Contaminants and Drinking-Water Sources in 2001: Recent Findings of the U.S. Geological Survey

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Conversion Factors, Water-Quality Units, and Abbreviations

Multiply	By	To Obtain
	Length	
nanometer (nm)	3.937×10^{-8}	inch (in.)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
liter (L)	0.2642	gallon (U.S.)

Chemical Water-Quality Units

Milligrams per liter (mg/L) or micrograms per liter (µg/L): Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams of solute) per unit volume (liter of water). One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numeric value in milligrams per liter is the same as for concentrations in parts per million, and the concentrations in mircrograms per liter is the same as for concentrations in parts per billion.

Contaminants and Drinking-Water Sources in 2001: Recent Findings of the U.S. Geological Survey

ABSTRACT

As the Nation's principal earth-science agency, the U.S. Geological Survey (USGS) studies numerous issues related to contamination of drinking-water sources. The work includes monitoring to determine the spatial and temporal distribution of contaminants; research to determine sources, transport, transformations, and fate of contaminants, and assessments of vulnerability. Much of the work is conducted in cooperation with the U.S. Environmental Protection Agency and other Federal, State, Tribal, and local governments, to help provide a scientific basis for resource management and regulation. Examples of recent results are presented for two broad categories of drinking-water projects: occurrence studies, and source-water assessments.

INTRODUCTION

The USGS conducts a wide range of hydrologic, geologic, biologic, and geographic activities that provide information to help understand, manage, and protect our Nation's sources of drinking water. Most of this work falls into two broad categories: (1) Collecting and interpreting data on the occurrence and distribution of drinking-water contaminants in rivers, lakes, and ground water, and (2) Assessing the characteristics of the rivers, lakes, watersheds, and aquifers that the Nation uses as sources of drinking water (source-water areas). Both of these broad categories include a component of research on fundamental hydrologic processes and methods. Much of the work is conducted in cooperation with the U.S. Environmental Protection Agency (USEPA) and other Federal, State, Tribal, and local governments, to provide a scientific basis for management of source waters. USGS programs related to drinking water include the National Water Quality Assessment (NAWQA) Program (http://water.usgs.gov/nawqa/), the Drinking Water Initiative, the Toxic Substances Hydrology Program (http://toxics.usgs.gov/), and the Cooperative Water Resources Program (http:/water.usgs.gov/wid/html/COOP.html). A few examples have been selected to illustrate the range of drinking-water-related projects recently completed or underway at the USGS. For more information on any of the examples, or for related inquiries, visit the USGS Drinking Water website at (http://water.usgs.gov/owq/dwi/), or visit the program websites listed in this report.

CONTAMINANT OCCURRENCE AND DISTRIBUTION DATA

Contaminant occurrence and distribution data that are used to conduct research and determine policy on drinking water are collected and analyzed by many Federal, State, and local agencies, as well as universities, consortiums, citizen groups, and similar organizations. These data are collected for many purposes and by various methods, with varying levels of detail and quality control. As the data vary, so does the availability and distribution of the data. For example, Consumer-Confidence Reports (CCRs) have recently been made available by all community water suppliers (those serving more than 10,000 people are required to mail the reports to their customers). CCRs explain which contaminants are monitored, as well as the concentration of those contaminants in the drinking water delivered to customers' homes (finished drinking water).

Data collected and analyzed with nationally consistent protocols by the USGS are typically derived from the smaller community systems (less than 10,000 customers), homeowners' drinking-water wells, and source-water areas. USGS programs include data-collection efforts on scales ranging from detailed assessments of the overall quality of local water resources to national assessments of the occurrence and distribution of selected contaminants. In addition, USGS programs collect data on contaminants that are currently regulated by the USEPA, such as arsenic, radionuclides, and microbial indicators, as well as many that are not, including selected degradates (breakdown products) of pesticides and volatile organic compounds (VOCs). Much of this information is collected through the USGS National Water-Quality Assessment (NAWQA) Program, which is designed to describe the status and trends in the quality of the Nation's ground- and surface-water resources and to provide a sound understanding of the natural and human factors that affect the quality of these resources. Nationally consistent methods of sampling and analysis (at very low concentration levels) facilitate integration of data collected at the local scale ("study unit") into "national synthesis" data sets and publications. Data on occurrence and co-occurrence (tendency to occur together) are collected for a range of contaminants including nutrients, pesticides, trace elements, radionuclides, and microbes. Through this and other programs, the USGS is providing new and valuable data on source-water and drinking-water quality across the Nation, made available through web pages, printed reports, and CD-ROM's. Information for your State or local area can be found on local USGS websites from these web pages:

Drinking Water Programs: http://water.usgs.gov/owq/dwi/
NAWQA: http://water.usgs.gov/nawqa/
General Water Programs: http://water.usgs.gov/wrd002.html.

Pesticides

Among the contaminants studied by the USGS with significance for drinking water are selected pesticides and degradates (breakdown products) (fig. 1). NAWQA results show that herbicides, insecticides, and their degradates are frequently detected, mostly at low concentrations, in both surface and ground water, in both agricultural and urban or

