well construction (such as depth), latitude and longitude, date and time of collection, well type, laboratory certification, and consistent field sampling protocols (Lapham and Tadayon 1996) but did not include considerations of the original objectives for which individual data were collected. Therefore, the locations of wells evaluated in this study were not selected as part of a nationally representative sampling design. The original objectives for sampling these wells are unknown and likely range from local or individual well assessments to larger regional assessments scattered throughout the United States. A variety of factors can affect and in some cases bias the interpretation of the subset of data used for this study including the density and location of sampling sites and the multitude of objectives for the original sampling. For example, a particular contaminant may have been targeted in a geographic area(s) because of a known or suspected source of contamination and consequently the sampling design may have been intentionally biased to that area(s). As a result, these data may be included with data from other sampling designs such as some local or statewide random sampling projects. Among the strengths of this approach, however, are the large number of sites for which data are available across large geographic regions that were sampled with consistent national protocols and laboratory procedures established by the USGS.

Therefore, although the data cannot be used to discern spatial or temporal patterns, determine causal relations, or provide a statistically representative analysis, they are a unique source of retrospective data for contaminant occurrence in a large number of domestic wells across the United States. Corroborative evidence to demonstrate the value of this approach is provided in a subsequent section (Additional Perspective from Other Studies).

Reporting Levels

Because laboratory methodologies may have changed over the time period used in this study, there can be several different reporting levels for a given constituent. Detection frequencies and comparisons with drinking water standards (MCLs) for contaminants with a range of reporting levels were based on using all data regardless of the associated reporting level. For example, the total number of wells used to calculate the detection frequency for alachlor was 3191 (Table 1) even though five different methods were used with reporting levels that ranged from 0.002 to 0.05 µg/L. Most importantly, the reporting levels are much lower than MCLs, and therefore, calculations of MCL exceedances were not affected or biased by high reporting levels for any of the contaminants. To simplify graphical presentation of the distributions of measured concentrations, a common reporting level (typically the highest reporting level associated with the largest number of data for a given contaminant; also called "assessment level") was used to generate box plots for all contaminants listed in Table 1. In this way, simple summaries of the distribution of the "measurable" or detected concentrations can be portrayed separately from the samples with no detections. Helsel (1990) explains limitations associated with using assessment levels for analysis of water quality data and offers guidance that may be of value in interpreting the results of this study.

Results

Data from 18,827 domestic wells met the criteria for selection in this study; however, the actual number of wells evaluated for a given contaminant was much less ranging from 2055 (for the herbicide 2,4-dichlorophenoxy acetic acid 2,4-D) to 15,495 (for fluoride) because of availability of requisite data for those wells (Lapham and Tadayon 1996). Although the data used in this study are not adequate for determining spatial patterns or statewide comparisons of contaminant occurrence, it is important to note that at least some data were available from every state and Puerto Rico (Figures 1 through 3). The number of analyses for a given contaminant varied widely among the states; in some cases, there were no data for one or more of the targeted contaminants.

Detections and MCLs

The number and frequency of detections, and percentage of wells with concentrations exceeding U.S. EPA MCLs were determined for each constituent separately (Table 2) as well as groups of all VOCs and all pesticides evaluated (Figure 4). Arsenic was analyzed in samples from 7580 wells and exceeded the MCL in ~11% of the wells (Figure 4). Uranium was analyzed in samples from 2390 wells and exceeded the MCL (30 µg/L) in ~4% of the wells (Figure 4). The U.S. EPA is currently determining drinking water standards for radon and has proposed two different potential standards as part of a multimedia mitigation program (U.S. EPA 2004). Based on these proposed standards, the lower concentration (300 pCi/L) is exceeded in 75% and the higher concentration (4000 pCi/L) is exceeded in ~9% of the 4820 wells evaluated for radon (see Concentration Distributions). Nitrate was analyzed in samples from 3465 wells and exceeded the MCL in ~8% (Table 2). In addition,

