Chapter 4—VOCs in Samples from Drinking-Water Supply Wells

Ground Water as a Drinking-Water Supply

Photograph courtesy of Mike Wolforth, Light Images

Ground water provides a drinking-water supply for about one-half the Nation's population, including almost all of the people who reside in rural areas.[1] Ground water supplies domestic wells and public wells in every State (fig. 12). Domestic wells are privately owned, self-supplied sources for domestic water use.[36] Public wells are privately or publicly owned and supply ground water for PWSs. In this report, the discussion of public wells refers to the quality of water captured by wells that supply drinking water to PWSs. As defined by the USEPA,[37] PWSs supply drinking water to at least 15 service connections or regularly serve at least 25 individuals daily at least 60 days a year.

Ground water is used as a drinking-water supply for about one-half the Nation's population, including almost all people residing in rural areas.

About 150 million people in the United States received their drinking water from domestic and public wells in 2000.[38, 39] Estimated withdrawals from domestic and public wells increased by about 60 and 100 percent, respectively, from 1965 to 2000 (fig. 13). In 2000, average daily withdrawal rates from domestic and public wells for drinking-water supply were 3.5 and 16 billion gallons per day (Bgal/d), respectively.[39]

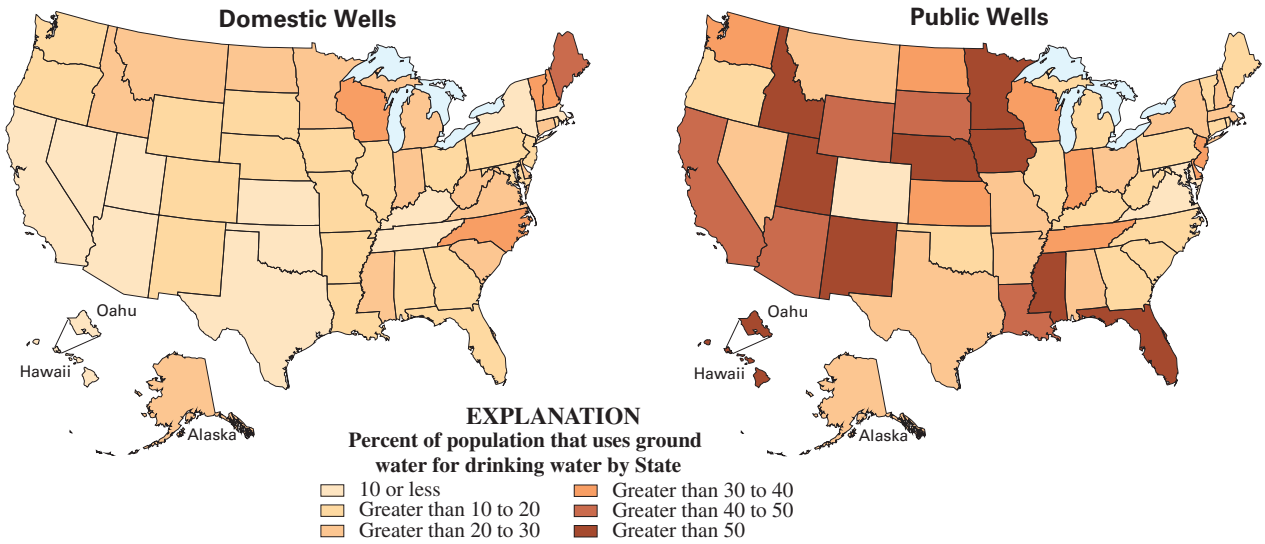


Figure 12. In most States, a greater percentage of the population is dependent on public wells than on domestic wells as a drinking-water supply.

For this NAWQA assessment, detection frequencies and concentrations of individual VOCs and VOC mixtures were examined to characterize the quality of ground water captured by drinking-water supply wells (sidebar 4). VOC detection frequencies for domestic well samples were determined using a two-tiered assessment level approach of 0.2 µg/L for 2,401 wells and 0.02 µg/L for a subset of 1,208 wells. Through a collaborative effort with researchers and water utilities, VOC detection frequencies also were determined for 1,096 public well samples at an assessment level of 0.2 µg/L. All samples from domestic and public wells were collected at the well head before any treatment or blending of the water.

In this chapter, a three-step approach was used to assess the relevance of VOC concentrations in **domestic** and **public well water** to human health and to assess monitoring needs for VOCs. First, VOC concentrations were compared to USEPA's MCLs for **regulated compounds** (sidebar 17), and to HBSLs for unregulated compounds (sidebar 18). Comparison of VOC concentrations to benchmarks aids in identification of VOC concentrations that may be of potential human-health concern (hereafter referred to as concentrations of potential concern). The spatial distribution of VOC concentrations of potential concern also are examined in this step. Second, the relative proportions of concentrations of potential concern for individual VOCs were determined for both well types. Third, VOCs detected at concentrations less than but within a factor of 10 of MCLs and HBSLs were identified. These VOCs, along with the compounds determined in the first step, may warrant inclusion in a low-concentration, trends-monitoring strategy, such as the approach used by the NAWQA Program. This monitoring may provide an early indication of VOC concentrations approaching levels of potential concern.

In addition, sources of contamination to domestic and public wells are discussed, and anthropogenic and hydrogeologic factors associated with the detection of VOCs are described for each well type. Lastly, VOC occurrence findings for domestic wells and public wells are compared.

17. MCLs Serve as Drinking-Water-Quality Benchmarks for PWSs

Under the authority of the SDWA, the USEPA establishes drinking-water standards, such as MCLs, to limit the level of contaminants in the Nation's drinking water. An MCL is a legally enforceable standard that sets the maximum permissible level of a contaminant in water that is delivered to any user of a PWS.[40] When setting an MCL, the USEPA also establishes a non-enforceable health goal or **Maximum Contaminant Level Goal (MCLG**). The MCLG is the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on human health would occur, and which allows an adequate margin of safety.[40] The MCL is set as close to the MCLG as feasible, taking into account the best available technology, treatment techniques, and cost considerations, as well as expert judgment and public comments. The USEPA reviews drinking-water standards every 6 years to determine if revisions are needed.

Established MCLs apply to 29 VOCs included in this NAWQA assessment. However, because MCLs apply to drinking water supplied to the public by PWSs, comparisons of VOC concentrations for samples collected at the well head in this assessment to MCLs are used only to indicate concentrations of potential human-health concern. Actual human exposure from drinking water is not described (sidebar 4).