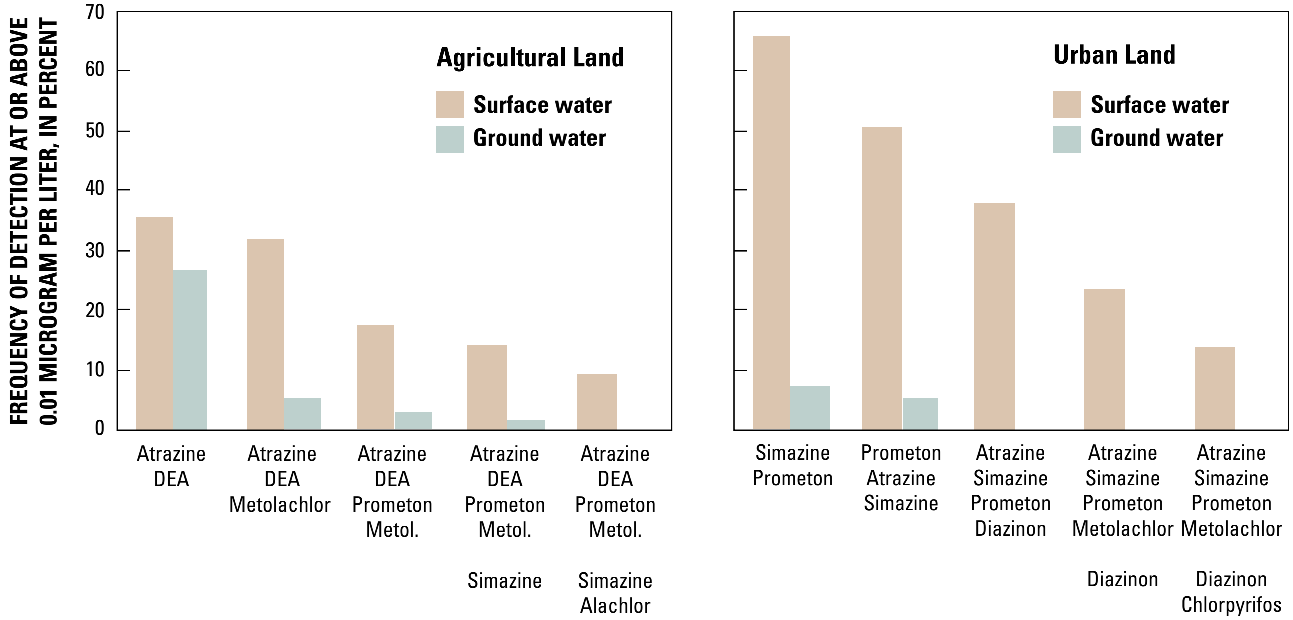


Figure 1. Common pesticide mixtures detected in waters of the United States. Left bar of each pair is for surface water; right bar is for ground water. (Modified from U.S. Geological Survey, 1999.) For more information about NAWQA nutrients results, please visit: http://water.usgs.gov/nawqa/nutrient.html.

residential areas. Identification of commonly occurring chemical mixtures of these compounds is helping to guide research on their health effects.

Volatile Organic Compounds

NAWQA also monitors a variety of volatile organic compounds and some degradates, including the gasoline additive methyl-*tert*-butyl ether (MTBE). This additive is widely used to abate air pollution in certain parts of the Nation designated as reformulated-gasoline (RFG) and oxygenated-gasoline (OXY) areas. At a reporting level of 0.2 mg/L, MTBE was detected in 21 percent of 480 wells located in RFG and OXY areas. In the rest of the Nation, MTBE detection frequency in ground water was 2 percent. Gasoline aromatic hydrocarbons (benzene, toluene, ethylbenzene, and xylenes, collectively known as BTEX)

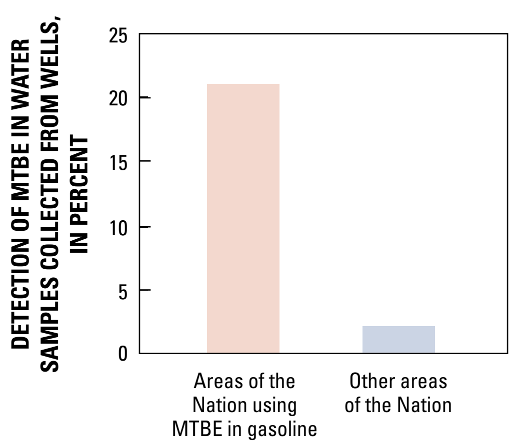


Figure 2. Percent detections of MTBE in United States wells.

were detected much less frequently (4 percent) than MTBE in ground water in these RFG and OXY areas (fig. 2).

Most of the detections of MTBE in ground water sampled in the NAWQA Program have been at concentrations less than the USEPA drinking-water advisory; however, the frequency of detection at concentrations above 5 mg/L and above the lower limits of USEPA's advisory (20 mg/L) in RFG and OXY areas is about 10 times higher than in the rest of the Nation. These NAWQA results have helped clarify the picture of MTBE occurrence, which is useful in discussions related to phasing out the additive. For more information on MTBE, please visit http://wwwsd.cr.usgs.gov/nawqa/vocns/.

Arsenic

Recently, a retrospective analysis of arsenic in groundwater resources was completed with data previously collected by USGS personnel and stored in the USGS National Water Information System (fig. 3). This information on arsenic occurrence helps in estimating the costs and benefits of the 2001 reduction in the maximum contaminant level from 50 to 10 mg/L. For more information on arsenic in ground water of the United States, please visit: http://co.water.usgs.gov/trace/arsenic/.

