BACTERIA, VIRUSES AND OTHER PATHOGENS

Key Takeaways

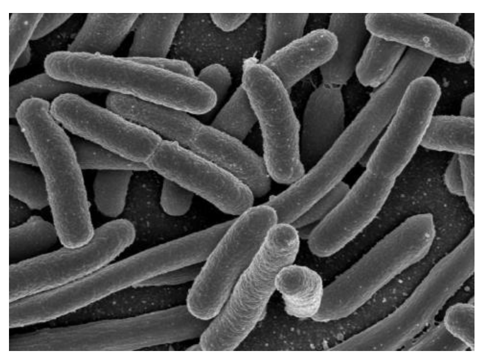
As you will read below, it is important to evaluate the occurrence of viruses and other pathogens in groundwater and groundwater-sourced water supplies and develop appropriate response tools in order to protect human health. Homeowner complaints about private well bacterial contamination events, which often correspond with manure spreading, are an ongoing concern for GCC agencies. The DNR and DATCP tried to update standards (NR 151) in order to address these issues, but they were not passed.

GCC member agencies continue to work on multiple initiatives related to reducing bacteria, viruses and other pathogens in groundwater (see groundwater management sections – DHS, DNR, DATCP, UWS, WGNHS).

For actions to address bacteria, viruses and other pathogens contamination in groundwater, see the Recommendations Section.

Sections in this document

What are bacteria, viruses and other pathogens?



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 microbial pathogens can often be traced to human or livestock fecal wastes that seep into the ground from sources such as inappropriately constructed or failing septic systems, leaking sanitary sewers or improperly managed animal manure. Since it is difficult and expensive to test for all pathogenic microorganisms, water samples are usually tested for microbial pathogen "indicators", such as total coliform bacteria, fecal coliform bacteria, *Escherichia coli* (*E. coli*) bacteria, enterococci bacteria or coliphage viruses. These indicator microbes are not necessarily harmful themselves, but are a warning sign that other, potentially pathogenic, microorganisms may be present.

Microorganisms are prevalent and abundant in the subsurface and in groundwater.[1] The United States Geological Survey[2] reports that "Most of the bacterial types found in soils and surface waters have also been found in shallow unconfined and confined aquifers". Virus abundance in an alluvial aquifer in Colorado has been reported as ranging from 80,000 to 1,000,000 cell count per milliliter[3]. While most microorganisms in the subsurface are harmless, pathogenic microbes from human and animal fecal waste sources can contaminate groundwater in areas where they can be readily transported through the subsurface to underground drinking water supplies.

There are no specific groundwater quality standards for pathogenic microorganisms in Wisconsin, but currently there are standards in ch. NR 140 for total coliform bacteria, an indicator of possible microbial pathogen contamination. The ch. NR 140 preventive action limit (PAL) and enforcement standard (ES) for total coliform bacteria are 0 coliform bacteria present in a tested sample. Public drinking water systems are regularly monitored for total coliform bacteria (WI NR 809.31-809.329), and these systems are tested for *E. coli*, and possibly other fecal indicators such as enterococci or coliphages, if coliform bacteria are found to be present.

In 2016 the Environmental Protection Agency (EPA) changed its rules related to the use of microbial pathogen indicators in the regulation of public drinking water systems. In 2016 the EPA's Revised Total Coliform Rule (RTCR) for public drinking water systems went into effect. Under the RTCR the existing total coliform bacteria drinking water maximum contaminant level (MCL) was removed and replaced with a total coliform treatment technique (TT). If total coliform bacteria are confirmed present in a public drinking water system the total coliform TT requires system assessment and corrective action. The EPA also established a drinking water MCL for *E. coli* bacteria under the RTCR. Detection of *E. coli* bacteria is considered a more specific indicator of fecal contamination, and the possible presence of harmful pathogens, than just detection of total coliform bacteria.

Total coliform bacteria include bacteria that naturally occur in the environment, and are, with a few exceptions, not harmful to humans. Under the RTCR, detection of total coliform bacteria is used as an indicator of possible microbial pathways into a public drinking water system. Under the RTCR, detection of *E. coli* bacteria in a public water supply system is an MCL violation. Public notification is required for a public drinking water system *E. coli* MCL violation. This notification instructs the public to either boil water from the public system before consuming, or to use bottled water.

Considering the changes that have been made to the public water system RTCR, the department has revised ch. NR 140 to establish groundwater quality standards for *E. coli* bacteria and to revise the current standards for total coliform bacteria. Rulemaking has now been completed to establish ch. NR 140 health based groundwater standards for *E. coli* bacteria and to transition total coliform bacteria from a health based standard to an indicator parameter groundwater standard. These revisions to ch. NR 140 have been approved by the Natural Resources Board and state legislature. They will be effective August 1, 2023.

What are the human health concerns?

Microbial pathogen 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 in 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. In 2007 an outbreak of norovirus, caused by contaminated well water, sickened 229 diners and staff at a Door County restaurant[4].

