If Groundwater Is Contaminated, Will Water from the Well Be Contaminated?

by Sandra M. Eberts

Introduction

In a recent study of public-supply-well water quality in the United States, nearly two-thirds of all samples from 932 public wells tapping 30 regionally extensive aquifers contained detectable amounts of drinking-water contaminants that originated entirely or primarily from manmade sources. Twenty-two percent of the samples contained at least one contaminant (manmade or naturally occurring) at concentrations greater than drinking-water standards or other human health benchmarks (Toccalino and Hopple 2010). These findings imply that water from nearly one in five public-supply wells in the United States may need to be treated or blended with more dilute water sources to decrease concentrations of drinking-water contaminants before delivery to the public. Removing contaminants from water intended for drinking is difficult and expensive. It also is becoming increasingly necessary (Job 2011). Consequently, understanding factors affecting public-supply-well vulnerability to contamination is important.

Public-supply-well vulnerability to contamination is not the same as groundwater vulnerability, but the two cannot be decoupled. Groundwater vulnerability is the tendency or likelihood for contaminants to reach a specified position in the groundwater system (National Research Council 1993). Groundwater vulnerability depends on three factors: (1) the presence of manmade or natural contaminant sources, (2) the combination of chemical and physical processes in the subsurface that affect contaminant concentrations, and (3) the ease of water and contaminant movement to and through an aquifer, or its intrinsic susceptibility (Focazio et al. 2002). When mapping groundwater or “resource” vulnerability, the target is frequently the water table or top of the aquifer (Frind et al. 2006); however, trace elements and radionuclides derived from aquifer solids may account for the majority of drinking-water standard or other human health benchmark exceedances in raw water from public wells (Toccalino and Hopple 2010).

Public-supply-well vulnerability depends on all of the above factors (contaminant input, contaminant mobility and persistence, and intrinsic susceptibility) but is further affected by the location, design, construction, operation, and maintenance of the well. This is because groundwater vulnerability, and thus water quality, is not uniform throughout an aquifer, and wells “sample” only part of an aquifer. In other words, well location determines whether a particular contaminant source is in the capture zone for the well. Screen placement determines which chemical and physical processes in the aquifer will 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, and at what concentrations. Well depth and pumping rate determine how quickly water and contaminants can travel from the water table to the well, and from what distance. The interaction of a well with the surrounding aquifer determines whether the well intercepts water moving along preferential flow pathways, which can affect the relative importance of each of the other factors contributing to its vulnerability. Finally, the pumping schedule determines when poor quality water can migrate between aquifer units by way of wellbore flow, thereby influencing the mix of contaminated and uncontaminated water that enters the well at different points in time (Eberts et al. 2013).

To summarize, a well affects its own vulnerability by drawing in water from a unique combination of flow pathways that are associated with different combinations of water and contaminant sources, aquifer geochemical conditions, and travel times, giving rise to the flux-averaged contaminant concentrations that occur in the
produced water. Thus, the vulnerability and water quality of every well is unique to itself. This is true even for wells within the same aquifer and wellfield (Eberts et al. 2013).

Assessing Public–Supply–Well Vulnerability to Contamination

Ideally, a public–supply–well vulnerability assessment pulls together data and information on each of the factors that can affect the vulnerability of a well to contamination. Numerous methods have been used to assess one or more factors affecting public-supply-well vulnerability in recent years (e.g., Frind et al. 2006; McMahon et al. 2008; Hinkle et al. 2009; Kauffman and Chapelle 2010; Mendizabal and Stuyfzand 2011; Starn and Bagtzoglou 2011; Molson and Frind 2012). The choice of methods and measures to use for a given assessment should vary according to the desired knowledge and the scale of the assessment. For example, groundwater age can serve as a measure of intrinsic susceptibility, but it might not be feasible to estimate groundwater age for the large number of wells that would be necessary for assessing public-supply-well vulnerability across a regionally extensive aquifer. In contrast, the percentage of well-drained soils—which does not account for as many underlying processes as groundwater age—might be a suitable measure of intrinsic susceptibility for an aquifer-wide assessment of public wells. Each vulnerability measure contributes to the certainty or uncertainty in a public-supply-well vulnerability assessment. Trading one measure for another might increase or decrease the amount of uncertainty in an assessment. The trade-offs might be necessary to understand the vulnerability of wells at the desired spatial scale (Eberts et al. 2013).

Distinguishing Public–Supply–Well Water Quality from Groundwater Quality

Chapelle et al. (2009) point out that “water quality” refers to a specific judgment as to how water of a given composition fits the perceived needs of the individual, group, or ecosystem using it. The quality of public drinking water in the United States is evaluated by using National Primary Drinking Water Regulations, which are legally enforceable standards (U.S. EPA 2009). Groundwater pumped from public-supply wells is not considered contaminated for the purpose of drinking until the allowable level of a contaminant has been exceeded.