Table 1
Reporting Levels and Numbers of Wells for Selected Contaminant Analyses

	Method 1	Method 2	Method 3	Method 4	Method 5	Method 6	Method 7	Method 8	Method 9
Alachlor									
Reporting level (µg/L)	0.05	0.0045/ 0.002/ 0.0024	0.002/ 0.0024/ 0.0045	0.05	—	—	—	—	—
Number of wells	158	1983	964	2	84	—	—	—	—
Atrazine									
Reporting level (µg/L)	0.05	0.001/ 0.007	0.001/ 0.007	0.009	—	0.0737	—	—	—
Number of wells	157	1969	964	15	2	2	104	—	—
Metolachlor									
Reporting level (µg/L)	0.05	0.002/ 0.013	0.002/0.013	—	—	—	—	—	—
Number of wells	158	1926	964	57	2	86	—	—	—
Prometon									
Reporting level (µg/L)	0.05	—	0.015/ 0.018	0.015/ 0.018	—	—	—	—	—
Number of wells	140	1	1926	1021	2	99	—	—	—
Simazine									
Reporting level (µg/L)	0.05	—	0.005/ 0.011	0.005/ 0.011	—	—	—	—	—
Number of wells	140	1	1926	1021	2	99	—	—	—
Chloroform									
Reporting level (µg/L)	3	0.1/0.2	0.2	0.052/ 0.024/0.1	—	—	—	—	—
Number of wells	380	1021	747	855	306	1430	—	—	—
MTBE									
Reporting level (µg/L)	0.2	3	0.2	0.112/ 0.17/0.2	—	—	—	—	—
Number of wells	340	203	783	794	307	907	—	—	—
PCE									
Reporting level (µg/L)	3	0.2/0.1	0.2	0.1/0.027/ 0.038	—	—	—	—	—
Number of wells	378	1018	745	739	263	1401	—	—	—
TCE									
Reporting level (µg/L)	3	0.2/0.1	0.2	0.1/0.038	—	—	—	—	—
Number of wells	377	1020	747	800	306	1405	—	—	—
Radon									
Reporting level (µg/L)	80/26	1	—	—	—	—	—	—	—
Number of wells	4113	52	8	647	—	—	—	—	—
Uranium-238									
Reporting level (µg/L)	0.4	0.4	0.4	0.4	0.01	0.01	1/0.018	1	—
Number of wells	13	57	183	7	184	2	1271	328	345

—, not available; 0.0045/0.002/0.0024, reporting levels over time for the analytic method.

nitrate concentrations exceeded 2 mg/L (a concentration that can be indicative of anthropogenic sources of nitrate) in ~34% of the wells evaluated. The MCLs for mercury (3397 wells evaluated) and fluoride (15,495 wells evaluated) were each exceeded in <1% of the wells evaluated. At least one of the targeted VOCs was analyzed in samples from 4971 wells (Figure 3), and <1% of all the VOC analyses exceeded an MCL (Figure 4). At least one of the targeted pesticides was analyzed in 3309 wells (Figure 1) and an MCL exceeded in only 4 wells (Table 2). Of the organic constituents evaluated, atrazine was the most frequently detected (24%; Figure 5). Simazine and metolachlor each were detected in ~9% of all wells and tied for second in frequency of detection of the organic contaminants. The third and fourth most frequently detected compounds were the VOCs methyl *tert*-butyl ether (MTBE) (6%) and chloroform (5%), respectively (Figure 6). Therefore, arsenic exceeds the MCL more often than any of the targeted compounds that have been assigned an MCL (Table 1).

Concentration Distributions

Although detections of all VOC and pesticide contaminants were low, the "measurable concentrations" (i.e.,

Arsenic — 7,580 wells

Radon — 4,820 wells

Nitrate — 3,465 wells

Uranium — 2,390 wells

Figure 1. Locations and numbers of wells with arsenic and nitrate analyses.

Figure 2. Locations and numbers of wells with radon and uranium analyses.

quantifiable concentrations in the low percentage of water samples with detections) are graphically depicted by omitting the samples with no detections in order to provide additional understanding of the distribution and ranges of measurable contaminant occurrence. Measured concentrations of the four most frequently detected VOCs and pesticides were assessed (Figures 7 and 8, respectively). Measurable concentrations for two of the four most frequently detected VOCs (perchloroethene [PCE] and trichloroethene [TCE]) are greater than the associated MCL more often than any other VOC with an MCL (Figure 7). The other two most frequently detected VOCs (MTBE and chloroform) have distributions of measurable concentrations that are similar to PCE and TCE, but no MCL exists for either of these two compounds individually (an MCL for total trihalomethanes, which includes chloroform along with several other trihalomethanes, has been established; however, no MCL exists for chloroform alone).

There are no MCLs for two of the four most frequently detected pesticides (metolachlor and prometon), but MCLs exist for atrazine (MCL = 3 µg/L) and simazine (MCL = 4 µg/L). Only one sample exceeded the atrazine MCL and ~25% of the measurable concentrations were within an order of magnitude of the MCL (Figure 8). No samples exceeded the simazine MCL and measurable concentrations generally were lower than that of atrazine (Figure 8). On the

other hand, measurable concentrations of metolachlor and prometon generally were higher than that of atrazine and simazine, although no MCL exists for these two compounds.

The two radionuclides evaluated for this study are naturally occurring (radon-222 and uranium), and a large range in measurable concentrations was observed (Figure 9). Uranium concentrations exceeded the MCL more than any VOC or pesticide. Radon-222 exceeded both of the MCLs being considered by the U.S. EPA (U.S. EPA 1999) more frequently than uranium-238, any VOC, and any pesticide evaluated.

Additional Perspective from Other Studies

As previously discussed, the multitude of objectives, detection levels, and time periods for which the data were collected introduce various sources of bias in the data. It is beyond the scope of this study to ascertain how many wells may have been sampled in areas of known or suspected sources of contamination compared to how many were sampled for general background data or other objectives. Additional perspective is obtained, however, when results of the study are put in context with summaries of a variety of previous studies including some with sampling designs targeting contaminant sources as well as general unbiased sampling designs.