Antibiotic resistance, associated with subsurface microorganisms, may also be a significant groundwater contaminant in some situations. Use of antibiotics at large animal feeding operations for growth promotion can result in antibiotic resistance (ineffectiveness of antibiotics in treating infections) spreading into the environment[5]. Groundwater monitoring around swine manure lagoons in Illinois found that antibiotic resistant genes, associated with leakage from the manure lagoons, were present in groundwater[6]. In a study of manure at a Wisconsin dairy farm, *E. coli* bacteria resistant to four different antibiotics were detected[7].

How widespread are bacteria, viruses and pathogens in Wisconsin?

Many factors influence microbial transport in the subsurface, both vertically through the unsaturated zone, and with groundwater flow through an aquifer. Processes such as filtration, adsorption and "die-off" can all affect the fate and transport of microbial pathogens[8]. These microbial removal and attenuation mechanisms can be complex, with a number of factors influencing how effective they may be at reducing the number of pathogens in groundwater. Factors such as soil depth, presence of preferential flow paths, soil saturation, microbial biofilms, temperature, pH, flow rate, soil microbial flora and soil organic matrix can all influence microbial pathogen transport and survival.

Fecal waste from humans, domesticated animals, wildlife, and insects can all be sources of pathogenic microorganisms in the environment. Discharges of human and domesticated animal fecal waste to the environment include wastewater effluent discharge and infiltration, and the land application of animal manure, septage and municipal wastewater biosolids. The land application discharge of human waste, and some animal waste, are regulated activities in Wisconsin. For these regulated activities, pathogen reduction, including soil treatment in the unsaturated zone, is required to remove and attenuate microbial pathogens that might be present in the waste. Soil treatment requirements in state administrative rules include minimum vertical separation distances between land disposal/application and groundwater. State rules also place limitations on waste discharge loading and application rates based on discharge site soil conditions.

Most bacteria entering the ground surface along with rainwater or snowmelt are filtered out or attenuated as water seeps downward through the unsaturated soil zone to groundwater, however, some strains of bacteria can survive a long time and may find their way into the groundwater by moving through coarse grained soils, shallow fractured bedrock, quarries, sinkholes, inadequately grouted wells or cracks in well casing. Water supply wells may also be contaminated by insects or small rodents that can carry microbial pathogens into wells with inadequate caps or seals.

In Wisconsin, it is well known that groundwater in areas with karst geology is vulnerable to microbial contamination and needs special consideration and protection. Karst geology includes areas with soluble carbonate bedrock that may have relatively large fractures through which water flows rapidly and where sometimes karst surficial features, such as sinkholes, caves and disappearing streams are present. 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 microbial pathogens. This results in a greater risk that viable pathogens may reach water supply wells. Soluble carbonate bedrock with karst potential can be found in some parts of the state, including Door County, parts of Kewaunee County and in southwestern WI. Some of these areas are especially vulnerable since, in addition to karst geology, they have very thin soil cover.

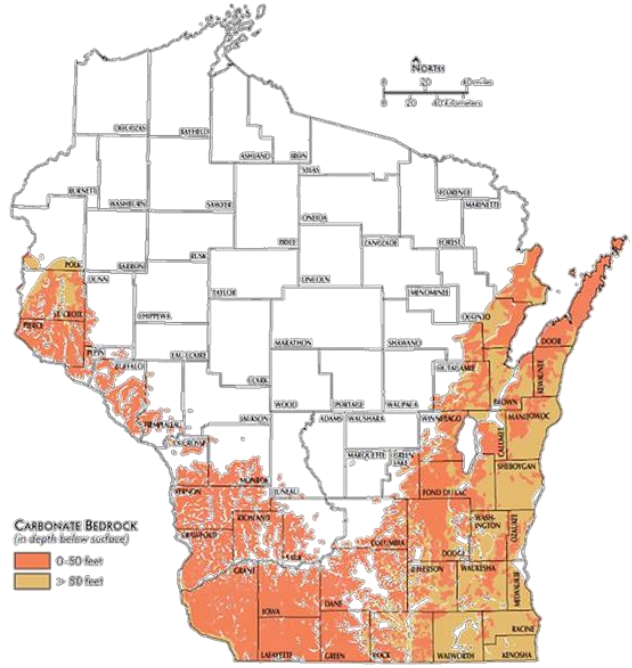
How are bacteria, viruses and other pathogenic contamination trending over time?

Analysis of statewide sampling results show that approximately 17% to 23% of private water supply wells in Wisconsin test positive for total coliform bacteria, and approximately 3% of private wells test positive for *E. coli* bacteria[9,10].

A study that sampled private water supply wells in Kewaunee County[11] showed that, county wide, private wells tested positive for total coliform bacteria at about the same percentage as statewide averages. Wells located in areas with shallower depths to bedrock, however, did test positive for total coliform and *E. coli* bacteria at percentages greater than state averages. Genetic markers, for microbial waste source indicators and pathogens, were detected, using polymerase chain reaction (PCR) molecular methods, in some of the study wells that were tested for those markers.

