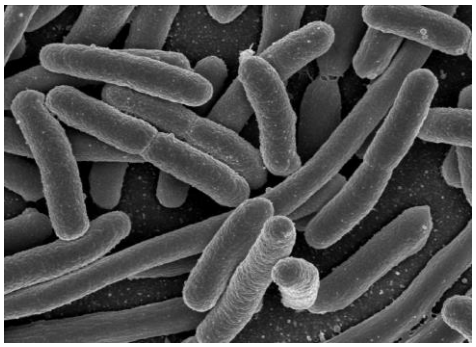
Pathogens

What are they?



E. coli, an indicator of fecal contamination. *Photo: NIAID*

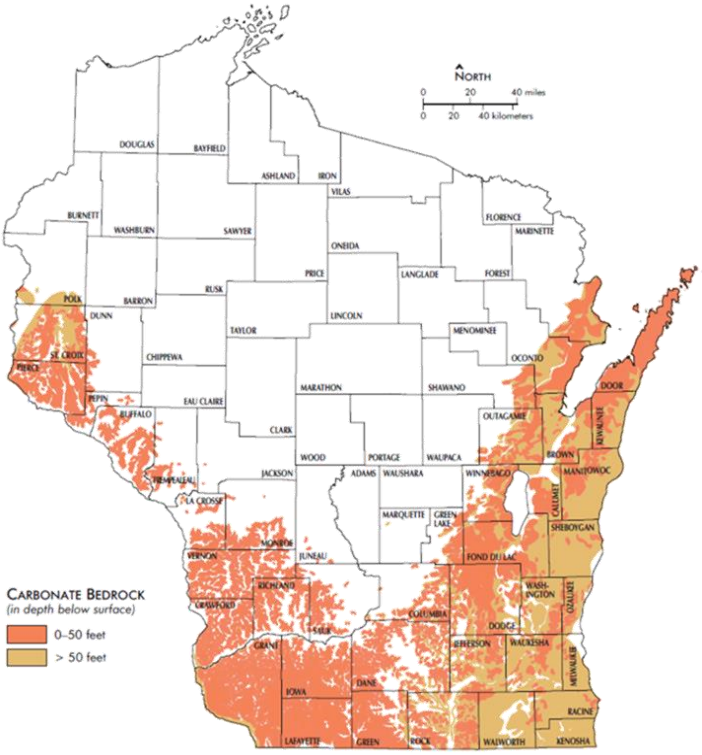
Pathogens are organisms or other agents that can cause disease, including microorganisms such as bacteria, viruses, and protozoa that can cause waterborne disease. Groundwater contamination by pathogens can usually be traced to human or livestock fecal wastes that seep into the ground from sources such as septic systems, leaking sanitary sewers, or manure. Since it is difficult and expensive to test for all pathogenic microorganisms, water samples are usually tested for microbial "indicators" – microbes that are not necessarily harmful themselves, but are a warning sign that other, potentially pathogenic, microorganisms may be present.

There are no groundwater standards for pathogenic microorganisms in Wisconsin, but pubic drinking water systems are regularly monitored for total coliform bacteria (WI NR 809.31-809.329). These systems may also be tested for fecal indicators such as *E. coli*, enterococci, or coliphages if coliform bacteria are found. Coliforms are a broad class of bacteria that are naturally present in the environment and are used as an indicator that other, potentially harmful, microorganisms may be present. Fecal indicators are microbes whose presence more specifically indicates that water may be contaminated with human or animal wastes. Pathogenic microorganisms in drinking water can make people very sick and can result in death. Common symptoms include diarrhea, cramps, nausea, and headaches. Microbial contamination may pose a special health risk for infants, young children, some of the elderly, and people with severely compromised immune systems.

Such contamination is of particular concern in public water systems, because a large number of people can be exposed to contamination in a short amount of time. In 1993, pathogen contamination at Milwaukee's surface water-sourced drinking water system resulted in 69 deaths and more than 403,000 cases of illness before the epidemic and its source were recognized. A 2007 outbreak of norovirus, caused by contaminated well water, sickened 229 diners and staff at a Door County restaurant (Borchardt et al. 2011).

