Assessing the Vulnerability of Public-Supply Wells to Contamination from Urban, Agricultural, and Natural Sources

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

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.

The study builds on previous NAWQA studies from 1991 to 2001 that found low levels of mixtures 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). Data from more than 1,000 public-supply wells within major water-supply aquifers are being evaluated in this study, and data from more aquifers and wells are scheduled to be added in 2009 (see map, p. 4).

This NAWQA study is focusing on the transport and chemical breakdown of selected anthropogenic contaminants from urban and agricultural sources, as well as contaminants from natural sources, within that part of the ground-water system contributing water to public-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. Scientists are also investigating how the operation of public-supply wells can affect their vulnerability to contamination.

Because subsurface processes and management practices differ among aquifers and public-water systems, public-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.

A national priority, a scientific challenge

About one-third of the U.S. population gets drinking water from public-supply wells. The occurrence of contaminants in these wells is highly variable (U.S. Environmental Protection Agency, 1999). To safeguard public health, we need a better understanding of how these wells can become contaminated.
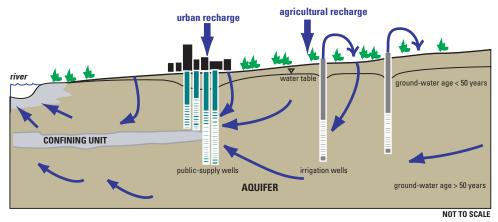
Understanding public-supply well contamination is also an economic issue because cleaning up contaminated ground water is expensive and difficult. Drinking water from public-supply wells must meet U.S. Environmental Protection Agency (USEPA) and (or) State water-quality standards. Vulnerability assessments based on sound science will help decision-makers *predict* which wells are vulnerable to contamination and design strategies to *prevent* future contamination, thereby sustaining 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 of the previous assess-

Contaminants assessed in this study

- Anthropogenic contaminants, including nitrate, pesticides and their breakdown products (such as atrazine and deethylatrazine), compounds found in wastewater; and volatile organic compounds (such as MTBE and disinfection by-products)

- Naturally occurring contaminants, including arsenic, uranium, radon, and radium

- Fecal contamination, using indicators such as *E. coli* and total coliform (bacteria) and coliphage (a group of viruses)

An aquifer system and public-water system in an urban setting. The water entering the well screens of the public-supply wells is of different ages and from different areas because of their long screened intervals, which commonly make public-supply wells vulnerable to contamination from multiple sources. In this example, sources of contaminants may include those associated with urban and agricultural land-use activities. Aquifer materials may also serve as sources of natural contaminants such as arsenic.

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 from which 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 millennia) since water reached the water table during recharge. Young 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 indefinitely without unacceptable consequences (Alley and Leake, 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).

ments have focused on the transport of contaminants to the water table rather than to public-supply wells.

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

Study results will provide a foundation for assessing the vulnerability of the Nation's public-supply wells to a variety of contaminants, and will help those involved in well siting and water-quality protection anticipate the response of different systems to changes in management practices. The results also will be useful to those involved in planning and implementing State source-water assessment and protection programs, as guided by the USEPA (U.S. Environmental Protection Agency, 1997).

General objectives of the study

- Identify the dominant contaminants and sources of those contaminants in public-supply wells in representative water-supply aquifers across the Nation

- Assess the effects of natural processes (such as degradation) and human activities (such as irrigation) 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 public-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 decisions on the quality of water from public-supply wells

Unique characteristics of the study

Sampling at different depths

The screened or open intervals of public-supply wells are commonly from tens to hundreds of feet in length; therefore, water from these wells is generally a mixture of waters of different ages that enter the well at different depths and are associated with different potential sources of contamination. The graphic on this page illustrates a situation where recharge to public-supply wells reflects urban and agricultural land-use activities. Specifically, water recharges the aquifer in the urban area containing urban-related contaminants, such as volatile organic compounds, and enters the well screens above water that has traveled from the more distant agricultural area where recharge water may contain contaminants such as agricultural pesticides.

Using a USGS-developed sampler (Izbicki, 2004), we are collecting samples at multiple depths in pumping public-supply wells to ascertain where and how contaminants from different

sources enter the wells. For example, samples collected from public-supply wellheads and analyzed for concentrations of multiple contaminants are being "dated" to determine ground-water age and compared to samples and ages of water entering the wells at various depths (see graph below). 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

Consistent methods are being used to collect and analyze data, and investigations are being conducted at both regional (tens to thousands of square miles) and local scales (less than 10 square miles). We can therefore compare and contrast results and identify the most important processes 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 distribution and concentration of nitrate between the water table and public-supply wells are controlled predominantly by dilution in some areas and by 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.
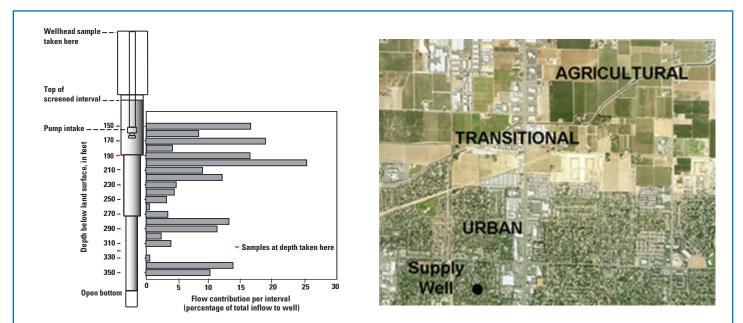
Exploring the consequences of uncertainty