Microbes

A growing number of USGS contaminant-occurrence studies include a microbial component. For example, the USGS Missouri District, in cooperation with the Missouri Department of Natural Resources, studied the occurrence of 3 types of bacteria and 2 types of viruses in 109 public-supply wells completed in the Ozark Aquifer within Missouri during 1997–98 (Davis, 2000; Davis and Witt, 2000). Results showed that 86 percent of the public-supply wells were free

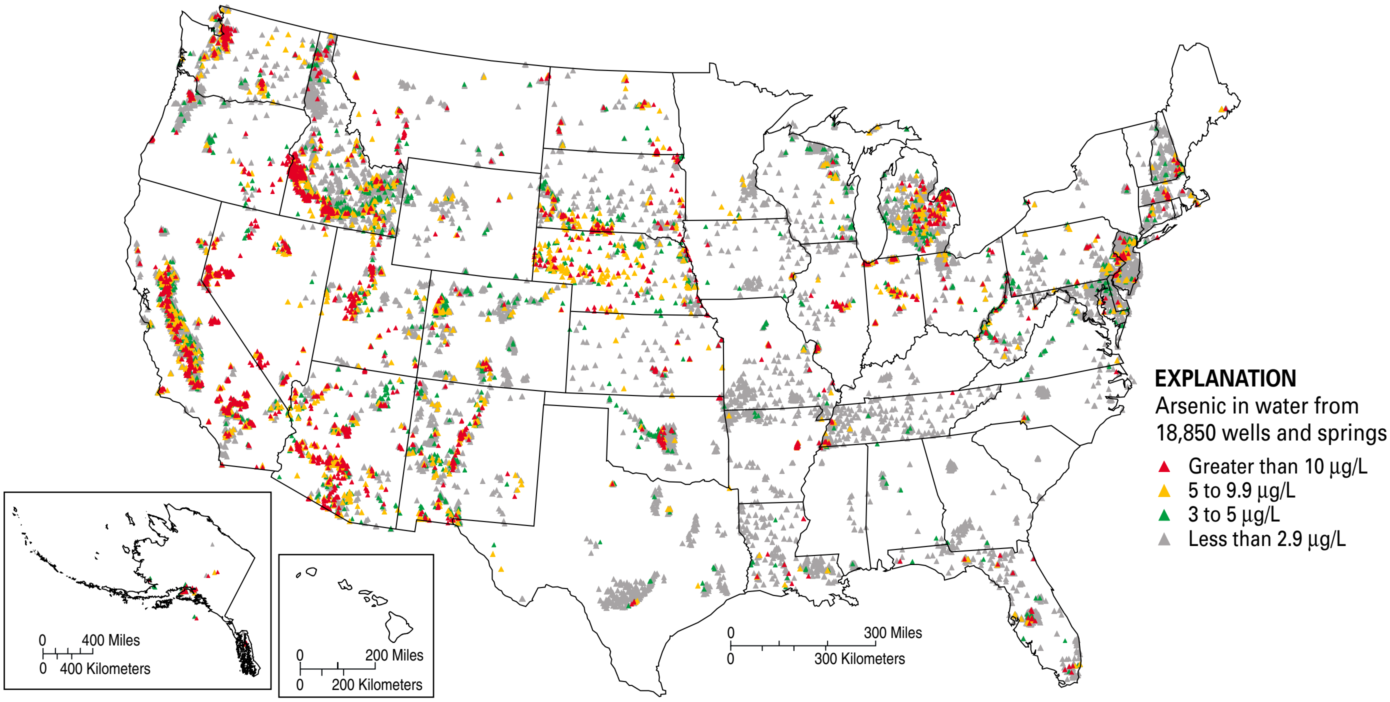


Figure 3. Concentrations of arsenic in ground water in the United States.

of these microbial contaminants—information useful to State regulators and health officials, as well as to water utilities and water users. For more information, please visit http://wwwdmorll.er.usgs.gov/missouri/fact-sheets/qw.fct.html.

In Georgia, Michigan, Washington, and Virginia, microbial studies include DNA fingerprinting and other techniques in an effort to identify sources of microbes in streams. These studies will help to protect water supplies from contamination by targeting source-reduction efforts toward those animal or human sources of fecal contamination most responsible for polluting certain streams. Please visit http://ga.water.usgs.gov/projects/chatm/description.html for details on the Georgia study and http://mi.water.usgs.gov/ for the Michigan studies.

Radionuclides

The USGS, in cooperation with the USEPA, the American Water Works Association, and the American Water Works Service Company, completed a targeted reconnaissance survey of 100 public ground-water supplies with an emphasis on areas of the country expected to have naturally occurring isotopes of radium (Focazio and others, in press). Other radionuclides analyzed to augment existing occurrence data included polonium-210 (Po-210) and lead-210 (Pb-210).

In water samples from many of the targeted public water-supply systems, Ra-224 (a short-lived isotope of radium) constituted a significant portion of the gross-alpha particle radiation in the drinking water (table 1).