Given this definition of water quality and the widespread detection of low levels of contaminants in water from public-supply wells, the following is a relevant question for wellfield operators, water-resources managers, drinking-water regulators, and scientists who constantly need to stretch limited resources, “If

Figure 1. Location of selected wells having low concentrations of manmade and naturally occurring drinking-water contaminants, typifying different aquifer-well combinations. Woodbury, Connecticut: volatile organic compounds (VOCs), nitrate, pesticides, uranium, and radon; unconsolidated sediment (sand); mostly oxic conditions; short well screen (10s of feet); and young water in well. Near Tampa, Florida: VOCs, nitrate, pesticides, arsenic, uranium, and radon; carbonate rocks; oxic and anoxic conditions; open hole; and mix of very young and generally young water in well. York, Nebraska: VOCs, uranium, and arsenic; layered unconsolidated sediment (sand); anoxic conditions in confined aquifer; well screen beneath clay confining unit; and mix of young and old water in well.
groundwater is contaminated, will water from the well be contaminated?” The answer is, “it depends.” That is, it depends on the proportions of (and contaminant concentrations in) the different waters in the aquifer that enter and mix in the well. For example, Eberts et al. (2012, 2013) simulate water-quality responses to hypothetical nonpoint-source contamination at several public-supply wells that produce different combinations of young and old (pre-1950s) groundwater. They show that wells with large fractions of young water would respond faster to land use change designed to reduce chemical fluxes to the water table, whereas wells with small fractions of young water would benefit from greater in-well dilution of manmade contaminants by old, unaffected water (Figure 2). Einarson and MacKay (2001) demonstrate how point-source contaminant releases of varying magnitude can affect supply wells operating at different extraction rates, and state, “We do not advocate reliance on in-well blending to maintain water supply standards but … . The process does occur, and understanding it is fundamental to determining the risks posed by contaminant plumes drawn into water supply wells.”

Interpreting Water-Quality Samples from Public-Supply Wells

In practice, knowledge gaps pertaining to the importance of low concentrations of contaminants detected in raw water from public-supply wells remain. Distinguishing situations in which low concentrations in public wells represent the tip-of-the-iceberg (in terms of water quality) from those that represent the maximum or near maximum concentration for the produced water (given the contaminant source) is critical for sustaining high-quality groundwater sources of drinking water. In other words, if one simply wants to know whether a manmade contaminant might reach a well, it may be sufficient to analyze the water from the well for extremely low concentrations of the contaminant to confirm a connection between the well and a local (often unknown) source of contamination (Plummer et al. 2008). However, if one needs to know whether to take action, one must make an effort to resolve what a sample from the well truly represents, regardless of whether the contaminant in the water is from a manmade or natural source.

Seven papers on public-supply-well vulnerability to contamination at different spatial and temporal scales from a 10-year U.S. Geological Survey study of the transport of anthropogenic and natural contaminants to supply wells (http://oh.water.usgs.gov/tanc/NAWQATANC.htm) are included in this issue of Groundwater. The papers were selected to provide an in-depth look at the quality of water from public-supply wells in several hydrogeologic settings. Together, the papers address a number of effects of well location, design, construction, and operation on the quality of water from public-supply wells. The paper
by Bexfield and Jurgens in this issue shows that the location of a well within a flow system—or hydrologic position—affects the quality of water produced by a well. The papers by Bexfield and Jurgens, Jurgens et al., and Yager and Heywood in this issue each demonstrate how seasonal differences in pumping schedules can lead to temporal variability in vulnerability and water quality, even for wells that produce water that is predominantly very old. The papers by Jurgens et al. and Yager and Heywood in this issue go on to show that such seasonal differences in the proportions of different waters that mix in wells can be quantified to improve understanding of the temporal variability of water quality at the wellfield scale. The paper by Starn et al. in this issue describes pumping-induced transience in groundwater flow at the basin scale and discusses how resulting changes in public-supply-well contributing areas and groundwater ages can lead to long-term water-quality trends at such wells. The paper by Musgrove et al. in this issue compares the vulnerability of public-supply wells in two karst aquifers and illustrates how differences in aquifer-well interactions among the systems affect well vulnerability and water quality. The paper by Chapelle et al. in this issue describes numerical mass balance modeling that explores the relation between aquifer geochemical conditions and water quality at public-supply wells. Finally, the paper by Böhlke et al. in this issue introduces an interactive educational webtool that allows one to explore the effects of aquifer-well interactions on the age mixture of water from a well, along with the influence of this age mixture on contaminant trends in the well water.

Conclusions

Drinking-water contaminants in groundwater are widespread. At the same time, resources for protecting or treating groundwater sources of drinking water are limited. It is therefore beneficial to understand which wells are most likely to produce water with high concentrations of drinking-water contaminants and which vulnerability factor(s) are most important for those wells so that management strategies can be tailored. The papers in this issue of *Groundwater* having a focus on public-supply-well vulnerability demonstrate how water from a public-supply well is a mixture of water from various parts of an aquifer that has picked up different types and amounts of contaminants, encountered different physical and geochemical conditions, and traveled at different flow rates to the well. The complexity of the water mixture in samples from such wells can require more elaborate interpretation than what is required for samples from monitoring wells because of the relatively large aquifer volume and associated conditions sampled by public wells; however, public-supply-well samples can be interpreted in ways that lead to valuable observations and conclusions (Mendizabal and Stuyfzand 2009; Eberts et al. 2013). Knowing what water-quality variables to measure, what spatial and temporal scales on which to measure them and how to interpret the resulting data can help resource managers explain and forecast the quality of water from their wells. Developing an understanding of the vulnerability factor (or factors) that most influence typical wells in different “type settings” is a logical next step, followed by an extrapolation of this understanding to less studied wells and areas.

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