Pesticides — 3,309 wells

Volatile Organic Compounds — 4,971 wells

Figure 3. Locations and numbers of wells with pesticide and VOC analyses.

Arsenic

The sampling design described by Montgomery et al. (2003) was developed to provide a statistically significant representative sample of privately owned domestic wells in bedrock across southeastern New Hampshire. Among the pertinent findings, Montgomery et al. (2003) documented concentrations of arsenic in excess of the MCL (10 μg/L) in 19% of the wells (untreated water sources) and showed that high concentrations were related to geologic formation. This is approximately twice as high as the percentage found in the current study (Table 2). This is a good example of a local-scale study designed to assess a contaminant
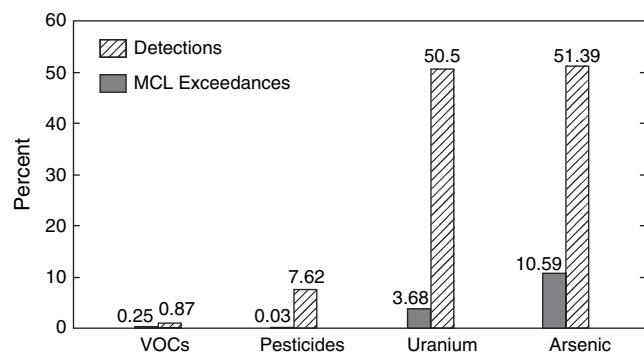
Figure 4. Detections and MCL exceedances for all analyses of VOCs, pesticides, uranium, and arsenic.

in an area known or suspected to have a prevalent source of the contaminant compared to the present national-scale study, which used the same laboratory reporting levels and sampling protocols but included a variety of sampling designs and objectives. In addition, the percentage of wells exceeding the MCL in this study is similar to the percentage of public supply wells exceeding the MCL (9%) in another national study of arsenic occurrence in untreated drinking water (Ryker 2003).

Atrazine and Nitrate

Atrazine, nitrate, coliform, and *E. coli* bacteria were analyzed in water collected from 5520 domestic wells in nine Midwestern states by the CDC in 1994 (CDC 1998). The study used a systematic geographical sampling approach based on proximity of domestic wells to a 10-mile grid overlain on the nine states and followed recent flooding of the Mississippi River valley. This approach avoids the potential bias that can be associated with sampling designs that target wells in or near known local sources of contamination; however, the land use in rural areas of these nine states is predominantly agricultural and therefore does not represent all parts of the United States. In addition, the unusual high streamflows at the time may have resulted in transport, dilution, and other factors associated with contaminant movement, especially where flooding near shallow wells occurred.

Frequency of detections and concentrations exceeding the MCL for atrazine and nitrate are shown in Table 3. The frequency of detection of atrazine was higher in this study (24%) than in the CDC study (14%). Although the CDC study analyzed total triazines, whereas atrazine alone was analyzed in the present study, the USGS reporting levels were much lower and therefore the differences in detections were likely due to differences in reporting levels and other study design considerations (e.g., a potential bias toward areas with known sources of atrazine). The nitrate analyses in both data sets had the same minimum reporting level and the MCL was exceeded in the CDC study more often (13% compared with 8%). The maximum concentrations of atrazine and nitrate are higher in the CDC study than in the present study. The reason for the higher concentrations is not understood; however, it was reported that most of the wells with high concentrations of these contaminants in the CDC study were dug or bored wells that were old and shallow and had large-diameter brick or concrete casings commonly in disrepair, therefore unusually susceptible to nearby sources of contamination and flooding. In addition, agricultural land use, which is common in rural areas of these nine states, is linked to elevated nitrate and atrazine concentrations in ambient ground water.

Volatile Organic Compounds

In a study supported by the American Water Works Association Research Foundation (AWWARF), Koch et al. (2003) analyzed water samples collected from 954 community water systems (including ground water and surface water) chosen as part of a stratified random sampling design representative of the 54,000 community water