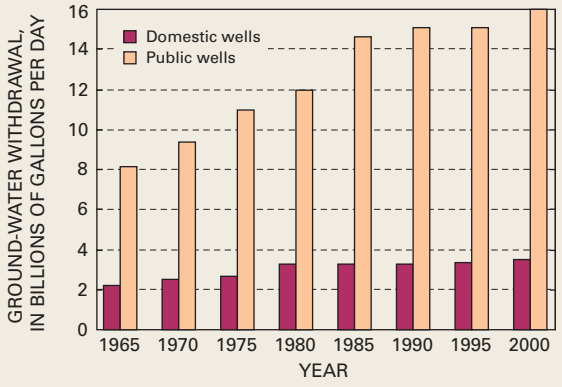


Figure 13. From 1965 to 2000, domestic well withdrawals increased by about 60 percent, whereas public well withdrawals increased nearly 100 percent.

VOCs in Domestic Well Samples

18. HBSLs Can be Applied to VOCs with no MCLs

HBSLs are estimates of benchmark concentrations of contaminants in water that may be of potential human-health concern. HBSLs are based on health effects alone and have been calculated for unregulated contaminants (those with no MCLs) analyzed by the NAWQA Program. HBSLs were developed by the USGS in collaboration with others (p. 13) using (1) standard USEPA Office of Water methodologies; and (2) the most current, USEPA peer-reviewed, publically available human-health toxicity information. HBSLs are regularly reviewed and, as needed, revised to incorporate the most recent toxicity information and research findings.

HBSLs are not regulatory standards and are not legally enforceable. HBSLs were calculated for 15 of the 26 unregulated VOCs in this assessment, but were not calculated for the remaining 11 VOCs due to a lack of toxicity information. Measured contaminant concentrations may be compared to HBSLs to evaluate water-quality data in a human-health context. Such comparisons can provide an early indication of when contaminant concentrations in water resources may merit additional study or monitoring.

Since 1998, the USGS, in collaboration with others, has made substantial progress in providing additional information about the potential human-health implications of its water-quality findings. USGS will continue its research to develop and refine approaches to expand its ability to evaluate contaminant concentrations in a human-health context at the State and national scales.

Additional information about HBSLs and ongoing research is available in other publications[20, 41, 42] and at *http://water.usgs.gov/nawqa/HBSL/*.

One or more VOCs were detected in 14 percent of the 2,401 domestic well samples at an assessment level of 0.2 µg/L. VOCs in these samples were not limited to a few compounds—more than two-thirds of the monitored VOCs were detected. In contrast, nearly one-half of 1,208 samples from a subset of these domestic wells had VOC detections using the low-level analytical method, for which an order-of-magnitude lower assessment level (0.02 µg/L) was applied. Furthermore, about 90 percent of the total VOC concentrations in samples with VOC detections were less than 1 µg/L.

Domestic well water may be vulnerable to low-level VOC contamination from many compounds.

Six VOCs had detection frequencies of 1 percent or larger at an assessment level of 0.2 µg/L (fig. 14, Appendix 8). Chloroform had the largest detection frequency, almost double that of MTBE, the second most frequently detected VOC. The 15 most frequently detected VOCs in domestic well samples represent six groups (fig. 14), indicating multiple contaminant sources.

The gasoline oxygenate, refrigerant, solvent, and THM groups each were detected in more than 2 percent of the domestic well samples. VOCs with multiple uses and/or widespread sources, for example VOCs within the solvent group, were detected throughout the Nation. Gasoline oxygenates were detected most frequently in domestic well samples in the New England and Mid-Atlantic States. Few samples contained fumigants, and

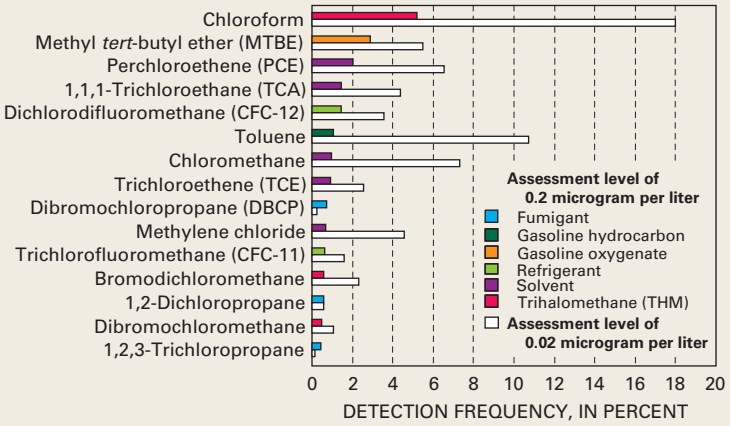


Figure 14. Detection frequencies in domestic well samples differed for the 15 most frequently occurring VOCs at assessment levels of 0.2 and 0.02 microgram per liter.

most of these occurred in the Central Valley of California and in New Jersey, Arizona, and Washington. VOCs used in organic synthesis seldom were detected. Additional information about spatial occurrence of VOC groups and selected compounds is available from the Circular's Web site.

About 1 percent of domestic well samples had VOC concentrations of potential human-health concern.

Six VOCs had concentrations greater than MCLs—DBCP, 1,2-dichloropropane, EDB, 1,1-DCE, PCE, and TCE (fig. 15A). VOC concentrations of potential concern occurred in about 1 percent of the domestic well samples. Fumigants accounted for about two-thirds of the 32 VOC concentrations of potential concern, and DBCP comprised about one-half of these.

