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Assessing the Vulnerability of Public-Supply Wells to Contamination from Sources in the Environment

What are the most important factors controlling contamination of public-supply wells, and how can we do a better job of predicting which supply wells are vulnerable to contamination?

By Sandra M. Eberts and Martha L. Erwin

In 2001, the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program began an intensive study to assess the vulnerability of public-supply wells to contamination from a variety of compounds commonly found in the environment.[1] The study involves more than 900 wells within eight major water-supply aquifers across the Nation. More aquifers and wells are scheduled to be added in 2005 and 2009 (see map, p. 3).

This NAWQA study is focusing on the transport and transformation (chemical breakdown) of both anthropogenic and natural contaminants within that part of the ground-water system from the water table or below to the wellheads of supply wells. Scientists are investigating how the linkage between contaminant sources and public-supply wells is affected by processes that occur below land surface—whereby contaminants are mobilized, dispersed, diluted, volatilized, adsorbed, and (or) degraded. They are also investigating how the operation of supply wells affects their contamination. Because these subsurface processes and management practices differ among aquifers and public-water systems, supply wells in different parts of the Nation are not equally vulnerable to contamination even where similar contaminant sources exist. The study is identifying these important differences, as well as similarities, in a complementary set of aquifer systems, urban settings, and public-water systems.

NAWQA studies from 1991 to 2001 found low levels of a mixture of contaminants in ground water near the water table in urban areas across the Nation (in about 90 percent of monitoring wells) and, less frequently, in deeper ground water typically developed for public supply (Hamilton and others, 2004). Following up on these findings, scientists are investigating water quality in the shallow and deeper parts of water-supply aquifers across the Nation, particularly within areas contributing recharge to public-supply wells. The study will provide a foundation for assessing the vulnerability of the Nation's public-supply wells to a variety of contaminants and help resource managers anticipate the response of different systems to changes in management practices.

Vulnerability assessments—a national priority, a scientific challenge

About one-third of the U.S. population gets drinking water from public-supply wells. The occurrence of drinking-water contaminants in these wells is highly variable (U.S. Environmental Protection Agency, 1999). To safeguard public health, a better understanding of how these wells can become contaminated is needed. Understanding supply-well contamination is also an economic issue because drinking water from public-supply wells must meet U.S. Environmental Protection Agency (USEPA) and (or) State water-quality standards. Collecting and analyzing water samples and cleaning up contaminated ground water are expensive and difficult operations. Therefore, vulnerability assessments based on sound science are needed to help water-resource managers *predict* which wells are vulnerable to contamination and design strategies to *prevent* future contamination, and therefore sustain the water supply.

Vulnerability assessments, however, are inherently uncertain. Scientists do not fully understand contaminant behavior in the subsurface, and there are limitations in the databases and models used to perform the assessments (National Research Council, 1993). An additional challenge is the need to strike a balance between complex, costly assessments and those that are oversimplified (Focazio and others, 2002). As a result, ground-water vulnerability has been assessed using many different methods (Nolan, 1998); most have focused on the transport of contaminants to the water table rather than to the wellhead.

