Transport of Anthropogenic and Natural Contaminants to Supply Wells

Frequently Asked Questions

What was the purpose of the study and the associated USGS circular?

As part of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program, a study of the Transport of Anthropogenic and Natural Contaminants to Supply Wells was conducted from 2001 to 2011 to shed light on factors that affect the vulnerability of water from public-supply wells to contamination. The study was designed as a follow up to earlier NAWQA studies that found mixtures of contaminants at low concentrations in groundwater near the water table in urban areas across the Nation (in about 90 percent of monitoring wells) and, less frequently, in deeper groundwater typically used for public supply (Hamilton and others, 2004). Although contaminants were less frequently detected in public-supply wells than in shallower monitoring wells, contaminant concentrations were nonetheless greater than drinking-water standards or other human health benchmarks in about 22 percent of public-supply-well samples (Toccalino and Hopple, 2010).

These previous NAWQA findings imply that water from nearly one in five public-supply wells in the United States might need to be treated or blended with more dilute water sources to decrease concentrations of drinking-water contaminants before delivery to the public. Therefore, understanding factors that affect the vulnerability of water from public-supply wells to contamination (or public-supply-well vulnerability) is important because removing contaminants from water intended for drinking is difficult, expensive, and—unfortunately—becoming increasingly necessary.

The USGS circular, which summarizes results of the recent study, describes factors that affect the vulnerability of water from public-supply wells to contamination from chemicals or microorganisms in the groundwater (Eberts and others, 2013; http://oh.water.usgs.gov/tanc/NAWQATANC.htm) Study findings presented in the circular can be applied by drinking-water practitioners to devise improved programs for monitoring public-supply wells and the aquifers they tap, and to identify the most beneficial protection mechanisms for a particular well. Insights gained from the study will aid managers in making informed decisions in siting and constructing new public-supply wells and will help them anticipate the response of different wells to changes in management practices. Ultimately, the findings of this study can be used to update and enhance existing assessments of public-supply-well vulnerability across the Nation, and to design strategies for preventing future contamination of such wells—thus sustaining the Nation's water supply.

What is the difference between groundwater vulnerability and public-supply-well vulnerability? Circular pages 2 – 3

Study findings demonstrate that groundwater vulnerability and public-supply-well vulnerability are not the same. Groundwater vulnerability is a function of contaminant input to the groundwater, which depends on the presence of contaminant sources (for example, leaky underground petroleum storage tanks), natural barriers between contaminant sources and the groundwater (such as a thick layer of dense clay in the soil overlying the aquifer), and artificial barriers designed to keep contaminants out of the groundwater (such as landfill liners). Groundwater vulnerability also is a function of the geochemical conditions in the aquifer and whether such conditions favor the continued mobility and persistence of contaminants once they are in the groundwater. Finally, groundwater vulnerability is a function of the intrinsic susceptibility of the water in different parts of the aquifer to contamination. In other words, it is a function of the physical characteristics of the aquifer that affect how easy it is for water and contaminants to travel within the subsurface.

The vulnerability of a public-supply well is a function of all the above factors but is further controlled by the location, design, construction, operation and maintenance of the well. For example, the location of a well determines whether a particular contaminant source is in the area that contributes water to the well. The placement of the well screen determines which geochemical conditions in the aquifer have influenced the water before it is pumped from the well and, therefore, which contaminants might be present in the water as it enters the well. The depth of the well screen and the pumping rate of the well determine how quickly water and contaminants can travel from the water table to that particular well, and from what distance.

What is intrinsic susceptibility?

Intrinsic susceptibility is a measure of the ease with which a contaminant in water can enter and move through an aquifer. It is a characteristic of the aquifer and overlying material, and independent of the contaminant characteristics or source.

What types of information can be used to understand the quality of water pumped from a public-supply well? Circular pages 3 – 7 & Chapter 3

Study findings indicate that information on contaminant input, contaminant mobility and persistence, and intrinsic susceptibility within the area that contributes water to a well can help answer the question, "Which contaminants in an aquifer might reach the well and when, how, and at what concentration might they arrive?" Preferential flow pathways (pathways that provide little resistance to flow) are an additional factor affecting the vulnerability of water from public-supply wells to contamination because such pathways influence the relative importance of each of the other factors. Many types of information can be used to evaluate the influence of these factors on the quality of water from a public-supply well. The choice of information (or measures) to use will depend on the desired knowledge and the scale of the assessment. Detailed measures are more practical for assessments involving a single well than for assessments involving many wells over a broad area.

USGS scientists found that the following measures—each related to a different aspect of public-supply-well vulnerability—are particularly useful for understanding the quality of water pumped from individual public-supply wells:

(1) the *sources of recharge* that contribute water to a well, and the contaminants associated with the recharge—a measure of contaminant input;
(2) the *geochemical conditions* encountered by water drawn into a well—a measure of contaminant mobility and persistence; and
(3) the *groundwater-age mixture* of different waters that blend (or mix) in a well—a measure of intrinsic susceptibility.