To make informed decisions about activities at a particular location, decision-makers need to know whether the location is contributing recharge to public-supply wells. They also need information about traveltimes between potential contaminant sources and public-supply wells. Because this information cannot be measured directly, decision-makers must rely on estimates that are inherently uncertain (due to limitations in the methods). We are exploring the consequences of this uncertainty, and helping decision-mak-

ers understand these consequences, by comparing estimates from traditional and probabilistic modeling approaches with actual water-quality data from public-supply wells.
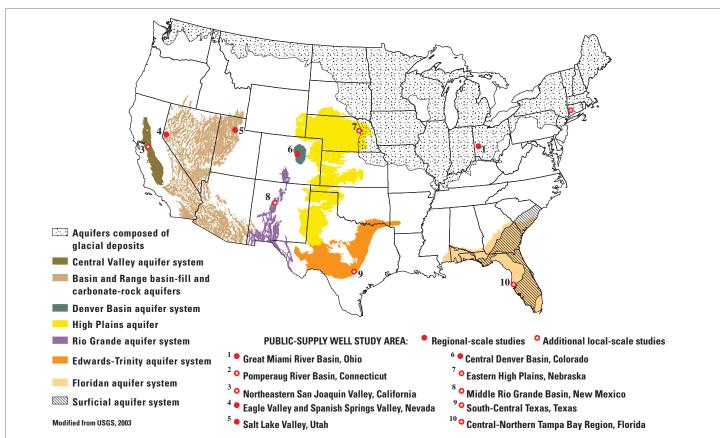
How this information can be used

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.

Inflow at different depths within a public-supply well. The aerial photo shows an approximately 63-square-mile area near the well. Water entering the well screen is associated with different potential sources of contaminants because of the different land-use activities in the areas contributing recharge to various intervals along the well screen, as well as the different aquifer materials through which water flows between the recharge areas and the well. The amount of contamination that might be contributed by any given interval is related to the volume of water that flows into the well along the interval and the concentration of any associated contaminants. Depth-dependent samples are a composite of all intervals beneath the sampling point; these samples are being analyzed for chemical quality and ground-water age and then compared to samples collected from the wellhead.

Locations of regional-scale studies of public-supply well vulnerability to contamination from urban, agricultural, and natural sources. Studies began in 2001 in eight States, in Texas and New Mexico in 2005, and are scheduled for Illinois and New Jersey or New York in 2009.

Map legend:

Aquifers composed of glacial deposits
Central Valley aquifer system
Basin and Range basin-fill and carbonate-rock aquifers
Denver Basin aquifer system
High Plains aquifer
Rio Grande aquifer system
Edwards-Trinity aquifer system
Floridan aquifer system
Surficial aquifer system

Modified from USGS, 2003

PUBLIC-SUPPLY WELL STUDY AREA: ● Regional-scale studies ⊛ Additional local-scale studies

1 ● **Great Miami River Basin, Ohio**
2 ⊛ **Pomperaug River Basin, Connecticut**
3 ⊛ **Northeastern San Joaquin Valley, California**
4 ● **Eagle Valley and Spanish Springs Valley, Nevada**
5 ● **Salt Lake Valley, Utah**
6 ● **Central Denver Basin, Colorado**
7 ⊛ **Eastern High Plains, Nebraska**
8 ● **Middle Rio Grande Basin, New Mexico**
9 ⊛ **South-Central Texas, Texas**
10 ⊛ **Central-Northern Tampa Bay Region, Florida**

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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 NAWQA Program in its second decade, which began in 2001. Other topics include effects of urbanization on stream ecosystems; ecological effects of nutrient enrichment; mercury in stream ecosystems; and sources, transport, and fate of agricultural chemicals. In addition, anthropogenic organic contaminants in source waters for many of the Nation's largest community water systems are being assessed; concentrations in source waters are being compared to concentrations in finished waters. During the Program's first decade, NAWQA scientists assessed surface- and ground-water chemistry, stream hydrology, habitat, and biological communities in 51 major river basins ("Study Units"; see map at http://water.usgs.gov/nawqa). Baseline assessments of pesticides, nutrients, VOCs, trace elements, dissolved solids, and radon, and of the condition of aquatic habitats and fish, insect, and algal communities are described in hundreds of reports, available at the Web site above. Reassessments planned in 42 of the Study Units in the Program's second decade will determine trends at many of the streams and ground-water sites; fill critical gaps in the characterization of water quality; and build upon findings that show how natural features and human activities affect water quality and aquatic ecosystems.