Samples with concentrations of potential concern were localized (fig. 15B) and may be associated with a specific VOC use, such as the historical application of DBCP on crops in the Central Valley of California from the late 1950s until the compound's ban in the late 1970s.[43] DBCP

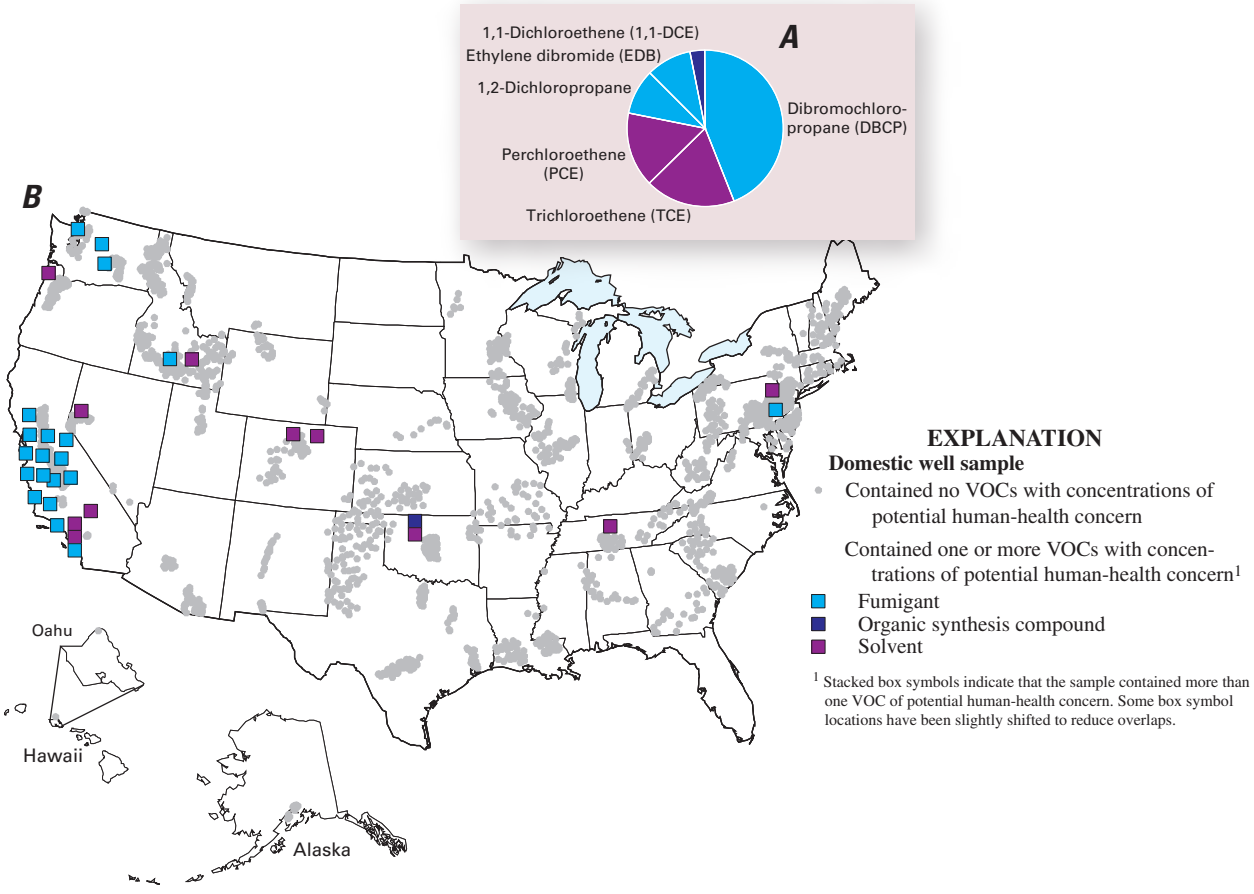


Figure 15. VOC concentrations of potential human-health concern in domestic well samples were predominantly for fumigants and solvents: (*A*) the fumigant DBCP accounted for nearly one-half of all these concentrations; and (*B*) concentrations of fumigants were most common in California.

19. Most Government Agencies Do Not Require Routine Monitoring of Water Quality for Domestic Wells

Although regulations vary by State, and also within States, the quality of water from privately owned domestic wells generally is the homeowner's responsibility. Routine monitoring is not required; however, most States and some local agencies provide guidance to domestic well owners through Web sites and printed materials.[45]

Raising awareness about the importance of regularly testing private wells is an important step towards ensuring a safe drinking-water supply for the population relying on domestic wells. As such, private well owners are advised by State and local agencies to test water annually to identify possible contaminants such as coliform bacteria, nitrate and nitrite, pesticides, radionuclides, heavy metals, and VOCs, and to compare test results to USEPA and State standards. No States currently require homeowners to take action to improve water quality if contaminants are detected in domestic well water. However, some States have introduced measures to assess water quality to aid in protection of human health. For example, in 2002 New Jersey passed a law that required "raw" or untreated water to be tested in wells included in real estate transactions.[46] Additionally, landlords must test water every 5 years and provide the test results to new tenants. VOCs, including benzene and TCE, were among the required compounds to be tested in the well samples.

Because water from domestic wells usually is not treated prior to use, the VOC occurrence data provided by this NAWQA assessment may reflect the quality of tap water used by many rural households. Prior to NAWQA's assessment, no major national studies had been conducted for a large number of VOCs in domestic well samples.

may have a half-life of about 6 years in ground water on the basis of an investigation in the eastern San Joaquin Valley, California.[43] This persistence, when coupled with the **intrinsic susceptibility** of the sand and gravel aquifers in the Central Valley, has resulted in ground-water contamination in an area where about one-tenth of the population relies on domestic wells for drinking-water supplies.

All six of the previously mentioned VOCs that were detected at concentrations of potential concern warrant inclusion in low-concentration, trends-monitoring programs. In addition, benzene, bromoform, carbon tetrachloride, chloroform, dibromochloromethane, 1,2-dichloroethane (1,2-DCA), methylene chloride, TCA, and vinyl chloride were detected at concentrations less than but within a factor of 10 of MCLs (Appendix 9). These VOCs also may warrant inclusion in such a monitoring program.

Septic systems and USTs are important potential sources of VOC contamination to domestic wells.

The finding that some VOC concentrations in domestic well samples were greater than or within a factor of 10 of an MCL is particularly noteworthy because testing of water from domestic wells is not federally mandated nor uniformly monitored (sidebar 19). Although HBSLs exist for 15 unregulated VOCs (sidebar 18), none of the compounds had concentrations greater than or within a factor of 10 of these benchmarks.

VOCs detected in domestic well samples could be from contaminant sources near the home, including septic systems, underground and aboveground storage tanks, fumigant applications, spills, pipelines, and sewer lines. Household septic systems are important potential sources of contamination to domestic wells (p. 45). USTs used to store fuels also are recognized as potential contaminant sources to domestic wells.[44]

Leaking gasoline, heating oil, and diesel fuel from storage tanks can result in low-level VOC contamination in ground water that serves as a domestic drinking-water supply. (Photograph by Connie J. Ross, U.S. Geological Survey.)