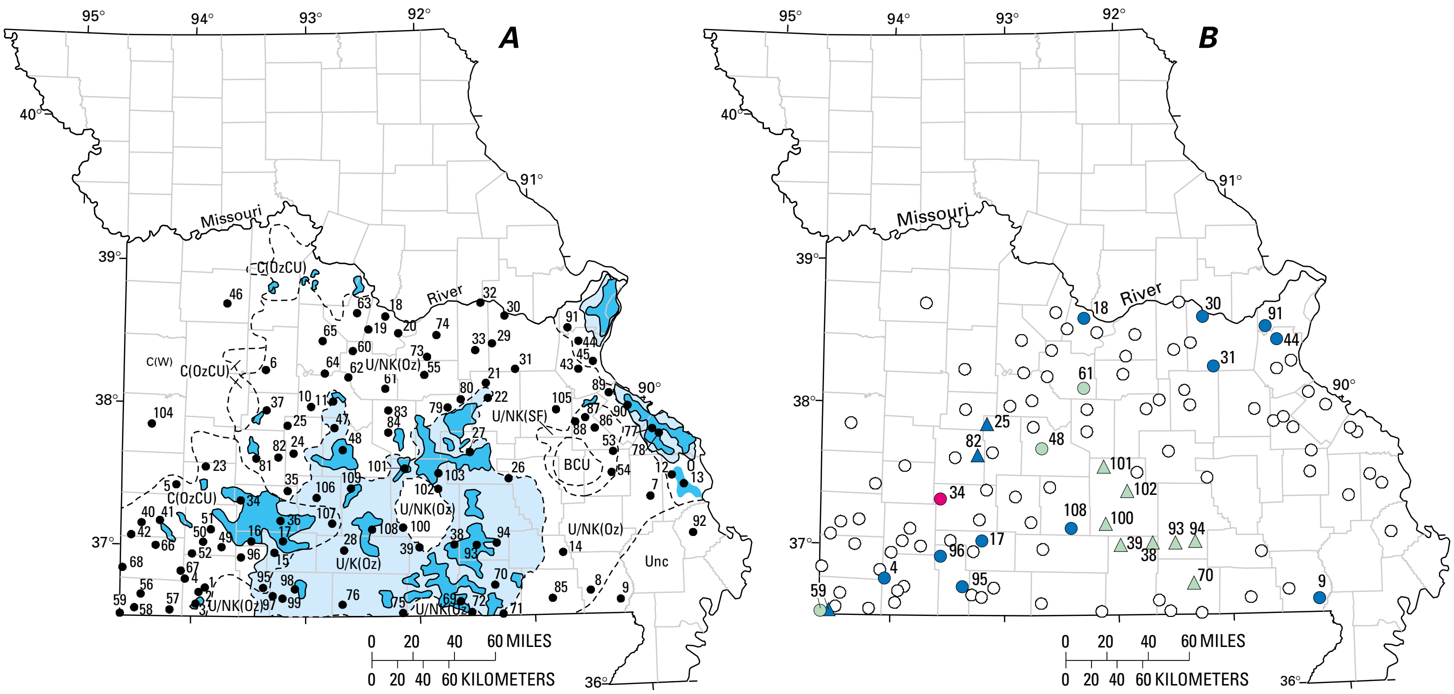
This finding is important because conventional monitoring procedures do not specify a maximum holding time for the samples to be analyzed for gross-alpha-particle radiation. Consequently, some analyses are made after most of the Ra-224 has decayed. This could lead to inaccurate indications of compliance with drinking-water standards where public water-supply wells tap radium-rich aquifers. The study also corroborated previous studies which indicated that the gross-alpha-particle screen used to determine combined radium (Ra-226 + Ra-228) compliance could be inadequate in some situations. These results are helping the USEPA and the States to develop strategies for more accurate assessment of radiological risks in drinking water. For more information in your area please visit http://water.usgs.gov/owq/dwi/ or http://co.water.usgs.gov/trace/.

Research Related to Contaminant Occurrence and Distribution

The USGS conducts basic research to help ensure that tomorrow's drinking-water programs address appropriate

Table 1. Summary of radionuclide concentrations in the multi-state survey (from Focazio and others, in press)

	Activity, in picocuries per liter				
Radionuclide	Mean	Median	Standard deviation	Maximum	Number of Samples
Ra-224	3.2	0.3	10.1	73.6	99
Ra-226	1.6	0.4	2.8	16.9	99
Ra-228	2.1	0.5	7.9	72.3	99
Pb-210	0.6	0.5	0.5	4.1	96
Po-210	0.1	0.01	0.5	4.9	96



EXPLANATION

		AQUIFER TYPE	
PRIMARY KARST AREA	C(OzCU)	Ozark aquifer overlain by Springfield Plateau aquifer and confined by Ozark confining unit
SECONDARY KARST AREA	U/NK(Oz)	Unconfined Ozark aquifer; nonsignificant karst features
--- BOUNDARY OF AQUIFER TYPE	U/NK(SF)	Unconfined St. Francois aquifer; nonsignificant karst features
•8 PUBLIC-WATER-SUPPLY WELL AND NUMBER (table 1)	BCU	Basement confining unit
	U/K(Oz)	Unconfined Ozark aquifer; primary and secondary karst features
	C(W)	Ozark aquifer confined by Western Interior Plains confining system
	Unc	Unconsolidated
	0	Other

EXPLANATION

ROUND 1 May-July 1997	ROUND 2 November 1997-March 1998	SAMPLES COLLECTED number is public-water-supply well identifier (table 1)
● 34		Enteric viruses present
● 17	▲ 25	Coliphage present
● 59	△ 70	Indicator bacteria present
○	○	Enteric viruses, coliphage, and indicator bacteria not present

Figure 4. Public-supply wells in Missouri sampled for microbes (A), and wells with detections (B).

questions with updated tools. Examples of these projects include development of laboratory analytical methods to detect targeted contaminants at very low concentrations and studies of the occurrence of emerging contaminants not currently regulated or monitored in drinking water supplies. Research topics also include chemical transformations and the breakdown of synthetic organic chemicals in the environment, methods development and use of environmental tracers to determine the ages and sources of ground and surface water contributed to wells and rivers, and detailed analyses of precursors associated with disinfection by-products.

The USGS Toxic Substances Hydrology Program (http:/toxics.usgs.gov/) conducts some of this research. For example, recent work in the Toxics Program has documented the prevalence of herbicide breakdown products (some of which have a toxicity similar to the parent compounds) in Iowa ground water, compared to the parent compounds (fig. 5) (Kolpin and others, 1999).

The Toxics Program also is developing laboratory analytical methods and conducting environmental occurrence studies on a variety of emerging contaminants in surface water and ground water, including selected veterinary and human antibiotics (chlortetracycline and sulfamethazine), prescription and non-prescription pharmaceuticals (for example, cimetidine and acetaminophen), sex and steroidal hormones (17 beta-estradiol and equilenin), and industrial and household wastewater products (triclosan and bisphenol A). Samples are being collected from water resources in a wide variety of land-use and hydrogeological settings (which may or may not be sources of drinking water). This research is being conducted in cooperation with the USEPA to provide additional data and interpretations on the occurrence of emerging contaminants in source-water areas used by community water systems, such as surface-water intake locations and wells used for public drinking water. Results may be used to guide research on health effects of low concentrations of these contaminants.