Table 2
Summary of Detections and MCL Exceedances for All Constituents Analyzed

	Number of Wells	Number of Detections	Detection Frequency (%)	MCL	Number of Wells with MCL Exceedances	Percentage of Wells with MCL Exceedances (%)
Inorganics						
Arsenic	7580	3895	51.39	10 µg/L	803	10.59
Cadmium	7083	826	11.66	5 µg/L	57	0.80
Fluoride	15,495	11,889	76.73	4 mg/L	126	0.81
Lead	7004	1683	24.03	15 µg/L[1]	134[1]	1.90[1]
Mercury	3397	410	12.07	2 µg/L	15	0.44
Nitrate	3465	3111	89.78	10 mg/L as nitrate	291	8.40
Radionuclides						
Radon-222[2]	4820	4730	98.13	300 pCi/L	3615	75.00
Radon-222	4820	4730	98.13	4000 pCi/L	434	9.00
Uranium-238	2390	1206	50.46	30 µg/L	88	3.68
Volatile organic compounds[3]						
Solvents						
1,2-Dichloroethane	4687	18	0.38	5 µg/L	4	0.09
cis-1,2-Dichloroethene	3699	20	0.54	70 µg/L	2	0.05
Dichloromethane	4622	48	1.04	5 µg/L	12	0.26
1,2-Dichloropropane	4757	29	0.61	5 µg/L	3	0.06
PCE	4544	134	2.95	5 µg/L	27	0.59
TCE	4655	95	2.04	5 µg/L	34	0.73
Tetrachloromethane[4]	4738	14	0.30	5 µg/L	1	0.02
Gasoline-related compounds						
Benzene	4778	24	0.50	5 µg/L	7	0.15
Methyl tert-butyl ether	3334	204	6.12	—	—	—
Disinfection by-products						
Chloroform[5]	4739	239	5.04	—	—	—
Fumigants						
Dibromochloropropane	2318	24	1.04	0.2 µg/L	22	0.95
1,2-Dibromoethane	2686	8	0.30	0.05 µg/L	8	0.30
Organic synthesis compounds						
1,1-Dichloroethene	4671	27	0.58	7 µg/L	5	0.11
Hexachlorobutadiene	3448	0	0.00	—	—	—
Chloroethene[6]	4547	1	0.02	2 µg/L	0	0.00
Pesticides						
Herbicides						
Alachlor	3191	45	1.41	2 µg/L	3	0.09
Atrazine	3213	771	24.00	3 µg/L	1	0.03
Deethylatrazine	3177	59	1.86	—	—	—
2,4-D[7]	2055	7	0.34	70 µg/L	0	0.00
EPTC[8]	2975	20	0.67	—	—	—
Metolachlor	3193	280	8.77	—	—	—
Metribuzin	3184	42	1.32	—	—	—
Prometon	3189	119	3.73	—	—	—
Simazine	3189	291	9.13	4 µg/L	0	0.00
Insecticides						
Carbofuran	2975	0	0.00	40 µg/L	0	0.00
Chlorpyrifos	2972	5	0.17	—	—	—
Diazinon	3045	42	1.38	—	—	—
Dieldrin	2990	22	0.74	—	—	—

—, not applicable.
[1]There is no MCL for lead; values reported are relative to the U.S. EPA action level of 15 µg/L.
[2]There is no MCL for radon-222; values reported are currently under review by U.S. EPA.
[3]The groupings of VOCs are provided for convenience. Individual VOCs often have various uses.
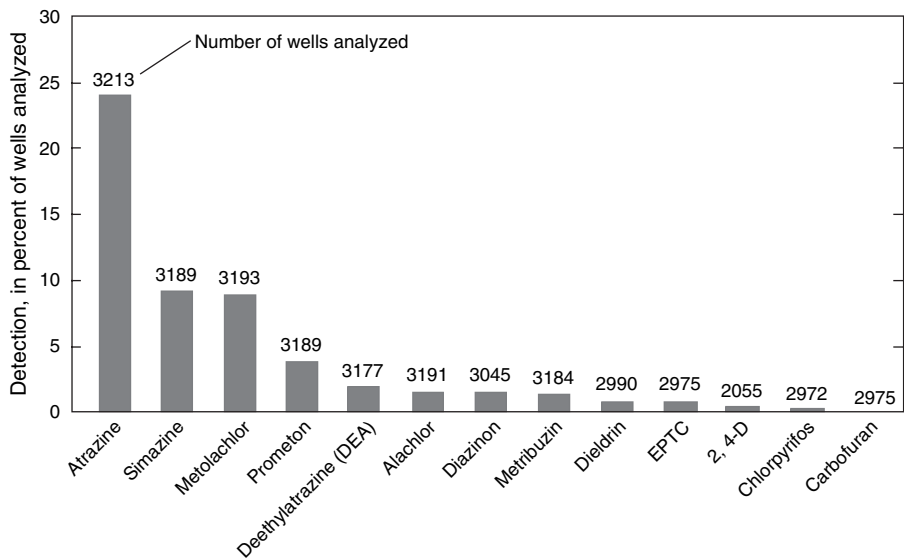[4]Also called carbon tetrachloride.
[5]Also called trichloromethane.
[6]Also called vinyl chloride.
[7]2,4-dichlorophenoxy acetic acid.
[8]5-ethyl dipropylthiocarbonate.

Figure 5. Detection frequencies of all pesticides analyzed.

systems nationwide. Samples were analyzed for MTBE, other ether gasoline oxygenates, their degradation products, and 62 other VOCs in the untreated source water used by the community water systems. It is important to note that domestic wells tend to be constructed differently than public supply wells, are shallower (Figure 10), and have much lower pumping rates than public supply wells. Consequently, the aquifer and geochemistry, the contributing areas, ages of pumped water, and the associated potential sources of contamination can also differ greatly between the two types of wells. The AWWARF study is a unique source of data based on a nationally consistent random sampling design. Because of the limitations previously discussed, it is not advisable to draw conclusions about differences in VOC occurrence in domestic wells compared with public supply wells; however, detection

frequencies of VOCs in the AWWARF study generally are similar to the low detection frequencies (6% or less) found in this study (Figure 11), with the exception of trichloromethane (chloroform).