VOCs in Public Well Samples

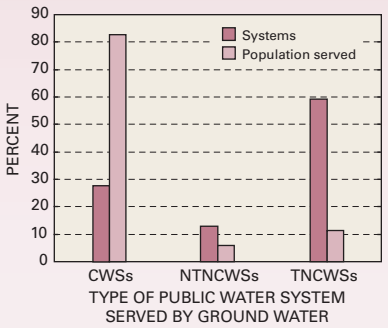
One or more VOCs were detected in about one-fourth of the 1,096 public well samples at an assessment level of 0.2 µg/L. Total VOC concentrations in about one-half of the samples with detections were less than 1 µg/L. Furthermore, about three-fourths of the 55 monitored VOCs were detected (Appendix 10), indicating that many VOCs are potential contaminants in public well water. Because the public well samples were collected before any treatment or blending of the water, these findings do not necessarily reflect the quality of drinking water ultimately supplied by the large number of PWSs that use ground water as a drinking-water supply (sidebar 20).

About one-fourth of the public well samples contained VOCs; however, total VOC concentrations generally were less than 1 µg/L.

Fifteen VOCs had detection frequencies of 1 percent or larger (fig. 16). Chloroform was the most frequently detected VOC in public well samples with a frequency of about 11 percent. Additionally three other THMs—bromoform, dibromochloromethane, and bromodichloromethane—each were detected in about 4 percent of public well samples. MTBE was the second most frequently detected VOC. The solvents PCE, TCE, TCA, 1,1-dichloroethane (1,1-DCA), and *cis*- and *trans*-1,2-dichloroethene (*cis*- and *trans*-1,2-DCE) were detected in 1 to 5 percent of the public well samples. In a national survey conducted by the USEPA (1981–1982), these solvents were among the most frequently detected VOCs in treated water from PWSs.[8]

20. Ground Water is Used by Many PWSs

Nearly 145,000 PWSs provide ground water for human consumption to about 112 million people in the United States.[38] PWS categories established by the USEPA include CWSs and non-community water systems (NCWSs). CWSs serve a residential population such as a municipality, mobile home park, or nursing home. NCWSs are divided into non-transient, non-community water systems (NTNCWSs), such as schools, hospitals, and factories; and transient non-community water systems (TNCWSs), such as campgrounds, motels, and gasoline stations. Nearly 60 percent of PWSs are TNCWSs, but more than 80 percent of the U.S. population is served by CWSs.[38]



Ownership and size of population served by PWSs may vary from very small, privately owned systems whose primary business is something other than water supply (such as mobile home parks) to large, publicly owned water utilities that serve millions of people.[47]

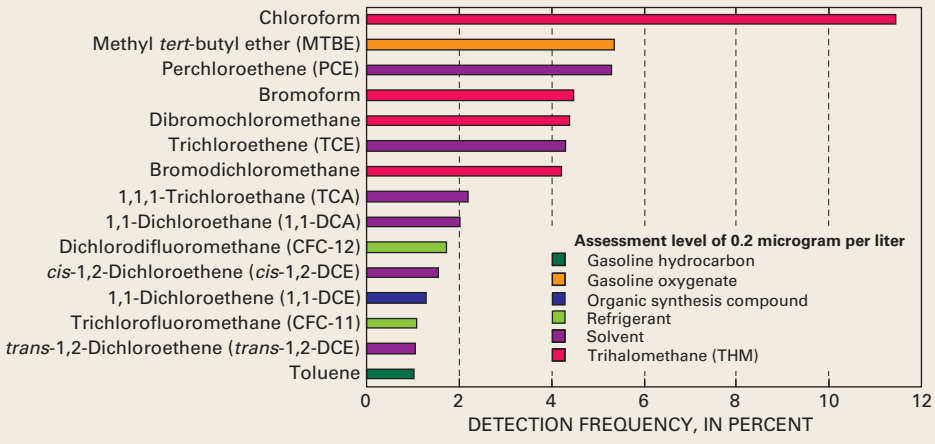


Figure 16. Trihalomethanes, solvents, and the gasoline oxygenate MTBE were among the 15 most frequently detected VOCs in public well samples.

21. Unregulated Contaminants, Including VOCs, are Monitored in PWSs

The 1996 SDWA Amendments require the USEPA to identify and publish a list of unregulated contaminants (referred to as the CCL) that are known or anticipated to occur in PWSs and that may require regulation with a national primary drinking-water standard.[49] In making regulatory determinations for compounds on the CCL, USEPA must determine whether (1) the contaminant may have an adverse effect on human health; (2) the contaminant is known to occur or there is substantial likelihood that the contaminant will occur in PWSs with a frequency and at levels of public health concern; and (3) in the sole judgment of the Administrator, regulation of such contaminant presents a meaningful opportunity for health risk reduction for people served by PWSs.[50] SDWA requires that the USEPA publish the CCL every 5 years and make regulatory determinations for at least five contaminants (also every 5 years).

The Unregulated Contaminant Monitoring (UCM) Program is the mechanism used to collect data for unregulated contaminants suspected to occur in drinking water.[51] The UCM list is revised every 5 years by the USEPA and is based primarily on the CCL.

Five VOCs monitored by NAWQA are currently listed on the second CCL published by the USEPA[52] and are prioritized for research and data collection efforts by the USEPA. These VOCs include bromomethane (methyl bromide), 1,1-DCA, 1,3-dichloropropene, MTBE, and 1,2,4-trimethylbenzene.[52] In public well samples collected for this national assessment, the isomers *cis*- and *trans*-1,3-dichloropropene were not detected, and bromomethane and 1,2,4-trimethylbenzene were detected in less than 1 percent of the samples. MTBE and 1,1-DCA had the largest detection frequencies of these five VOCs, 5.4 percent and 2.0 percent, respectively (Appendix 10).

THMs and solvents had the largest detection frequencies among VOC groups in public well samples (15 and 10 percent, respectively). In addition, gasoline oxygenates, predominantly MTBE, occurred in about 5 percent of the samples. All other groups were detected in about 3 percent or less of the samples. Spatial patterns of occurrence differed for VOC groups (see Circular's Web site). Detections of solvents, THMs, and gasoline hydrocarbons were distributed throughout the Nation. Gasoline oxygenates were detected primarily in the New England and Mid-Atlantic States, and in Florida and California. Detections of fumigants were predominantly in Hawaii and in the eastern coastal area of the United States.