What is groundwater recharge?

Groundwater recharge is water that infiltrates the earth and reaches the saturated zone. Infiltrating recharge water can pick up contaminants from the land surface or unsaturated zone, thereby acting as a source of contamination to some aquifers and wells.

Why is it important to understand the sources of recharge water for a well?
Circular page 4 & Chapter 3

Different sources of recharge water can contain different types and amounts of drinking-water contaminants. Consequently, the quality of water pumped from a public-supply well depends on the proportions of (and contaminant concentrations in) the different waters that originate in different recharge areas and eventually enter and mix in the well.

- Identifying the sources of recharge that contribute water to different wells helps explain differences in contaminants and contaminant concentrations in wells that are close to each other but that draw in water from different recharge areas.

- A change in the source(s) of recharge for a public-supply well can bring about a change in the quality of the water produced by the well. Consequently, even a change in the general characteristics of the water from a well—temperature, pH, alkalinity, and dissolved-solids concentration—warrants investigation so that any new source(s) of water (and associated contaminants) for the well can be identified and managed to minimize adverse effects.

What are geochemical conditions?

For groundwater, the term geochemical conditions refers to factors or circumstances that affect the chemical reactivity of substances dissolved in the water.

Why is it important to understand the geochemical conditions encountered by water drawn into a public-supply well? Circular page 5 & Chapter 3

Geochemical conditions influence whether a contaminant that has been released to the groundwater will travel with the groundwater, react with the aquifer material, or degrade before reaching a public-supply well.

- Communities that determine whether the water from their public-supply well(s) is being drawn from oxic, anoxic, or multiple geochemical zones within an aquifer will have insight into which drinking-water contaminants in the groundwater are likely to reach their well(s) and which are likely to be assimilated by the aquifer before the water arrives at a well.

- Changes in groundwater flow in some aquifers have altered geochemical conditions and caused contaminants such as arsenic and uranium (which occur naturally in aquifer rock or sediment) to dissolve into the groundwater and migrate to public-supply wells. Consequently, monitoring is needed when developing aquifers for increased water supply so that changes in aquifer geochemical conditions that can affect drinking-water-contaminant concentrations do not go unnoticed.

What is groundwater age and how does it relate to groundwater vulnerability?

Groundwater age is the amount of time that has passed since the water entered the aquifer and was no longer in contact with the atmosphere. For example, if groundwater is determined to be 11 years old, it means that 11 years have passed since the water infiltrated through sediments or rocks and reached the water table. Groundwater can be days, months, years, or even hundreds or thousands of years old. Because groundwater can become contaminated when chemicals on the land surface dissolve into infiltrating recharge water, young (recently recharged) groundwater that enters a well is more vulnerable to contamination from human activities near the land surface than older, deeper groundwater that simultaneously enters the well. However, old groundwater can pick up naturally occurring drinking-water contaminants, such as arsenic, from the sediments or rocks through which it passes.

Why is it important to understand the ages of the different waters that blend (or mix) in a public-supply well? Circular pages 6 – 7 & Chapter 3

The water pumped from a public-supply well did not recharge the surrounding aquifer at a single point in time. Rather, public-supply wells produce water with a mixture of groundwater ages. The groundwater-age mixture for a well directly affects the quality of the water produced by the well. For example, wells that produce water with a groundwater-age mixture that corresponds to a period of recharge that is longer than the duration of contaminant input will benefit from some in-well dilution of the contaminants entering the well. This is because some of the water entering the well will have recharged the aquifer either before or after the time period during which the contaminants were released to the groundwater. Consequently, wells that produce water with a wide range of groundwater ages have some ability to protect themselves from high levels of contamination.

- Knowledge of groundwater-age mixtures can be used to help prioritize protection efforts. For example, managing contaminant sources within source-water protection areas defined by groundwater traveltime is more beneficial for wells that produce predominantly young water than for wells that produce water that is generally older than the specified traveltime.

- Understanding that there is a tradeoff when a well is deepened to decrease its vulnerability to anthropogenic contaminants in young, shallow groundwater can help guide development decisions; deeper water that has been in contact with the aquifer material for a longer period of time often contains higher concentrations of naturally occurring drinking-water contaminants that can be more difficult to remove from the water, such as arsenic.

- Recognizing that several years or even decades of monitoring will not be enough to characterize water-quality changes in wells that produce predominantly old water can lead to better monitoring programs. A combined monitoring and modeling approach is needed for such wells to determine how long contaminant concentrations will continue to increase in the produced water after nonpoint-source-contaminant input at the water table is reduced.