Shapiro et al. (2004) evaluated archived chromatograms of untreated water samples collected from hundreds of domestic and public supply wells in the United States and showed that water in all domestic wells evaluated was impacted by anthropogenic activities. The chromatograms, which originally were analyzed for chlorofluorocarbon age dating, provided detection capabilities for some halogenated VOCs on the order of parts per quadrillion. Three or more halogenated VOCs were detected in 100% of the chromatograms and 10 or more were detected in 77%. The high detection frequencies are a direct result of the low detection capabilities and are greater than all other known
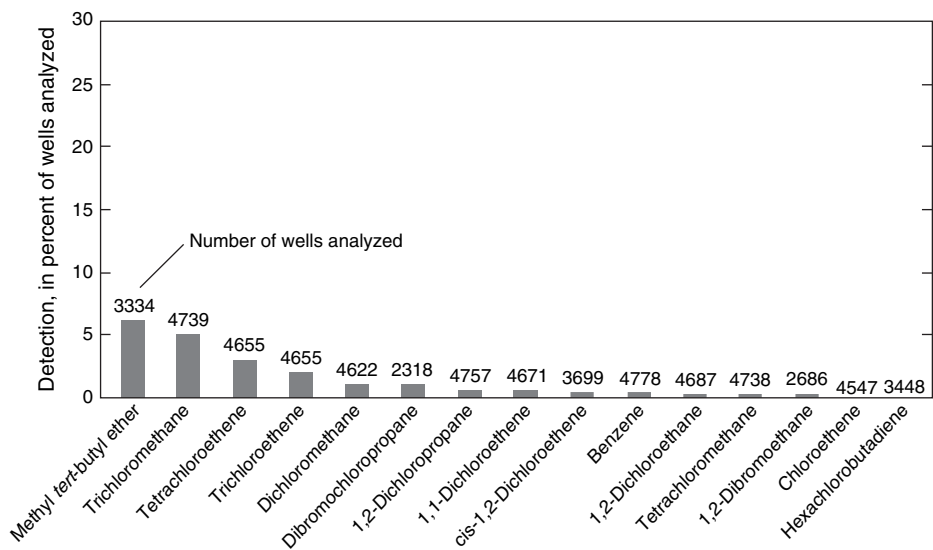
Figure 6. Detection frequencies of all VOCs analyzed.
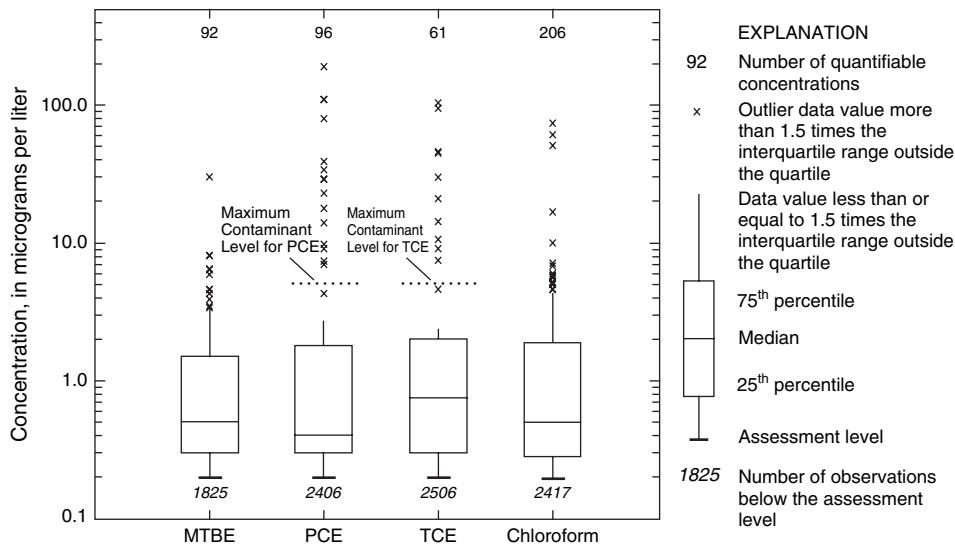
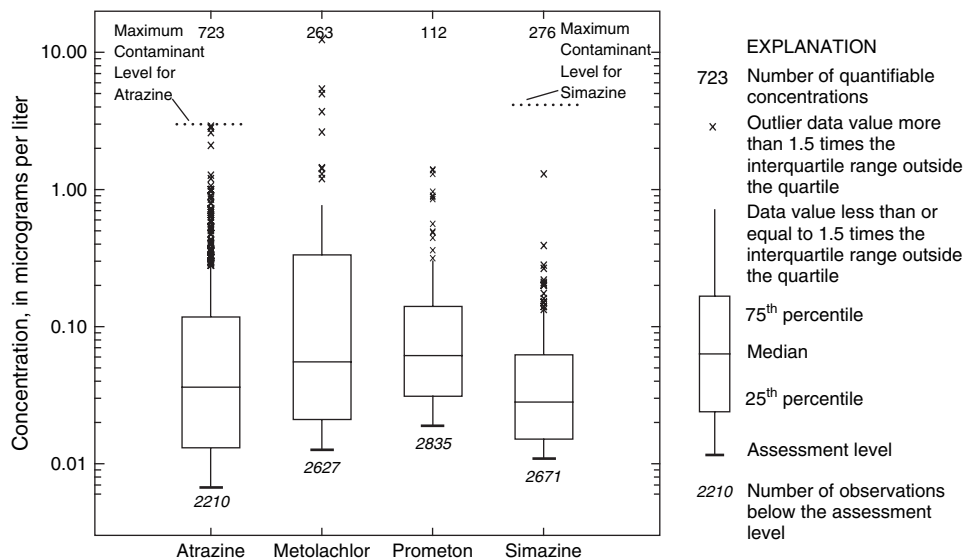**Figure 7. Summary of concentrations of the four most frequently detected VOCs.**