Drinking water from PWSs is monitored for regulated contaminants and also for selected unregulated contaminants that may be considered for new drinking-water standards (sidebar 21). Five of the 29 regulated VOCs had one or more concentrations greater than MCLs (fig. 17A). These VOCs with concentrations of potential concern are 1,1-DCE, methylene chloride, PCE, TCE, and vinyl chloride and generally occurred in highly populated areas of the Nation (fig. 17B). None of the 15 unregulated VOCs with HBSLs had concentrations greater than these benchmarks. The solvents PCE and TCE comprised about three-quarters of the concentrations of potential concern.

About 2 percent of public well samples had VOC concentrations of potential human-health concern.

The regulated compounds benzene, bromodichloromethane, bromoform, carbon tetrachloride, chloroform, dibromochloromethane, 1,2-DCA, 1,2-dichloropropane, and *cis*-1,2-DCE were detected at concentrations less than but within a factor of 10 of MCLs (Appendix 11). In contrast, none of the 15 unregulated VOCs with HBSLs had concentrations within a factor of 10 of these benchmarks. The 5 VOCs with concentrations greater than their MCLs and the 9 VOCs within a factor of 10 of their benchmarks may warrant inclusion in a low-concentration, trends-monitoring program.

Potential sources of VOC contamination to public wells include leaking aboveground and underground storage tanks, sewer lines, effluent from septic systems, landfills, industrial sites, accidental spills, and areas where chemicals have been disposed of improperly.[48] Additionally, businesses associated with populated areas, such as dry cleaners, gasoline stations, auto repair and re-painting shops, and industrial fabricators that use VOCs

to clean and degrease material and equipment or complete other processes, may be potential contaminant sources. Other possible VOC sources include industrial and motor vehicle emissions to the atmosphere,[53] highway runoff, and urban stormwater runoff.[54]

The detection of VOCs in public well samples has been shown to be associated with the CWS size (sidebar 22). VOCs were detected more frequently and at greater concentrations in samples from very large systems than from smaller systems.[13] A study by the USEPA Office of Drinking Water (1981–1982) also found that samples from large PWSs had more frequent VOC detections and greater VOC concentrations than small systems.[8]

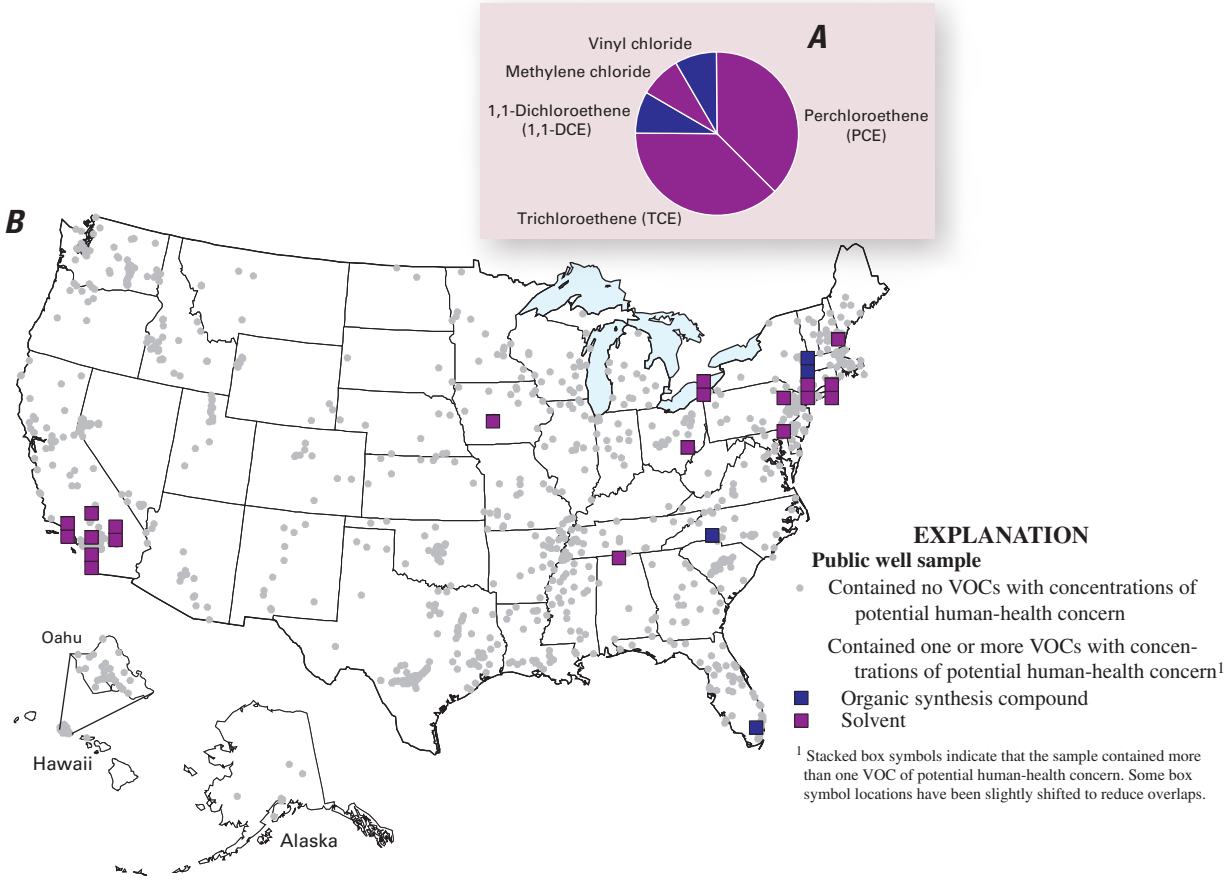


Figure 17. VOC concentrations of potential human-health concern in public well samples included solvents and compounds used in organic synthesis: (*A*) solvents accounted for about 85 percent of these concentrations; and (*B*) these concentrations occurred predominantly in the highly populated areas of southern California and the New England and Mid-Atlantic States.

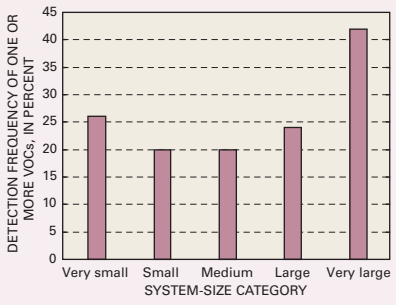
Comparison of VOCs in Samples from Domestic and Public Wells

22. VOCs Occur More Frequently in the Water Supply of Very Large CWSs than Other System Sizes

The USGS assisted in a nationwide survey (1999–2002) to characterize the occurrence of VOCs in ground water that served as a drinking-water supply for CWSs.[13] The survey used a statistically stratified design for sampling 575 public wells from randomly selected CWSs representative of the five size categories as follows:

CWS Size	Population Served
Very small	less than 500
Small	501 to 3,300
Medium	3,301 to 10,000
Large	10,001 to 50,000
Very large	more than 50,000

In general, VOCs were detected most frequently in the very large CWSs. As of 1998, very large CWSs using ground water collectively provided drinking water to about 26 million people. VOC detections were significantly related to urban land use and population density associated with large systems.[13] In particular, detections of gasoline hydrocarbons, solvents, and refrigerants were detected more frequently in ground-water supplies from very large CWSs than from smaller sized systems.