For more information, please visit the following web sites:

- USGS Toxic Substances Hydrology Program, http://toxics.usgs.gov/
- USGS National Water Quality Laboratory, http://wwwnwql.cr.usgs.gov/.

The research on disinfection by-product precursors has focused on the characteristics of naturally occurring organic substances from various vegetation types that make them more or less likely to produce toxic trihalomethanes (THM) (such as chloroform) by combining with chlorine during disinfection. For example, one study found that, contrary to expectations, agricultural drainage water from islands composed of peat had a lower tendency to form THM than water from open river channels (Bergamaschi and others, 1999b; Bergamaschi and others, 1999a). These findings will help in making decisions on managing the lands and waters of the Sacramento-San Joaquin Delta in California to minimize the risk for drinking-water consumers in southern California. For more information, please see http://water.usgs.gov/nrp/proj.bib/aiken.html.

SOURCE-WATER ASSESSMENTS

As required by the 1996 amendments to the Safe Drinking Water Act (P.L.104-182), States, Tribes, and water suppliers are conducting assessments to delineate surface- and ground-water source areas, to inventory potential sources of contamination, and to evaluate susceptibility of supplies to contamination. USGS contributions to these efforts range from national assessments of contaminant occurrence and vulnerability, to comprehensive statewide assessments, to targeted studies designed to answer a specific question. A few examples are described below. Others may be found at http://water.usgs.gov/owq/dwi/.

Source-Area Characteristics of Large Public Surface-Water Supplies

A cooperative project between the USEPA and the USGS was designed to assist State regulatory agencies in meeting the requirements of source-water assessment programs by providing a nationally consistent way to define the characteristics of source-water areas.

The product of this project is a CD-ROM that includes information on water time of travel during average streamflow conditions that could be used for segmenting the source-area watersheds as suggested in a USEPA (1997) guidance report. The information from the project may also

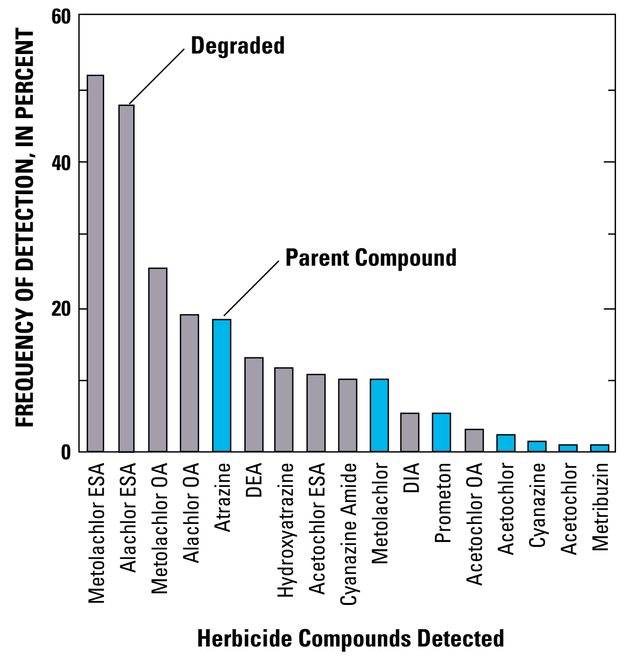


Figure 5. Frequency of detection for selected herbicide compounds (adjusted to a common detection threshold of 0.20 microgram per liter) and breakdown products in Iowa. (From Kolpin and others, 1999).

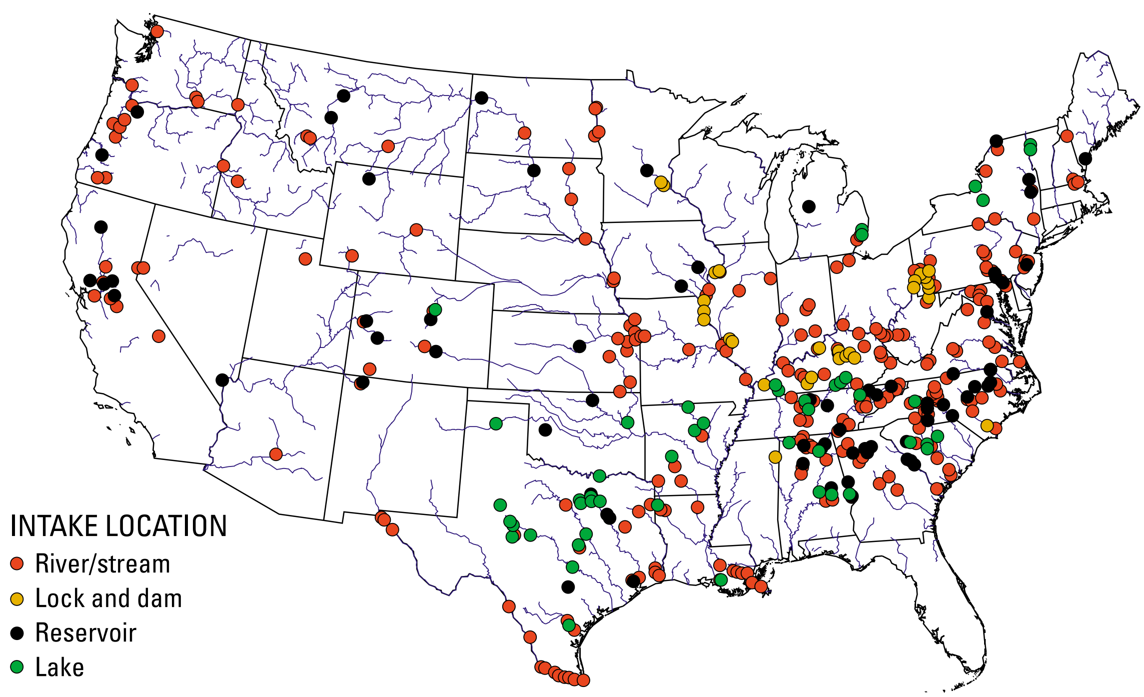


Figure 6. Location of 525 drinking-water intakes for large public water supplies in the United States.