Occurrence in Wisconsin

In Wisconsin, it is well known that groundwater in areas with karst geology – soluble rocks with many large fractures through which water flows rapidly – is vulnerable to microbial contamination and needs special consideration and protection. In these areas, particularly where there is also thin soil cover and shallow groundwater levels, there is little opportunity for soil to slow and attenuate the transport of microbes. This results in a greater risk that pathogens will remain viable when they reach the groundwater. Karst geology can be found across much of the state. Door and Kewaunee Counties are especially vulnerable since these areas additionally have very thin soils. Around 34% of private well samples test high for total coliforms in these areas, as opposed to 17% in the state overall (Knobeloch et al., 2013).



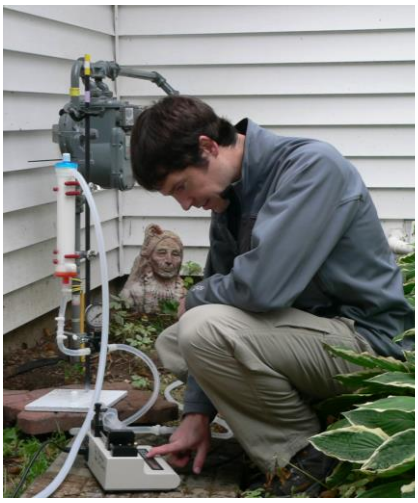
Karst potential in Wisconsin. Areas with carbonate bedrock within 50 feet of the land surface are particularly vulnerable to groundwater contamination. *Figure*: [WGNHS]

A more recent, emerging concern is the presence of viruses in drinking water wells, including norovirus, adenovirus, and enterovirus. This contamination does not necessarily correlate well with total coliform bacteria (Borchardt et al., 2003b) because viruses have different transport properties than bacteria. Recent research studies have detected human enteric viruses in both public and private wells in Wisconsin (Borchardt et al., 2003a, 2004, and 2007), but there is limited statewide data since testing for viruses is expensive, not routinely performed, and levels cannot be reliably inferred from total coliform results. In cities where such studies have been conducted, such as La Crosse and Madison, transport of viruses from municipal sewer systems to groundwater supplies is known to occur very rapidly – on the order of weeks rather than years – and accurate detection requires frequent sampling and testing specifically for viruses (Hunt et al., 2010; Bradbury et al., 2013). Results suggest that viral contamination of groundwater may occur at other municipal water systems because such wells are generally completed in areas with sanitary sewers.

The risk of finding pathogens in groundwater is seasonably variable but typically highest following spring snowmelt or large rainstorms that generate runoff, since these events create large pulses of water that move quickly through the ground, potentially carrying microbes from septic systems, sewer mains, and manure sources (Uejio et al., 2014). Nutrient management plans can help reduce the risk of contamination due to manure spreading, but even with the best management practices it is difficult to eliminate occurrences. Over 60 private wells have had to be replaced due to manure contamination at a cost to the state of over $500,000 since 2006 (Source: DNR Well Compensation Fund records).

It is important to note that there is very clear evidence that disinfection with chlorine or ultraviolet light can dramatically reduce the risk of illness from viruses and other microbial sources (Borchardt et al., 2012; Lambertini et al., 2012; Uejio et al., 2014). Continuous disinfection is not dependent on indicator tests to protect human health. However, this is not required by law for public water systems that source their drinking water from groundwater. About 60 municipalities in Wisconsin do not disinfect their public water supplies.

GCC Agency Actions



Dr. Sam Sibley, UW-Madison Department of Soil Science, collects a well water sample from a residential home to analyze using new MST tools. Video story at: https://youtu.be/dpE58Rd4i4E. *Photo*: *Carolyn Betz, UW ASC*

Homeowner complaints about private well *bacterial* contamination events, which often correspond with manure spreading, are an ongoing concern for GCC agencies. Unfortunately, the standard methods for testing for bacteria do not show whether the bacteria are derived from human or animal sources and until 2007 there were no readily available methods for testing for manure. Funding from the Wisconsin Groundwater Research and Monitoring Program (WGRMP) has supported the development of laboratory techniques that have made it possible to discern whether bacteria are from human, animal or other sources (Pedersen et al., 2008; Long and Stietz, 2009). These microbial source tracking (MST) tools include tests for *Rhodococcus coprophilus* (indicative of grazing animal manure), *Bifidobacteria* (indicative of human waste) and *Bacteroides* (indicative of recent fecal contamination by either humans and/or grazing animals). A more recently developed analysis can successfully detect bovine adenoviruses to indicate bovine fecal contamination of groundwater (Sibley et al., 2011). The DNR has been using these tools as they become available to determine the source of fecal contamination in private wells. MST results since 2007 indicate that the majority of well water samples are contaminated with grazing animal waste, less than 10% of samples indicate microbial contamination from human sources, and approximately 20% of samples have no indication of microbial contamination (Laura Chern, personal communication). DNR's Drinking Water & Groundwater and Runoff Management programs are working with the DATCP nutrient management program to find ways of controlling this major source of contamination.