analyses of VOCs in drinking water including the present study. Although concentrations could not be quantitatively determined, Shapiro et al. (2004) estimated that concentrations are much lower than MCLs where they exist and many are indicative of atmospheric inputs. Therefore, atmospheric sources of the targeted contaminants can impact domestic well water quality in widespread parts of the United States, but the concentrations typically are below most commonly used detection capabilities including those used in the present study.

Radon and Uranium

Sloto (2000) summarized analyses of water samples collected primarily from domestic wells to show the occurrence and distribution of selected naturally occurring radionuclides in the ground water of southeastern Pennsylvania. Concentrations of radon-222 analyzed in 912 wells exceeded 300 and 4000 pCi/L in 89% and 16% of the

sampled wells, respectively. Uranium-238 concentrations generally were much lower with nondetects in ~45% of the wells (49% in the present study) and concentrations in water from only 2 of 362 wells greater than the MCL. Concentrations of radon-222 generally are lower and uranium-238 generally higher in the present study than in the southeastern Pennsylvania study (Table 4). This is consistent with Sloto's (2000) observations that data for the southeastern Pennsylvania study included many wells intentionally sampled in the Chickies Quartzite, a formation known to be an important source of radon-222 (Senior and Vogel 1995) and that uranium does not occur in "elevated" concentrations in southeastern Pennsylvania. It is important to note that much of the domestic well data summarized by Sloto (2000) were stored in NWIS and therefore represent a subset of the overall data used for the present study.

Hess et al. (1985) summarized radioactivity data from thousands of public and domestic wells across the United

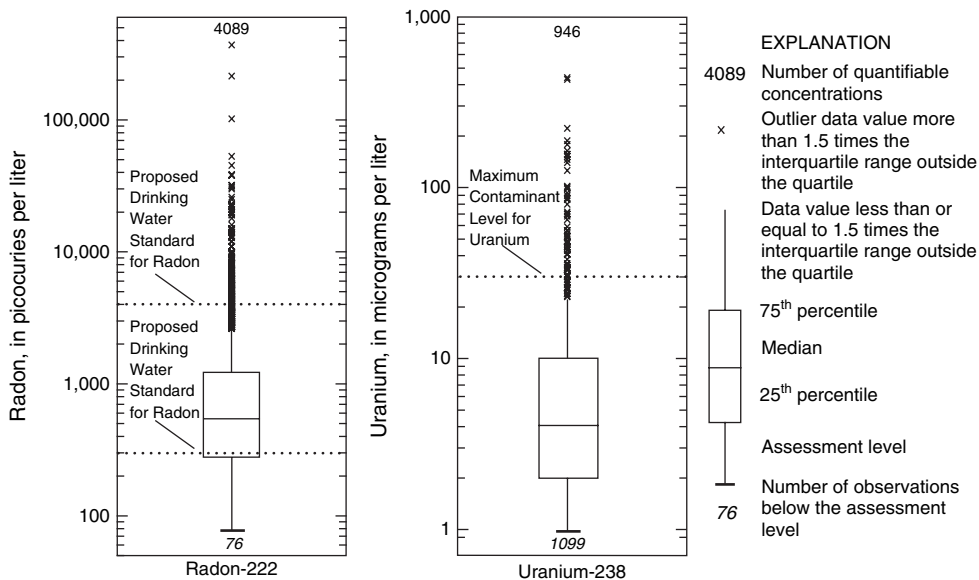**Figure 8. Summary of concentrations of the four most frequently detected pesticides.**

Figure 9. Summary of concentrations of radon-222 and uranium-238. Data are censored by the highest common reporting level.