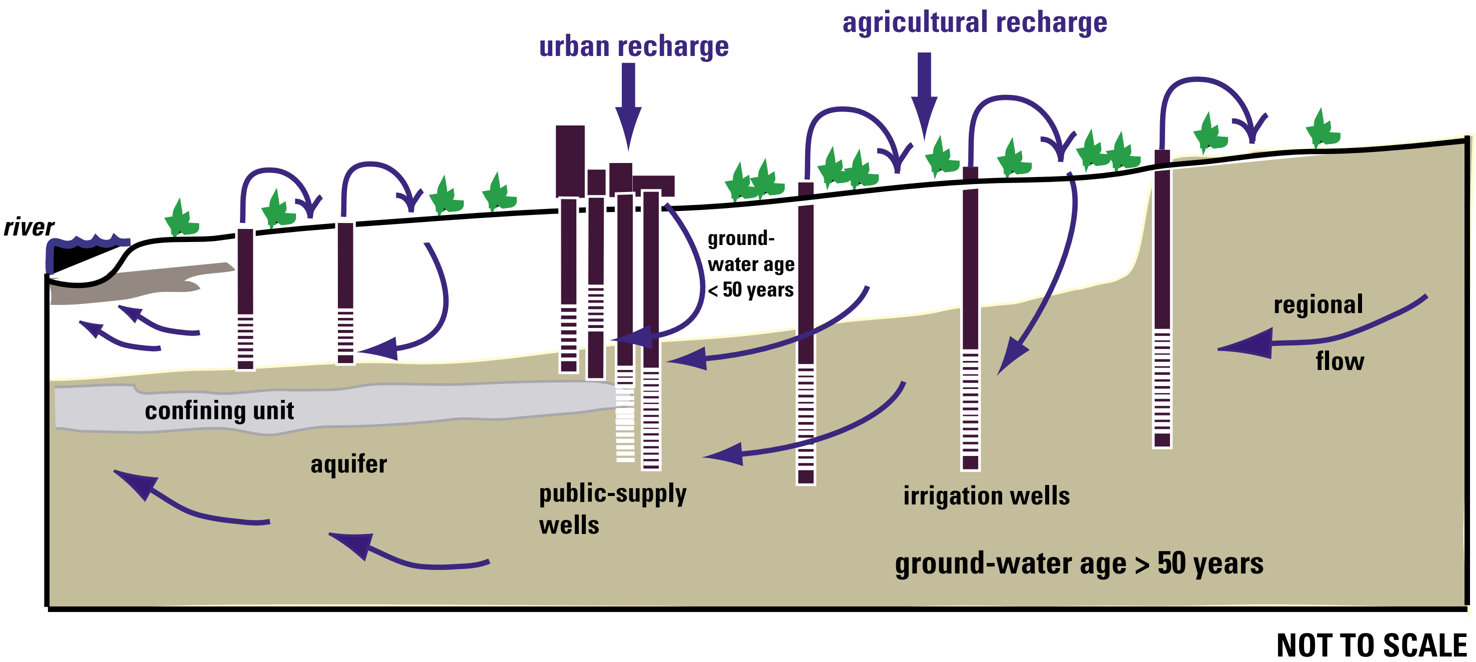
In the current study, we address the challenges of vulnerability assessments by collecting and analyzing similar data

Some potential drinking-water contaminants

- Anthropogenic contaminants including nitrate, pesticides and their breakdown products (such as atrazine and deethylatrazine), compounds found in wastewater, and volatile organic compounds including disinfection by-products
- Naturally occurring contaminants including arsenic and uranium
- Waterborne pathogens including *E. coli*, total coliform, and coliphage (a virus)

About one-third of the U.S. population drinks water from public-supply wells.

[1] The study is not investigating the possible threat posed to public-supply wells from bioterrorism.



An aquifer system and public-water system in an urban setting. Note that the water entering the well screens is of different ages and from different areas. Many public-supply wells are vulnerable to contamination from multiple sources, including land-use activities within the areas contributing recharge and naturally occurring minerals in the subsurface such as arsenic and uranium.

Important concepts

Ground-water vulnerability—the likelihood that contaminants will reach a specified reference location in a ground-water system (the water table, deep within the aquifer, a public-supply well, the interface between ground and surface water) (National Research Council, 1993).

Area contributing recharge—the surface area at the water table or a surface-water body where water entering the ground-water system eventually flows to the well. Estimates of areas contributing recharge to public-supply wells are made in order to target ground-water protection practices (Franke and others, 1998).

Ground-water age—the time elapsed (ranging from days to milennia) since water entered the saturated zone during recharge. Younger ground water tends to be more susceptible to contamination from current sources at the land surface than older ground water (Focazio and others, 2002). Water discharging from a well is usually a mixture of waters of different ages.

Ground-water sustainability—the development and use of ground-water resources in a manner that can be maintained for an indefinite amount of time without unacceptable consequences (Alley and others, 2004). Water quality and water quantity are equally critical for the long-term sustainability of the Nation's water supply (U.S. Geological Survey, 2002).

within a variety of settings, including unique data collected using new tools. We are developing a library of site-specific models to help sort out the most important factors to include in vulnerability assessments in different settings at both regional and local scales.

