Conclusions and Recommendations

Conclusions

Human enteric viruses are a common contaminant in water produced by municipal wells in Madison, Wisconsin. Viruses were found in all wells sampled monthly, though not in every sample from every well. The percentage of virus-positive samples ranged from 60% in wells know to have multi-aquifer construction or shallow casings to 18 % in well 30, a new, deep well deeply cased across a regional aquitard. The presence of viruses in wells cased and grouted 200 to 300 feet below a regional aquitard raises disturbing questions about aquifer vulnerability in confined-aquifer settings usually thought to be well-protected from surface contaminants.

Although we are unable at this time to elucidate the transport pathway for viruses from the surface to the wells, several lines of evidence suggest that transport is rapid – on the order of months or weeks rather than years. Because they require a human host, these viruses must originate at or just below the land surface. Identical viral serotypes were found in sewage and groundwater, and the mix of viral species varied with time through the project. Moreover, virus detections in wells, and virus concentrations in lakes and sewage varied together through time. This temporal correlation is consistent with relatively rapid transport.

The Madison Lakes are probably not the main source of the viruses found in the Madison municipal wells. Lake water contained some but not all of the serotypes found in the wells, and virus levels in lake water are generally low. Furthermore, the $^{18}O/^{2}H$ signature of water produced by most Madison wells is not consistent with a significant lake water component of recharge.

The most likely source of the viruses in the wells is the leakage of untreated sewage from the Madison sewer system. Untreated sewage sampled at the Madison sewage treatment plant contains virus concentrations several orders of magnitude higher than concentrations observed in wells or lakes. Review of sewer construction and location data, the shear total length of city sewers (hundreds of miles), and the evidence that sewers are not completely water-tight suggests that leakage of sewage to the subsurface environment probably occurs in at least some parts of Madison. Given the high concentrations (millions of genomic copies per liter) of viruses in sewage, it would take very little sewage to produce the virus concentrations observed in the wells.

Human enteric viruses might be excellent tracers of recent groundwater. They have the desirable tracer characteristics of detectability over several orders of magnitude, high mobility, short analytic times and relatively reasonable cost, and are time-specific due to constantly changing serotypes. Although the presence of detectable tritium in a well is

almost always and indicator or recent recharge to the well, the absence of tritium (at a detection limit of 0.8 TU) does not necessarily indicate that the well will be virus-free. In fact detection of viruses many be a far more sensitive indicator than tritium of a proportion of "young" groundwater in a well if the well captures a virus source.

Recommendations

This study shows that human viruses can be commonly present in groundwater in deep bedrock wells. To protect human health, communities in Wisconsin and elsewhere that use groundwater for a drinking water source should consider using chlorination or other water treatment techniques to deactivate viruses, and work to ensure that these systems are operating correctly.

Sampling for viruses requires a time series approach because virus concentrations, and virus species, vary with time in individual wells.

Untreated sewage contains very high concentrations of viruses and should be considered a source of groundwater contamination. Wisconsin communities should evaluate sewer infrastructure to determine the potential for leakage of untreated sewage to the subsurface. For example, communities might wish to prioritize sewer repair or replacement within the contributing areas of municipal wells. Research on the impacts of sewers on groundwater quality should be encouraged.

Human enteric viruses represent a potentially powerful new tracing tool for hydrogeologic studies. Both fundamental (theoretical and column studies) and applied (field evaluations) research on the use and effectiveness of viruses as tracers should be undertaken.