VOC occurrence in samples from domestic and public wells is compared in this section. Additionally, VOC data for public well samples are compared to the findings of previous investigations (sidebar 23). Domestic well samples had fewer compounds and mixtures, lower detection frequencies, and smaller VOC concentrations than public well samples.

VOCs were detected more frequently and had more concentrations of potential human-health concern in public well samples than in domestic well samples.

The 10 most frequently detected VOCs for each well type are shown in figure 18. The three most frequently detected VOCs were the same for samples from domestic and public wells—chloroform, MTBE, and PCE. Some of the 55 VOCs were not detected at the 0.2 µg/L assessment level (table 5) in any domestic or public well samples (18 and 14 VOCs, respectively). VOCs within the organic synthesis group had the greatest proportion of compounds with no detections for both well types. In contrast, all of the VOCs in the THM and refrigerant groups were detected in samples from both well types. All of the VOCs in the gasoline hydrocarbon group were detected in public well samples, whereas four of these VOCs were not detected in domestic well samples (table 5).

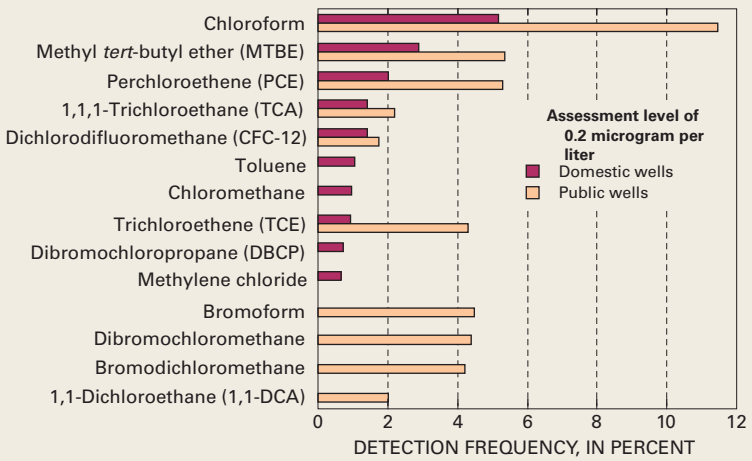


Figure 18. Although the top 3 of the 10 most frequently detected VOCs were the same for samples from domestic and public wells, the overall signature of VOC detections associated with domestic and public wells differed.

Table 5. VOCs with no detections in samples from domestic or public wells at an assessment level of 0.2 microgram per liter.

[ND, VOC not detected; --, VOC detected]

Compound	Well type	
	Domestic	Public
Fumigants		
Bromomethane	ND[1]	--
Dibromochloropropane (DBCP)	--	ND
cis-1,3-Dichloropropene	ND[1]	ND
trans-1,3-Dichloropropene	ND[1]	ND
Ethylene dibromide (EDB)	--	ND
Gasoline hydrocarbons		
n-Butylbenzene	ND	--
Styrene	ND	--
o-Xylene	ND	--
m- and *p*-Xylenes[2]	ND	--
Gasoline oxygenate		
Ethyl *tert*-butyl ether (ETBE)	ND[1]	--
Organic synthesis compounds		
Acrolein	ND[1]	ND
Acrylonitrile	ND[1]	ND
Hexachlorobutadiene	ND[1]	ND
1,2,3-Trichlorobenzene	ND[1]	ND
Vinyl bromide	ND[1]	ND
Solvents		
1,3-Dichlorobenzene	ND	ND
Hexachloroethane	ND[1]	ND
n-Propylbenzene	--	ND
1,2,4-Trichlorobenzene	ND[1]	ND
1,1,2-Trichloroethane	ND	ND

[1]VOC also was not detected in a subset of domestic well samples analyzed using a low-level method and with no assessment level applied.

[2]Considered as 2 of the 55 compounds included in this assessment.

23. NAWQA's VOC Assessment Can Be Placed in the Context of Other Studies for Public Wells

This NAWQA study provides one of the few existing national assessments of VOCs in public well samples. The few previous studies of VOC occurrence generally were based on samples of drinking water. One such study was completed by the USEPA during 1981–1982 and focused on 29 VOCs in treated water from CWSs.[8] In this study, VOC concentrations greater than 5 µg/L were found in 2.9 percent of samples from CWSs serving less than 10,000 people and in 6.5 percent of the samples from CWSs serving more than 10,000 people. Although untreated water was sampled for this NAWQA assessment, VOC occurrence in these size categories was similar, 2.4 and 7.8 percent, respectively.

A recent study completed in 2002 by the USEPA,[55] based on compliance monitoring data, also provided information on the quality of drinking water from PWSs. In the USEPA study, nine VOCs—benzene, carbon tetrachloride, 1,2-DCA, 1,1-DCE, methylene chloride, 1,2-dichloropropane, PCE, 1,1,2-trichloroethane, and TCE—each had concentrations greater than their MCL in less than 0.7 percent of the PWSs sampled. In public wells sampled by the NAWQA Program, only four of these VOCs—1,1-DCE, methylene chloride, PCE, and TCE—each had concentrations greater than their MCL in less than 0.9 percent of the samples.

The 15 most frequently detected VOCs in domestic well samples represented all VOC groups with the exception of organic synthesis compounds (fig. 14), whereas VOCs in public well samples were predominantly THMs, solvents, and the gasoline oxygenate MTBE (fig. 16). Total concentrations for each VOC group were summed for each sample with detections. For domestic well samples, organic synthesis compounds had the greatest **median** total concentration (1.1 µg/L), and refrigerants had the lowest (0.3 µg/L). For public well samples, solvents had the greatest median total concentration (0.7 µg/L), and gasoline hydrocarbons had the lowest (0.4 µg/L).