General objectives of the study

- Identify the dominant sources of contaminants in public-supply wells in representative water-supply aquifers across the Nation.
- Assess the effects of natural processes (such as dilution) and human activities (such as well-field management) on the occurrence of contaminants in public-supply wells in representative aquifers.
- Identify the factors that are most important to incorporate into public-supply-well vulnerability assessments in different settings and at different spatial scales; develop simple methods and models for screening supply wells for vulnerability to contamination in unstudied areas and from newly emerging contaminants.
- Increase understanding of the potential effects of water-resource development and management practices.

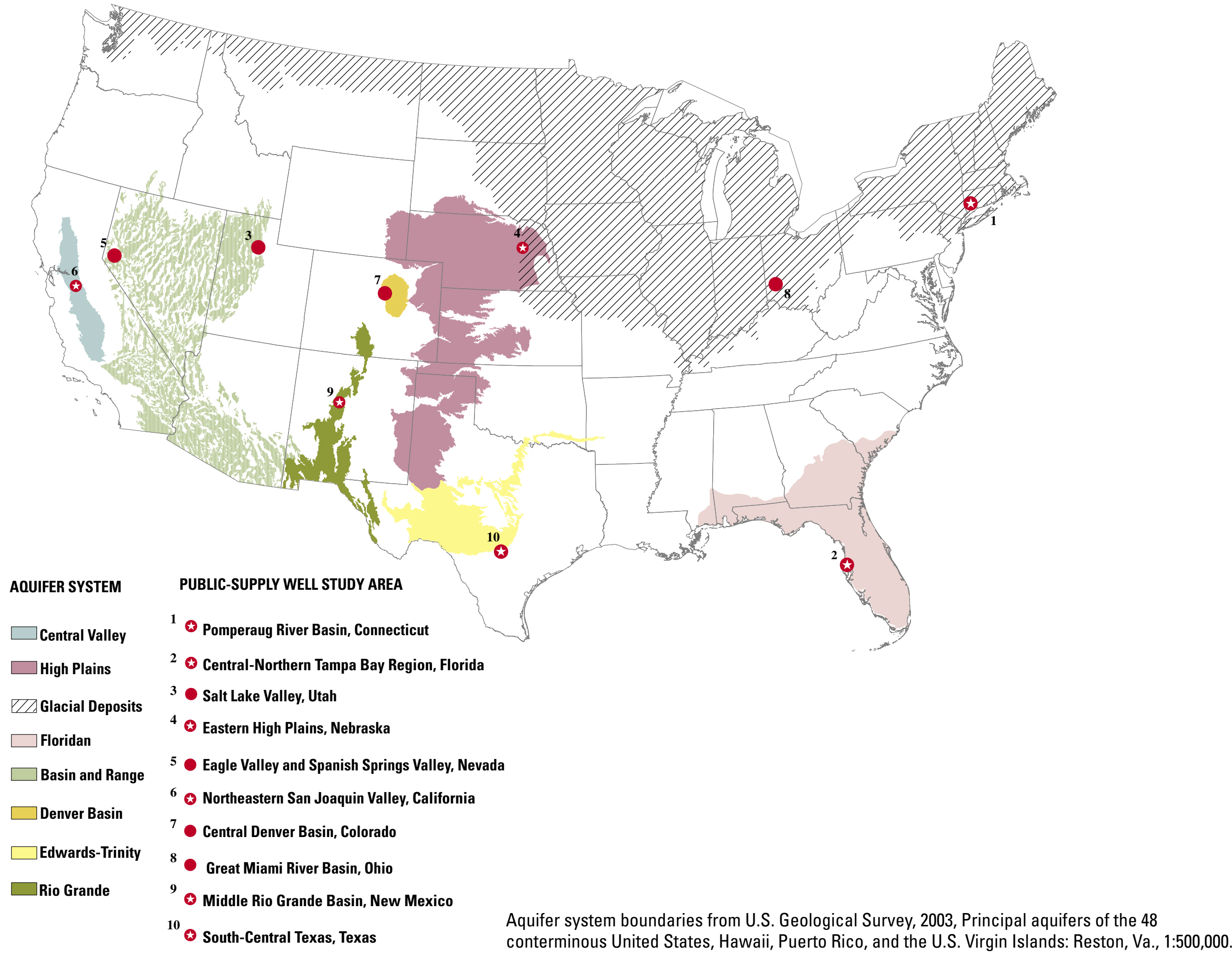
Unique characteristics of the study

Sampling at different depths

Using a USGS-developed sampler (Izbicki, 2004), we are collecting samples at several depths in pumping public-supply wells to ascertain where and how contaminants from different sources enter the wells. For example, samples collected at the wellheads of public-supply wells and "dated" to determine ground-water age are being compared to samples and ages of water entering the wells at different depths that are associated with different potential contaminant sources (see graph, p. 3). This analysis is helping to evaluate the usefulness of ground-water age samples from wellheads for predicting the risk of contamination.

Evaluating multiple settings and scales