What is a preferential flow pathway?

A preferential flow pathway is a subsurface route that provides little resistance to groundwater flow, such as a bedrock fracture or the wellbore of a non-pumping well. Preferential flow pathways are associated with relatively short groundwater traveltimes.

Why is it important to know whether a preferential flow pathway is influencing the quality of water from a public-supply well? Circular pages 8 – 9 & Chapter 4

Preferential flow pathways often deliver the youngest, most vulnerable groundwater to a well. When a well is pumping, it can cause groundwater-flow rates within a preferential flow pathway to become high compared with contaminant degradation rates, reducing the effectiveness of natural processes that degrade groundwater contaminants (for example, denitrification). Rapid flow through preferential flow pathways also can increase concentrations of naturally occurring contaminants in groundwater when it brings together water and aquifer materials that are not in chemical equilibrium. In addition, preferential flow pathways can create favorable conditions for the transport of pathogenic microorganisms: rapid traveltimes, which reduce the opportunity for microorganism die-off, and relatively large interconnected openings, which reduce the removal of microorganisms by filtration through aquifer materials or sorption to rocks.

- When preferential flow pathways are indicated, protecting a delineated area around a public-supply well from contamination is necessary but may be insufficient for protecting the well's water from contamination. This is because preferential flow pathways make it difficult to know where the youngest groundwater that is drawn into a well actually originates. In such cases, a general campaign to engage the entire community in groundwater protection might be worthwhile.

- Because preferential flow pathways often deliver young vulnerable groundwater to wells, the ability to recognize the influence of preferential flow pathways on the quality of water from a well can help resource managers prioritize monitoring and protection of their most vulnerable wells. One way to identify the influence of preferential flow pathways is to look for water-quality patterns in historic well records. For example, seasonal water-quality fluctuations in the records for a deep public-supply well can indicate preferential flow because recharge water is not likely to travel from the water table through the aquifer matrix to a deep well screen within a single season.

- If manmade preferential flow pathways (such as wells screened through multiple aquifers or screened through different geochemical zones within the same aquifer) are affecting the quality of water being produced by a public-supply well, resource managers have an opportunity to devise effective means of preventing or minimizing flow through these features and reduce the vulnerability of the water from the well to contamination.

How can information on the different factors affecting public-supply-well vulnerability be used to improve protection? Circular pages 10 – 11 & Chapter 5

Results of this study indicate that most processes controlling water quality in public-supply wells are related to a limited number of factors. However, the relative importance of any one factor might be different for different wells. These differences can have implications for how managers would protect different wells from contamination. For example, two study wells contained low concentrations of both anthropogenic and natural contaminants but the quality of water from the well in California was improved by changing the pumping schedule for the well, whereas the quality of water from the well in Nebraska would derive greater benefit by preventing water in an overlying contaminated aquifer from migrating down nearby irrigation wellbores to the deep aquifer used for public supply.

Obtaining new data and information on the different factors affecting public-supply-well vulnerability to contamination and (or) reevaluating existing data and information in light of the factors can result in new insight into the vulnerability, and water quality, of a public-supply well. Such insight can enable resource managers to prioritize actions for sustaining a high-quality groundwater source of drinking water.

Are there regional patterns in public-supply-well vulnerability?

Circular pages 12 – 13 & Chapter 5

The vulnerability of every well is unique but not necessarily random. Spatial patterns in the underlying factors affecting public-supply-well vulnerability to contamination (contaminant input, contaminant mobility and persistence, and intrinsic susceptibility) exist. Consequently, systematic regional patterns in public-supply-well vulnerability to a variety of contaminants should be discernible and predictable. Although such vulnerability patterns remain largely unexplored in the United States, the study identified differences in the relative vulnerability of water from public-supply wells in several sand and gravel aquifers to contamination from volatile organic compounds (VOCs). More specifically, water from public-supply wells in many aquifers in the Western United States was found to have low vulnerability to the gasoline components benzene, toluene, and MTBE when compared to water from wells in glacial aquifers in the Eastern United States. The difference is due to the predominantly oxygen-rich (oxic) conditions in the western aquifers that promote the degradation of these compounds, together with the generally older water produced by the western aquifer wells. The presence of older water indicates that, first, there is more time for degradation reactions to proceed before water reaches public-supply wells in the western aquifers, and second, older water, which is generally free of anthropogenic contaminants, is available to dilute any such contaminants in younger water entering the western wells.

Where can I learn more about the USGS NAWQA study of the transport of anthropogenic and natural contaminants to supply wells?

The study circular, other scientific reports, fact sheets, a podcast and tools for evaluating factors affecting public-supply-well vulnerability to contamination can be found at the Transport of Anthropogenic and Natural Contaminants to Supply Wells website

Where can I learn more about other NAWQA studies?

NAWQA Program homepage