24. Specific VOC Mixtures Occurred Infrequently, But Were More Common in Public Well Samples

All specific mixtures of VOCs occurred in less than 1 percent of domestic well samples, and in less than 4 percent of public well samples at an assessment level of 0.2 µg/L. The table below ranks the 10 most common VOC mixtures by their detection frequency in domestic well samples and in public well samples, and shows the more common occurrence of mixtures in public well samples.

[MTBE, methyl *tert*-butyl ether; PCE, perchloroethene; TCA, 1,1,1-trichloroethane; TCE, trichloroethene]

Rank	VOC mixture	Detection frequency, in percent
	Domestic well samples	
1	PCE–TCA	0.62
2	Chloroform–PCE	.50
2	Chloroform–MTBE	.50
2	PCE–TCE	.50
5	Dibromochloromethane–chloroform	.42
6	Chloroform–TCA	.37
6	TCA–TCE	.37
8	PCE–MTBE	.33
9	Bromoform–dibromochloromethane	.29
9	Bromoform–chloroform	.29
	Public well samples	
1	Bromodichloromethane–dibromochloromethane	3.4
2	Bromodichloromethane–chloroform	3.2
3	Bromoform–dibromochloromethane	2.9
4	Dibromochloromethane–chloroform	2.5
5	Bromodichloromethane–dibromochloromethane–chloroform	2.4
6	PCE–TCE	2.3
7	Bromodichloromethane–bromoform	2.0
7	Bromodichloromethane–bromoform–dibromochloromethane	2.0
9	Bromoform–chloroform	1.7
10	Bromoform–dibromochloromethane–chloroform	1.6

Samples from domestic and public wells had about the same number of VOCs with concentrations of potential concern (6 and 5 VOCs, respectively) (table 6). VOCs with concentrations of potential concern in both well types included 1,1-DCE, PCE, and TCE. Domestic wells had three additional VOCs with concentrations of potential concern—DBCP, 1,2-dichloropropane, and EDB; and public wells had two additional VOCs with concentrations of potential concern—methylene chloride and vinyl chloride (Appendixes 9 and 11). Overall, domestic well samples had a smaller percentage of samples with VOC concentrations of potential concern than public well samples (1.2 and 1.5 percent, respectively).

VOCs with the largest proportion of concentrations of potential concern differed between well types (figs. 15A and 17A). For domestic well samples, fumigants and solvents had the most concentrations of potential concern, with DBCP having the greatest proportion. For public well samples, solvents and compounds used for organic synthesis had the most concentrations of potential concern, with PCE and TCE each having the greatest and equal proportions. VOC concentrations of potential concern for domestic wells were located predominantly in the Central Valley and other areas of California, whereas concentrations of potential concern for public wells generally occurred in southern California and in the New England and Mid-Atlantic States.

VOC mixtures were detected more frequently in public well samples than in domestic well samples.

Occurrence of mixtures may result from persistence of VOCs in the environment, co-occurrence of parent compounds with their degradation by-products, multiple compounds sharing the same source, and wide distributions of VOCs that may have overlapping sources.[12] VOC mixtures occurred less frequently in domestic well samples (3.9 percent) than in public well samples (13.4 percent) at an assessment level of 0.2 µg/L. Furthermore, a single VOC occurred more frequently than multiple VOCs in domestic well samples, whereas detections of single VOCs and multiple VOCs were about equal in public well samples (table 6). Also, concentrations of individual VOCs in mixtures generally were greater than the compound's concentration when detected alone in a sample.

Solvents, THMs, and the gasoline oxygenate MTBE comprised the 10 most frequently detected VOC mixtures for domestic well samples (sidebar 24). In contrast, all but 1 of the 10 most frequently occurring VOC mixtures for public well samples were mixtures of THMs; the exception was the

Table 6. Statistics for VOC occurrence in samples from domestic and public wells at an assessment level of 0.2 microgram per liter.

[MCL, Maximum Contaminant Level; HBSL, Health-Based Screening Level; µg/L, micrograms per liter]

Occurrence information	Well type	
	Domestic	Public
Detections		
Number of VOCs detected	37	41
Frequency of one or more VOCs, in percent	14.0	26.2
Frequency of VOC groups, in percent	trihalomethanes (THMs), 5.3 solvents, 4.9 gasoline oxygenates, 2.9 refrigerants, 2.1 gasoline hydrocarbons, 1.5 fumigants, 1.2 organic synthesis compounds, 0.2	trihalomethanes (THMs), 14.7 solvents, 9.9 gasoline oxygenates, 5.3 refrigerants, 2.6 gasoline hydrocarbons, 2.2 fumigants, 1.3 organic synthesis compounds, 1.4
Most frequently detected VOCs, in percent	chloroform, 5.2 methyl *tert*-butyl ether (MTBE), 2.9 perchloroethene (PCE), 2.0	chloroform, 11.4 methyl *tert*-butyl ether (MTBE), 5.4 perchloroethene (PCE), 5.3
Concentrations		
Total VOC concentrations less than 1 µg/L, in percent	62.2	49.8
Total VOC concentrations greater than 10 µg/L, in percent	6.6	8.4
Median concentration of samples with detections for the three most frequently detected VOCs, in µg/L	chloroform, 0.5 methyl *tert*-butyl ether (MTBE), 0.6 perchloroethene (PCE), 0.4	chloroform, 0.6 methyl *tert*-butyl ether (MTBE), 0.6 perchloroethene (PCE), 0.7
Detections and concentrations of potential human-health concern		
Number of VOCs with concentrations greater than their MCL	6	5
Frequency of concentrations greater than their MCL, in percent	1.2	1.5
Number of VOCs with concentrations greater than their HBSL	0	0
Frequency of concentrations greater than their HBSL, in percent	0	0
Total number of VOCs with concentrations of potential human-health concern	6	5
Multiple VOCs		
Total number of VOCs that occurred in mixtures	38	40
Number of VOCs occurring only in mixtures	16	18
Frequency of well samples with a single VOC detection, in percent	10.1	12.8
Frequency of mixtures in all wells, in percent	3.9	13.4
Frequency of mixtures in well samples with VOC detections, in percent	27.7	51.2

solvent mixture PCE–TCE. Solvents, however, were common components of VOC mixtures in public well samples that occurred at detection frequencies lower than those for the mixtures listed in sidebar 24.

Generally, public wells are more vulnerable to low-level VOC contamination than domestic wells.