Because consistent methods are being used to collect and analyze data and investigations are at both regional and local scales, we can compare and contrast results from different settings, and then identify the most important processes or factors to include in vulnerability assessments applied at different scales and in a variety of water-supply aquifers. For example, nitrate is detected in ground water in most participating study areas. The dominant process controlling the distribution and concentration of nitrate between the water table and supply wells varies from dilution in some areas to

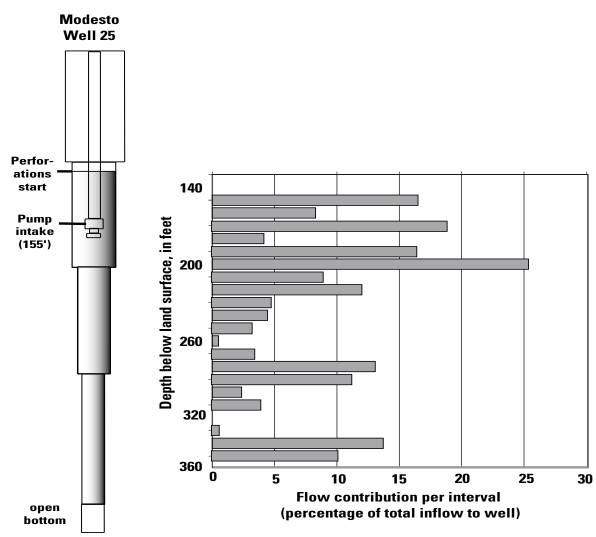


Locations of study areas. Regional-scale studies of public-supply well vulnerability to contamination from environmental sources began in 2001 in 8 States. Stars indicate sites of additional local-scale investigations. Studies will begin in Texas and New Mexico in 2005 and are scheduled for Illinois and New Jersey or New York in 2009. *See p. 4 for study-area contacts.*

dispersion or degradation in others. Using models developed for each study area, we are exploring how these differences in subsurface processes affect the response of different aquifer systems to common management practices.

Exploring the consequences of uncertainty

To make informed decisions about activities at a particular location, water-resource managers need to know whether that location is contributing recharge to public-supply wells. They also need information about travel times between potential contaminant sources and supply wells. Because this information cannot be measured directly, managers must rely on estimates that are inherently uncertain (due to limitations in the methods). We are exploring the consequences of this uncertainty by, for example, comparing estimates from traditional modeling approaches and probabilistic modeling approaches with actual water-quality data from supply wells. Information about the limitations of these different approaches is useful for decision-makers.

