Assessment of Virus Presence and Potential Virus Pathways in Deep Municipal Wells

Abstract

Among the many waterborne pathogens of humans, enteric viruses have the greatest potential to move deeply through the subsurface environment, penetrate aquitards, and reach confined aquifers. Previous research revealed the presence of viruses in water from two of three deep bedrock wells sampled in Madison, WI. Virus presence in these wells was particularly surprising because the wells were cased through a regional aquitard thought to provide protection for the wells. This present study is a follow-up to the previous work and is intended to (1) obtain a time series of virus, isotopic, and geochemical data from several municipal wells completed in a deep bedrock aquifer, (2) use these data sets to evaluate virus presence and, if present, the potential sources of the viruses and pathways to the wells, and (3) evaluate the possibility that virus transport occurs through the well casing, grout or annular space.

During 2007 and 2008 we sampled six deep municipal wells for viruses on an approximately monthly basis. Three of these wells had shallow casings, and three were cased through a regional aquitard. We also collected virus samples from local lakes and from untreated sewage and sampled groundwater and lake water for major inorganic ions and isotopes of hydrogen and oxygen.

Viruses were detected at least twice in every one of the six wells, but no well was virus-positive in every sampling round. Overall, 43 percent of the samples were virus-positive, and virus concentrations ranged from 0.00 to 6.15 genomic copies per liter (gc/l), with a mean of 0.47 gc/l. Samples from three wells were positive for virus infectivity. Lake samples were positive 78 percent of the time, and ranged from 0.00 to 27.6 gc/l, with a mean of 5.8 gc/l. Not surprisingly, Madison sewage was extremely high in viruses, with all samples positive, and concentrations ranging from about 50,000 to over two million gc/l, with a mean of 581,000 gc/l. Virus results varied significantly with time, and there is apparent correlation between virus levels in sewage, lakes, and groundwater.

Several different species (serotypes) of viruses were identified in wells, sewage, and lake water during this study, and in many cases wells and sewage contained identical virus serotypes. Detected viruses include Enteroviruses echovirus 3, echovirus 6, echovirus 11, Coxsackie A16 and B4, Adenoviruses 2, 6, 7, 41, as well as G1 norovirus and Rotovirus. The apparent correlation between viral serotypes found in sewage, lakes, and groundwater suggests very rapid transport from the sources to wells. Viral serotypes vary seasonally and annually, and so correlation between surface and subsurface serotypes would be unexpected if transport times from the surface to groundwater exceed many months. The Madison Lakes are probably not the main source of the viruses found in the wells as lake water contained some but not all of the serotypes found in the wells, and wells without lake-derived water had viruses present. Furthermore, the $^{18}O/^{2}H$ signature of water produced by these wells is not consistent with a significant lake water

component of recharge to most of the wells sampled. Virus levels in surface water were much lower than in sewage, thus significant volumes of lake water would be required to produce the virus levels measured in the wells.

The most likely source of the viruses in the wells is the leakage of untreated sewage from the Madison sewer system. 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 recently recharged groundwater in urban settings if virus sources exist. They have the desirable tracer characteristics of detectability over several orders of magnitude, high mobility, and are time-specific due to constantly changing serotypes. Although the presence of detectable tritium in a well is almost always an indicator of 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.