assist Federal, State, and local water-monitoring agencies in identifying rivers, impoundments, and watersheds of importance to drinking-water supplies and to related local and regional monitoring programs and water-protection efforts. The first phase provides hydrologic and watershed information for the source areas of 525 surface-water intakes operated by the largest 437 public water suppliers in the conterminous United States (fig. 6). These suppliers serve populations greater than 10,000 with intakes in watersheds larger than 1,000 square kilometers and provide drinking water to a total of 50 million people. The source-area data and calculations were originally assembled for the recently developed USGS national water-quality model SPARROW (Smith and others, 1997), and are summarized by source area in the CD-ROM data base (Alexander and others, 1999). The information on the CD-ROM is helpful to municipalities and water utilities who need to assess and protect their source water on the basis of the time it takes to get to their intakes. For more information please see http://water.usgs.gov/nawqa/sparrow/.

California—Disinfection By-Product Precursors

Naturally occurring organic compounds (humic substances) derived from the decay of plants in source-water areas can combine with chlorine and other halogens used to disinfect drinking water to produce trihalomethanes (THM) (such as chloroform) and other toxic by-products. In California, water from the Sacramento and San Joaquin Rivers (fig. 7) is pumped to the southern part of the State to be used as drinking water by 22 million consumers. At times, the USEPA drinking-water standard of 0.1 mg/L THM is exceeded when the water is treated. About 20 to 50 percent of the THM precursors originate from agricultural drainage water from peat soils on islands in the Sacramento-San Joaquin Delta. A recent USGS study in cooperation with the California Department of Water Resources (Fujii and others, 1998) found that, as expected, THM production potential, dissolved organic carbon concentration, and ultraviolet absorbance at a wavelength of 254 nanometers (UV-254) were all highly correlated. Also as expected, anaerobic soil (without oxygen) tended to produce dissolved organic carbon with greater aromaticity (more benzene rings in the chemical structure) than aerobic soils (with oxygen). However, an unexpected result was that aromaticity of the naturally occurring organic matter was not correlated with its potential to form THM during disinfection with chlorine. This means that a simple test for aromaticity, such as the UV-254 test, may not be a good predictor of THM formation potential. More work will be needed to identify the types of humic substances that serve as THM precursors in this environment. Results will eventually help guide decisions on managing the land and water resources of the Delta region to minimize drinking-water-quality problems. For more information, please see http://ca.water.usgs.gov/rep/wrir984147/.

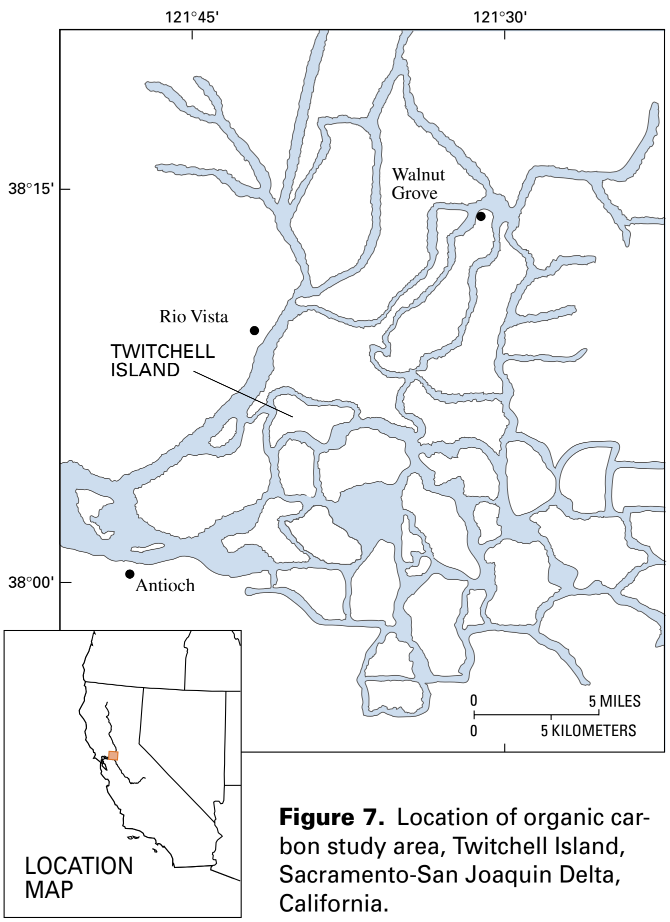


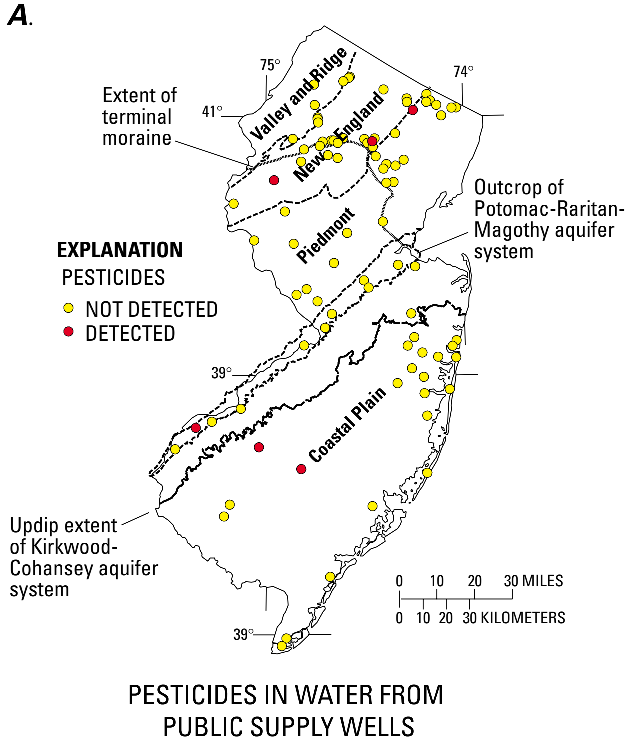
Figure 7. Location of organic carbon study area, Twitchell Island, Sacramento-San Joaquin Delta, California.