Over the past 15 years, GCC agencies and collaborators have carried out groundbreaking work on *viruses* in drinking water and the impact on human health. An early indication of the significance of the problem came in the early 2000s, when researchers at the Marshfield Clinic Research Foundation demonstrated that levels of viruses in private wells do not exhibit strong seasonal trends and are not correlated with commonly used indicators such as total coliform and fecal enterococci (Borchardt et al., 2003a and 2003b). A subsequent study with the USGS looking at LaCrosse municipal wells drew similar conclusions and further concluded that nearby surface waters were not the source for the viruses; rather, viruses in LaCrosse wells were likely traceable to leaking sanitary sewers (Borchardt et al., 2004; Hunt et al., 2005). This was not shocking in a city like LaCrosse, where municipal wells are located in a shallow sand and gravel aquifer, relatively close to underground pipe infrastructure. However, municipal wells completed at depth, below confining layers of shale that separate shallow from deep aquifers, were presumed to be well-protected. The geology in the Madison area meets this description, yet collaborators from the Marshfield clinic, WGNHS, and the University of Waterloo discovered human enteric viruses in Madison municipal wells in 2007, indicating that all aquifers are potentially vulnerable to microbial contamination (Borchardt et al., 2007; Bradbury et al. 2013). In recognition that disinfection with chlorine or ultraviolet light can dramatically reduce virus populations, a subsequent study compared drinking water quality

and illnesses in Wisconsin communities that do not routinely disinfect their water (Borchardt et al., 2012; Lambertini et al., 2012). This work concluded that 6% to 22% of gastrointestinal illness incidents were directly attributable to viruses in drinking water in these communities. This figure may be as high as 63% among children under 5 years old during periods when norovirus was abundant. In response, the DNR developed a rule mandating disinfection of municipal drinking water but this was repealed by the state legislature in 2011. Nationally, the EPA included virus types found in the Wisconsin studies on the list of 30 unregulated contaminants that were monitored from 2013 to 2015 in 6,000 public water systems across the United States in order to gather information to support future drinking water protection.

Future Work

Improving best practices for well construction in the vulnerable karst areas of the state is an ongoing topic of concern. In addition to significant threat to health posed by manure sources, there are indications that current requirements for septic systems and leach fields may be inadequate to protect public health and the environment in areas where wells draw from shallow carbonate aquifers. This points to a need to revise the requirements for the construction of private water wells in these areas.

Most of the current data on bacterial contamination in Wisconsin is derived from private well samples. However, public drinking water systems that disinfect their water supplies are also required to sample quarterly for bacteria from the raw water (before treatment) in each well. The DNR recently began tracking total coliform detects in the raw water sample through its Drinking Water System database, so evaluation of this monitoring data from public wells may enhance understanding of statewide bacterial contamination. This understanding would be further enhanced by an analysis of the equivalence and positive predictive value of the laboratory methods (PCR kits, testing protocols) used to measure concentrations of bacteria and bacterial indicators in groundwater.

Pumping test at one of Madison's municipal wells, part of a WGRMP-funded study to enhance understanding of fractures and virus transport. *Photo*: *Jean Bahr*

There are unanswered questions about viruses in drinking water as well. While previous work has clearly demonstrated where viruses in municipal wells come from (sanitary sewers) and how fast they travel (on the order of weeks), the exact mechanism of entry in cities like Madison is unknown and cannot be explained by normal assumptions about hydrogeology. A study funded by the WGRMP is currently exploring whether the rapid transport of viruses between the shallow and deep aquifers in Madison can be explained by vertical fractures in the shale layer that separates them. More research is also needed on the survival times of various viruses in groundwater aquifers.

Finally, additional public health studies where clinical samples and water samples are collected simultaneously, such as those conducted by GCC researchers in La Crosse, are needed to better describe the relationship between cause of illness and groundwater pathogens.

Further Reading

DNR overview of bacteriological contamination in drinking water [link]

DNR overview of cryptosporidium in drinking water [link]

DHS fact sheet on manure contamination of private wells [link]

WGNHS overview of karst landscapes [link]

WGNHS report on municipal drinking water safety [link]

DNR list of municipal drinking water systems that disinfect [link]

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