As previously described for ground water in general (p. 24 and 25), many factors can be associated with the source, transport, and fate of VOCs. Results of statistical models used in this assessment indicated that for samples from both domestic and public wells, hydrogeologic factors

Comparison of VOCs in Domestic and Public Well Samples—Continued

associated with an increased probability of detecting VOCs included high aquifer recharge and high soil permeability. Furthermore, dissolved-oxygen concentration in samples from domestic and public wells was an important factor associated with the occurrence of individual VOCs.

Anthropogenic factors strongly associated with the increased probability of VOC detections in both well types included population density and percentage of urban land use near the sampled wells. Additionally, the probability of detecting VOCs was associated with the number of nearby RCRA hazardous-waste facilities. For public well samples, increased MTBE occurrence was associated with local use of this VOC in gasoline.

Although hydrogeologic and anthropogenic factors associated with VOC occurrence were similar for both well types, findings from this assessment indicate that public well water has the potential for more frequent detections of individual VOCs and mixtures and for greater concentrations than domestic well water. These findings are apparent despite the much deeper median depth of sampled public wells (303 feet) than domestic wells (104 feet). In general, deep public wells are presumed to be less vulnerable than shallow domestic wells to anthropogenic contaminants that originate on or near the land surface. However, several factors including large withdrawal rates from public wells and proximity to developed areas explain, at least in part, why public wells have a larger vulnerability to VOC contamination despite their typically greater depths.

Two recently completed NAWQA Study-Unit investigations explain, and figure 19 illustrates, reasons for the differences in VOC occurrence between domestic and public wells. A study of paired domestic and public wells within the High Plains aquifer system in the central part of the United States indicated that water containing surface-derived anthropogenic compounds from near the water table was drawn more quickly to the higher

Photograph courtesy of Mike Wolforth, Light Images

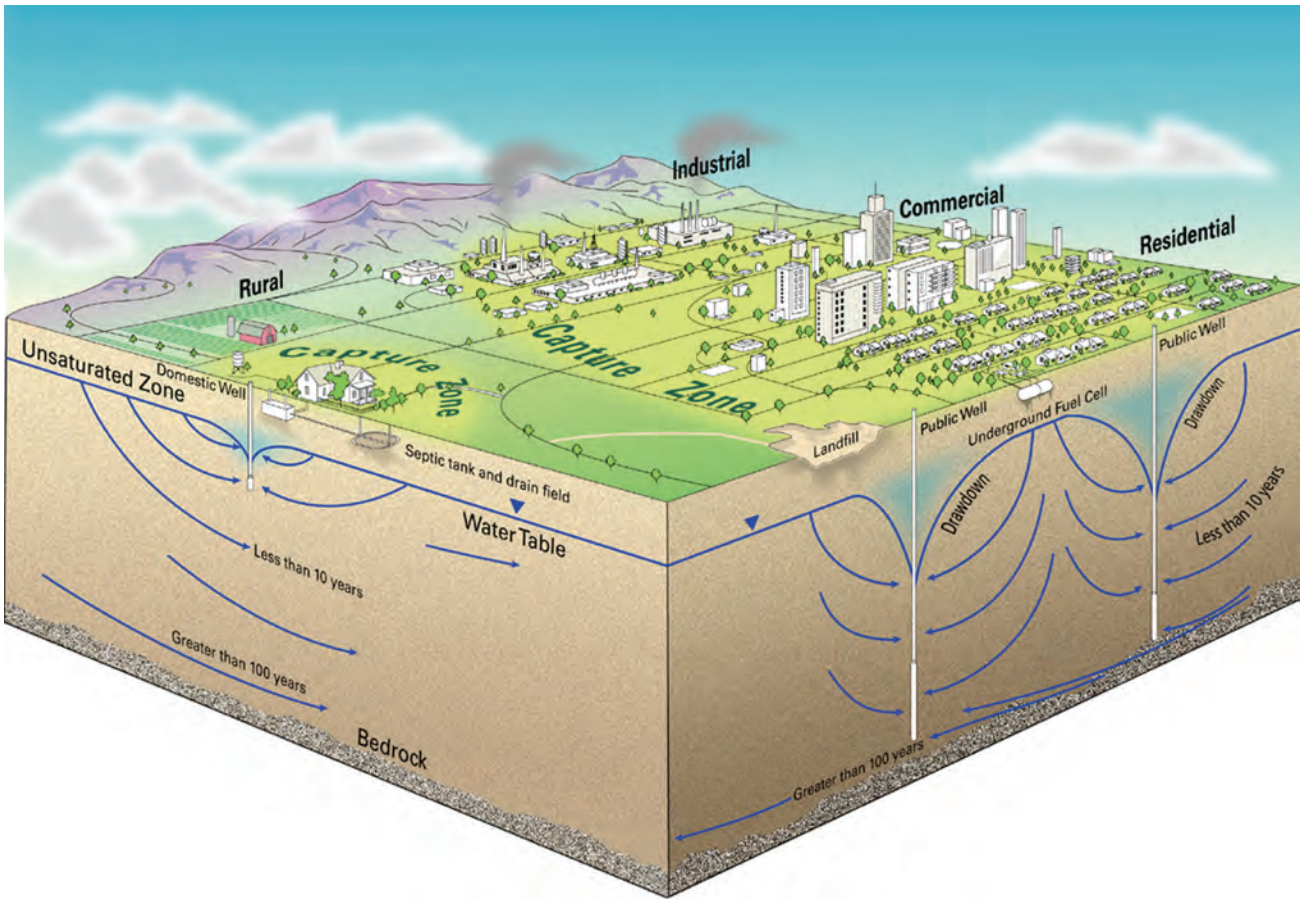


Figure 19. Differences in hydrogeologic and anthropogenic factors can affect the quality of ground water that supplies domestic and public wells.

volume pumping systems.[56] Production rates of public wells create a larger capture zone, greater drawdown, and faster movement of water from the top of the water table to the well screen than the comparatively low production rates of domestic wells.

Relatively young water in recently recharged ground water can be intercepted by both domestic and public wells (fig. 19). The frequent occurrence of MTBE in samples from public wells in the Kirkwood-Cohansey aquifer system in southern New Jersey was attributed to the capture of young ground water through the interception of flowpaths with short traveltimes.[57] Furthermore, for the same aquifer system, public wells intercepted VOCs from multiple land uses and point sources within a large contributing area.[48, 58] Additionally, deep public wells also can intercept ground water flowing along extensive paths associated with long residence times. This water may contain degradation by-products from parent compounds. VOCs that had substantial historical use, but whose use has been reduced or phased out, may be potential contaminants in ground water with relatively long flowpaths.