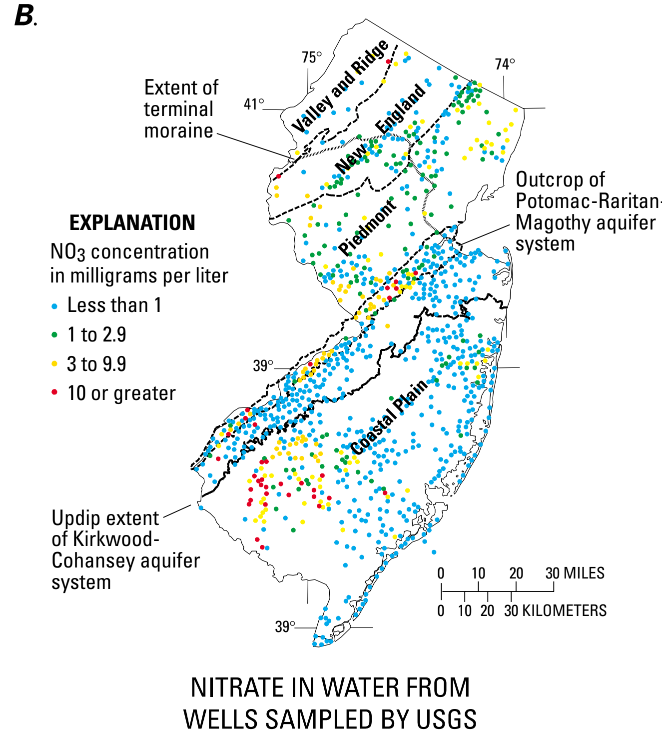
New Jersey—Vulnerability of Public-Supply Wells to Contamination

In collaboration with the New Jersey Department of Environmental Protection, the USGS has been collecting data on contaminant occurrence in both surface-water and ground-water source areas, and relating the results to geology, soils, land use, and other factors that affect vulnerability (fig. 8). Classification of public-supply wells according to their vulnerability to pesticides has already led to substantial cost savings through monitoring waivers for water suppliers whose sources are shown to be at low risk for contamination. Sampling is underway for analyses of volatile organic compounds, nitrates, metals, microbes, and radioisotopes in more than 2000 public-supply wells and at 50 surface-water intakes as part of a comprehensive statewide source-water assessment. The results will be used to target monitoring toward the more susceptible wells and intakes, to help guide source-water protection programs, and to help guide development of future water supplies. For more information, please see http://nj.usgs.gov/gw/maps/index.html and http://nj.usgs.gov/pub/onlinepubs.html.

Michigan—Arsenic in Ground Water, and Statewide Source-Water Assessment

Ground water in parts of southeastern Michigan contains concentrations of naturally occurring arsenic in excess of the USEPA maximum contaminant level of 10 micrograms per liter. In cooperation with several counties, the USGS is studying the sources and geochemical reactions responsible for the elevated arsenic levels. Maps being produced for each





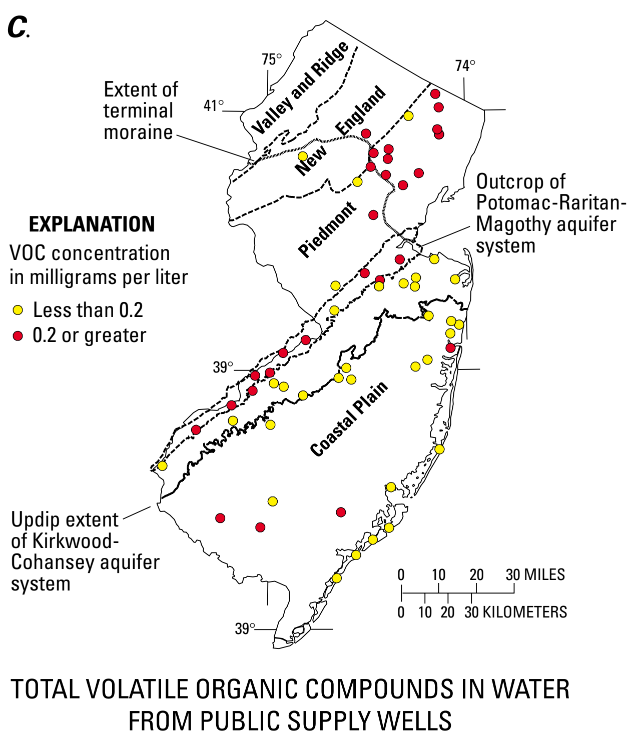


Figure 8. Data used for statewide source-water assessments of (A) pesticides, (B) nitrate, and (C) volatile organic compounds in ground water in the State of New Jersey.

county of the study show the distribution of elevated arsenic concentrations. Results will help homeowners and utilities avoid high-arsenic areas when they develop new wells, and could help the development of strategies to mitigate existing arsenic problems.