States. Radon concentrations were analyzed in samples collected from 434 domestic wells and varied from no detection to 7000 pCi/L, with a geometric mean of 920 pCi/L for the entire United States. In contrast, the geometric mean concentration of radon from 6298 samples collected at public ground water supplies was 130 pCi/L, with a high concentration of 2400 pCi/L. Hess et al. (1985) also summarized uranium data collected from 800 ground and surface water sites used for public drinking water systems supplying large populations. There were only three samples with uranium concentrations exceeding 10 pCi/L in this summary, and Hess et al. (1985) conclude that there is a need for more data from small systems (including domestic wells).

Summary

Water samples collected from thousands (18,827) of domestic wells throughout the United States were analyzed for 13 pesticides, 15 VOCs, 2 radionuclides, and 6 other inorganic constituents. This investigation did not include contaminants that are associated with taste and odor (e.g.,

iron, sulfates), corrosion (e.g., pH), and other issues (e.g., pathogenic disease) that are also known to be of concern to domestic well owners across the United States. The chemicals evaluated in this study represent a range of inorganic and organic contaminants with known or suspected natural and anthropogenic sources and geochemical conditions. Although the wells were not selected as part of a statistically representative design, the range of contaminants assessed and the large numbers of wells evaluated provide a unique snapshot of the quality of drinking water in domestic wells in the United States. Results of previously published data on a range of contaminant groups have provided additional perspective on this retrospective analysis of domestic well water quality on a national scale.

Inorganic contaminants were detected in many of the wells and, generally, concentrations exceeded MCLs more often than the organic contaminants (although the majority of samples were still below MCLs). Arsenic was detected in ~52% of the wells and exceeded the MCL in ~11%. Arsenic exceeded the MCL more than uranium, any VOC, and any pesticide analyzed. Uranium was detected in

Table 3
Atrazine and Nitrate Results from CDC Midwestern Domestic Well Survey and This Study

|	Number of Analyses	Reporting Level	Percent Detected	Percent Exceeding MCL	Mean Concentration	Maximum Concentration
Nitrate (CDC)	5520	0.01 mg/L	65.4	13.4	8.4 mg/L	266 mg/L
Nitrate (this study)	3465	0.01 mg/L	89.8	8.4	3.6 mg/L	246 mg/L
Atrazine (CDC)[1]	5520	0.05 µg/L	13.6	0.2	0.4 µg/L	29 µg/L
Atrazine (this study)[2]	3213	0.001–0.05 µg/L	24.0	0.03	0.03 µg/L	5 µg/L

[1]Atrazine analyses include all structurally related triazine compounds.
[2]Atrazine only.
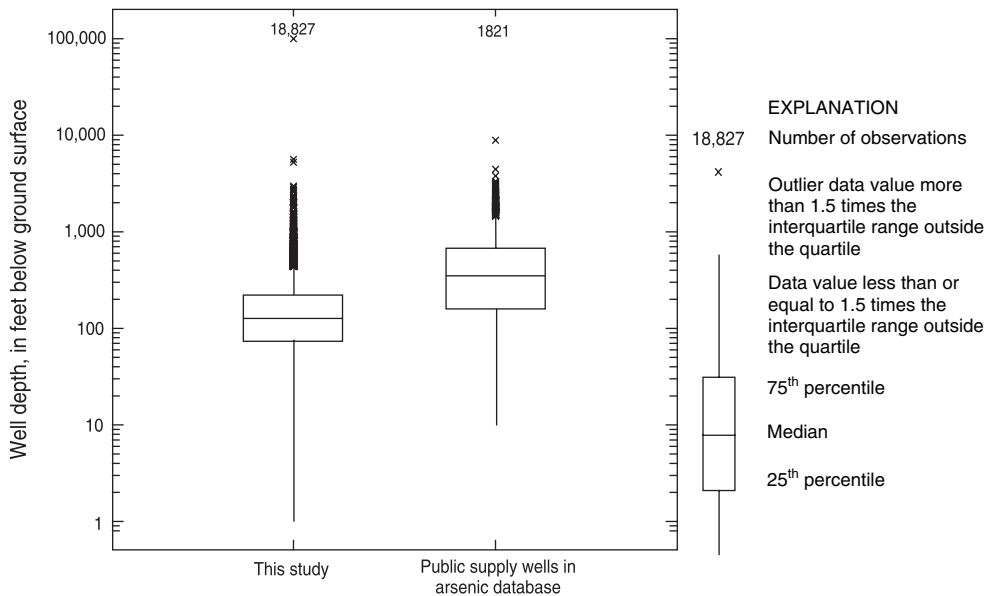
Figure 10. Graphical comparison of domestic well depths (this study) and public supply well depths analyzed in a previous study (Focazio et al. 2000).