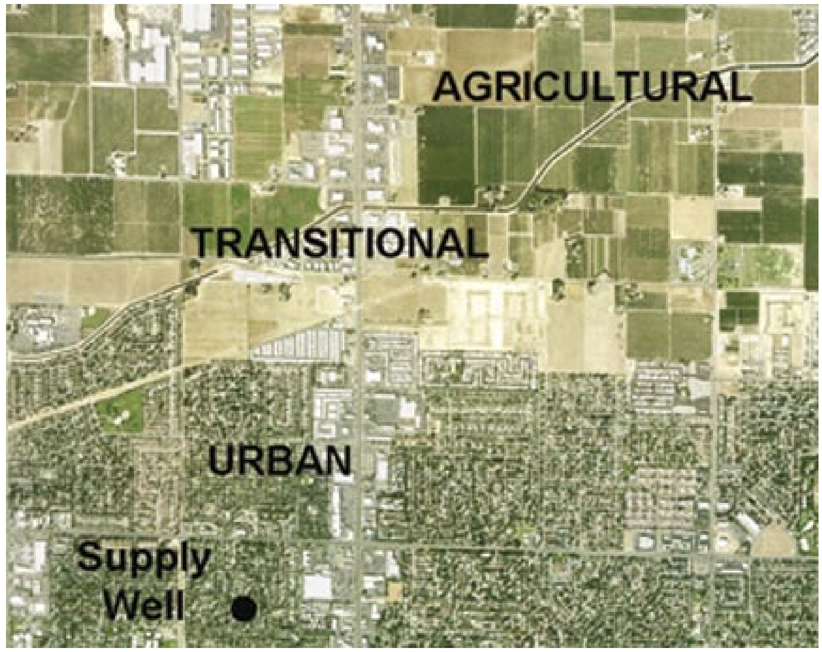


Inflow at different depths within a public-supply well in Modesto, Calif., fall of 2004. Water entering the well screen at different depths is associated with different potential sources of contaminants. Depth-dependent samples are being analyzed for water quality and ground-water age and are being compared to samples collected at the wellheads of public-supply wells.

How this information can be used

Study results, models, and other decision-support tools will apply to broad classes of contaminants, including newly identified, emerging contaminants, and will help water managers and scientists:

- Better understand how and why contamination of public-supply wells occurs
- Improve assessments of the vulnerability of ground water and public-supply wells to contamination, even in unmonitored areas
- Choose new sites for water supply and develop and prioritize monitoring programs
- Evaluate various resource-development and management scenarios



Area surrounding Modesto, Calif., supply well 25 (approximately 63 square miles). Recharge from these different land-use areas would be associated with different types of contaminants, some of which may eventually reach the well.

For additional information, contact:

Sandra Eberts, Team Leader
(614) 430-7740, smeberts@usgs.gov

Craig Brown, Connecticut (860) 291-6766 cjbrown@usgs.gov

Christy Crandall, Florida (850) 942-9500 ext 3030, crandall@usgs.gov

Bernard Stolp, Utah (801) 908-5061 bjstolp@usgs.gov

Matthew Landon, Nebraska (402) 437-5836 landon@usgs.gov

Michael Rosen, Nevada (775) 887-7683 mrosen@usgs.gov

Karen Burow-Fogg, California (916) 278-3087, krburow@usgs.gov

Suzanne Paschke, Colorado (303) 236-4882 ext 352 spaschke@usgs.gov

Mary Ann Thomas, Ohio (614) 430-7736 mathomas@usgs.gov

Laura Bexfield, New Mexico (505) 830-7972 bexfield@usgs.gov

Lynne Fahlquist, Texas (512) 927-3508 lfahlqst@usgs.gov

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The NAWQA Program

The study of public-supply well vulnerability is one of five national priority topics being addressed by the National Water-Quality Assessment (NAWQA) Program in its second decade of studies, which began in 2001. Other topics include effects of urbanization on stream ecosystems (USGS Fact Sheet 042-02); ecological effects of nutrient enrichment (USGS Fact Sheet 118-03); mercury in stream ecosystems (USGS Fact Sheet 016-03); and sources, transport, and fate of agricultural chemicals (USGS Fact Sheet 2004-3098).

During the Program's first decade (1991-2001), NAWQA scientists assessed water chemistry, stream hydrology, habitat, and biological communities in 51 major river basins ("Study Units"; see map at **http://water.usgs.gov/nawqa**). The assessments characterize the ambient water resource—the source of about 60 percent of the Nation's drinking water and water for industrial, irrigation, and recreational uses. During its first decade, NAWQA made baseline assessments of pesticides, nutrients, volatile organic compounds, trace elements, dissolved solids, and radon, as well as the condition of aquatic habitats and fish, insect, and algal communities. These findings are described in hundreds of reports, available at the NAWQA Web site above.

In the second decade of studies, 42 of the 51 study units are planned to be reassessed to determine trends at many of the streams and ground-water monitoring sites; to fill critical gaps in the characterization of water-quality conditions; and to build upon earlier NAWQA findings that show how natural features and human activities affect water quality and aquatic ecosystems.