The USGS is also cooperating with the State of Michigan on a statewide source-water assessment project with four components:

(1) Use of hydrogeologic information, ground-water age dating, and historical water-quality data to determine susceptibility of wells in karst areas to contamination,

(2) Delineation and characterization of critical assessment zones for seven Michigan rivers used for water supply, based on time of travel to the intakes,

(3) Susceptibility analyses for water-supply intakes on the Great Lakes, using a protocol developed by the USEPA and the Great Lakes States, and

(4) Hydrodynamic modeling and particle tracking to determine susceptibility of 14 intakes on the St. Clair and Detroit Rivers, serving 5 million people, to contamination from accidental releases (spills) of toxic substances.

Texas—Statewide Source-Water Assessment

In cooperation with the Texas Natural Resources Conservation Commission, the USGS is determining the occurrence of pesticides and volatile organic compounds in drinking-water aquifers and reservoirs throughout the State. These results are being integrated, along with data on the environmental setting; geologic and hydrologic characteristics; chemical, water, and waste management practices; and land use/cover,

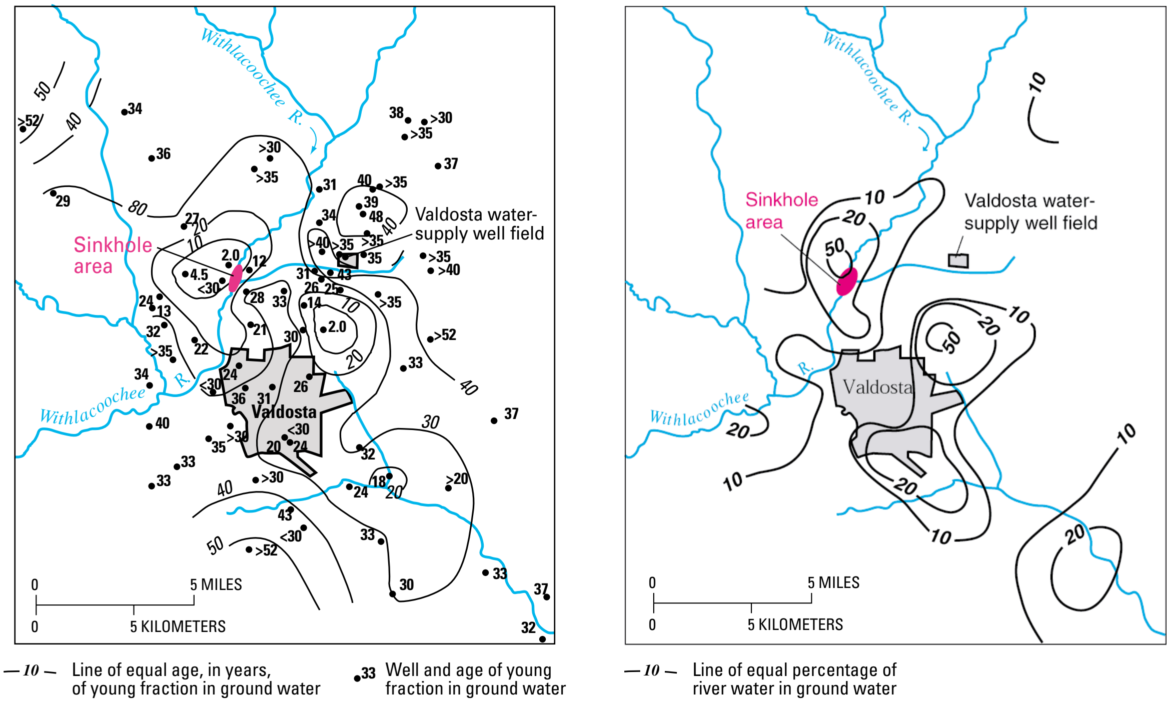


Figure 9. Ages of the young fraction in the Upper Floridan aquifer at Valdosta, Ga., in June, 1991 (A); and estimated percentage of Withlacoochee River water in ground water in the Upper Floridan aquifer, June 1991 (B). (Modified from Plummer and others, 1998a, 1998b.)

into software that will help determine the susceptibility of ground-water source areas statewide to contamination.

New Hampshire—Arsenic in Relation to Rock Type

USGS geologists and hydrologists are combining water-quality data with maps that show rock types grouped according to similar chemical properties. The resulting lithochemical maps show the likelihood of finding elevated concentrations of certain naturally occurring contaminants such as arsenic. The maps will be useful for predicting water quality in areas where samples have not yet been collected. For more information visit http://water.usgs.gov/pubs/wri/wri994000/.

Research Related to Source-Water Assessments

In areas of complex hydrogeology, it can be difficult to accurately delineate zones of ground-water contribution to wells and zones where ground water is under the direct influence of surface water (GWUDI). These are among the most widely debated issues in determining conjunctive delineations (areas where both ground- and surface-water flow toward a well or intake) for source-water assessments. Methods and field applications of environmental tracers (including stable and radioactive isotopes and other conservative compounds) are being developed by USGS researchers for a range of hydrologic investigations (Coplen and others, 1999; Cook and Bohlke, 1999; Busenberg and Plummer, 1992) that address the relations of surface and ground water and the estimation of the age of ground water. For example, environmental tracers were used to estimate the age of ground water and to establish the connection between, and relative percentages of, surface water and ground water in a sole-source karst aquifer (characterized by limestone caves, springs, and sinkholes) in Georgia (Plummer and others, 1998a, 1998b; fig. 9). These techniques are increasingly becoming standard tools for hydrologists, and as interest has grown in this field, the techniques are becoming more affordable and easier to use for practical applications. Franke and others (1999), however, showed that the most successful studies of zones of contribution tend to result from approaches in which numerical simulation and field measurements, such as environmental tracers and geophysical investigations, are combined. For more information on the USGS National Research Program please visit http://water.usgs.gov/nrp/. For more information on USGS activities in source water assessments please visit http://water.usgs.gov/owq/dwi/.

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