~51% of the wells and exceeded the MCL in ~4% of the wells. The U.S. EPA is considering two levels for radon drinking water standards as part of a multimedia mitigation program; the lower concentration (300 pCi/L) was exceeded in 75% of the wells tested and the higher concentration (4000 pCi/L) was exceeded in ~9%. Nitrate was detected in ~90% of the wells and exceeded the MCL in ~8%. In addition, nitrate concentrations exceeded 2 mg/L (assumed indicative of anthropogenic sources of nitrate) in ~34% of the wells. The MCLs for mercury (3397 wells evaluated) and fluoride (15,495 wells evaluated) were each exceeded in <1% of the wells evaluated.

The organic contaminants (pesticides and VOCs) analyzed were not detected in the majority of wells and detected concentrations were typically below drinking water standards. Atrazine, one of the targeted pesticides, was detected in ~24% of the wells and only one well exceeded the MCL for atrazine. MCLs have been established for four other pesticides evaluated in this study but only one (alachlor) exceeded the MCL in 3 of 3191 wells evaluated. Two of the targeted VOCs (MTBE and chloroform) were detected in >5% of the wells, and concentrations were greater than any MCL in only 125 samples of ~5000 samples tested for any VOC.
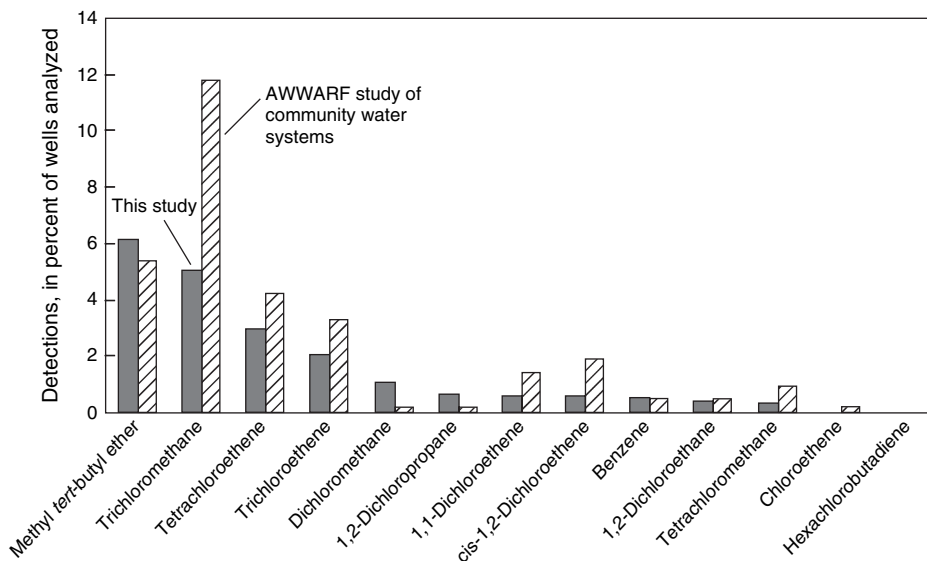
Figure 11. Graphical comparison of VOC detections in domestic wells (this study) and public supply wells from another study (Koch et al. 2003).

Table 4
Percentage of Wells Exceeding Proposed and Existing MCLs for Radon-222 and Uranium-238 in Southeastern Pennsylvania and This Study

	Radon-222		Uranium-238
	>300 pCi/L	>4000 pCi/L	>30 µg/L
This study (%)	75	9	3.7
Sloto (2000) southeastern Pennsylvania (%)	89	16	0.6

Summaries of previously published studies of the water quality of domestic and public supply wells for a range of contaminant groups including arsenic, nitrate, atrazine, several VOCs, radon-222, and uranium were presented in context with results from the present study. These contaminant groups typically are associated with a range of potential sources of contamination and geochemical conditions. This additional perspective shows that the data used in this study probably include a subset of wells sampled in areas known or suspected to be associated with sources of contamination, but overall, the data set also includes many wells that were sampled in other areas, thereby providing a range of water quality conditions nationally.

Conclusions

Several naturally occurring inorganic contaminants (e.g., arsenic, uranium, and radon) evaluated in this study were present in many domestic wells at concentrations above existing or potential MCLs, indicating that natural sources of contamination are present in domestic wells on regional scales in the United States. Nitrate, a naturally occurring inorganic contaminant known to have significant anthropogenic sources, was above the MCL in many (~8%) of the domestic wells evaluated. Although most organic contaminants evaluated were not detected in most wells, there was a notable presence of some (e.g., atrazine, alachlor, MTBE, chloroform) at low concentrations in some well water, indicating the potential for local sources of anthropogenically derived organic contamination. In addition, previous studies have documented the potential for atmospheric transport of some organic contaminants and the associated widespread presence at trace concentrations in water collected from domestic wells across the United States.

Because self-supplied drinking water is not federally regulated or monitored, there is a lack of nationally representative domestic well water quality data and information for the 45 million Americans who supply their own drinking water in the United States. However, the large retrospective data set and interpretations developed for this study can provide a starting point to support development of hypotheses and related studies of domestic well water quality and the potential for associated public health concerns. This study also underscores the need for assessments of sources, occurrence, transport, cause, and health effects of domestic well water contamination.

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