The Southwest Wisconsin Groundwater and Geology (SWIGG) study looked at the presence of total coliform bacteria and genetic markers for microbial waste source indicators and pathogens in private water supply wells in Grant, Iowa and Lafayette Counties[12]. The study area, in southwestern Wisconsin, has karst geology and relatively thin soil cover. Sampling found total coliform bacteria in private wells in the study counties at percentages greater than, or similar to, statewide averages. Waste source and pathogen genetic markers were detected, using PCR molecular methods, in some of the study wells that were tested for those markers. The study also found possible correlations between a number of well construction, geologic and land use factors and potential sources of well contamination.

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 can create large pulses of water that move quickly through the ground, potentially carrying microbes from septic systems, sewer mains and manure sources[13]. Nutrient management plans can help reduce the risk of contamination due to manure spreading, but even with the best manure management practices it is difficult to eliminate occurrences. Since 2006, more than 60 private wells in Wisconsin have had to be replaced due to manure contamination, at a cost to the state of over $500,000[14].



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

An emerging concern is the potential presence of viruses in drinking water wells, including noroviruses, adenoviruses and enteroviruses. Virus contamination may not necessarily correlate well with total coliform bacteria detection in groundwater because viruses can have different transport properties than bacteria[15].

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 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 to gather information to support future drinking water protection. In that sampling, the Unregulated Contaminant Monitoring Rule 3 (UCMR-3) sampling effort, the presence of enterovirus was evaluated using microbial culture methods, and the presence of enterovirus and norovirus genetic material was evaluated using PCR methods. No culturable enteroviruses, or enterovirus or norovirus genetic material, was reported detected in Wisconsin during the UCMR-3 sampling effort.

Homeowner complaints about private well bacterial contamination events, which often correspond with manure spreading, are an ongoing concern for GCC agencies. DNR's Drinking Water & Groundwater and Runoff Management programs has worked with DATCP's Nutrient Management program staff to find ways of controlling this major source of contamination. The DNR, in conjunction with DATCP, has revised performance standards and prohibitions related to manure land application in areas of the state with carbonate bedrock and shallow soils.

Improving best practices for well construction in the vulnerable karst areas of the state is an ongoing topic of concern. In addition to the potential threat to health posed by manure sources, there are indications that inadequately constructed and maintained septic systems and leach fields could also be sources of microbial groundwater contamination and therefore detrimental to 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 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 suggested that municipal sanitary sewers may be potential sources of viruses in groundwater, the exact mechanism of entry in cities like Madison is unknown and cannot be explained by normal assumptions about hydrogeology. More research is needed on the transport and survival times of various viruses in groundwater aquifers.

Public and private water samples are not regularly analyzed for viruses due to the high cost of the tests. The presence of coliform bacteria has historically been used to indicate the water supply is not safe for human consumption. Recent findings, however, show that coliform bacteria do not always correlate with the presence of enteric viruses. GCC member agencies are involved with research and risk reduction measures related to this issue.

Further Reading

- DNR overview of bacteriological contamination in drinking water
- DNR overview of cryptosporidium in drinking water
- DHS fact sheet on manure contamination of private wells
- WGNHS overview of karst landscapes
- WGNHS report on municipal drinking water safety
- DNR list of municipal drinking water systems that disinfect

References

1. Griebler, C., Lueders, T. 2009. Microbial biodiversity in groundwater ecosystems. Freshwater Biology, 54(4): 649-677. Available at *https://onlinelibrary.wiley.com/doi/10.1111/j.1365-2427.2008.02013.x*

2. USGS, United Sates Geological Survey - Michigan Water Science Center. 2017. Bacteria and Their Effects on Ground-Water Quality. Available at *https://mi.water.usgs.gov/h2oqual/GWBactHOWeb.html*

3. Pan, D., Nolan, J., Williams, K., Robbins, M., Weber, K. Abundance and Distribution of Microbial Cells and Viruses in an Alluvial Aquifer. 2017. Frontiers in Microbiology. DOI:10.3389/fmicb.2017.01199Corpus ID: 12970321. Available at *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5504356/*

4. Borchardt , M. A. , K. R. Bradbury, E. C. Alexander, R. J. Kolberg, S. C. Alexander, J. R. Archer, L. A. Braatz, B. M. Forest, J. A. Green, S. K. Spencer. 2011. Norovirus outbreak caused by a new septic system in a dolomite aquifer. Ground Water, 49(1):85-97.

5. Gilchrist, M., Greko, C., Wallinga, D., Beran, G., Riley, D., Thorne, P. 2007. The Potential Role of Concentrated Animal Feeding Operations in Infectious Disease Epidemics and Antibiotic Resistance. Environmental Health Perspectives, Volume 115, Number 2, February 2007

6. Krapac, I. G., Koike, S., Meyer, M. T., et al. 2004. Long-Term Monitoring of the Occurrence of Antibiotic Residues and Antibiotic Resistance Genes in Groundwater near Swine Confinement Facilities. Proceedings of the 4th international conference on pharmaceuticals and endocrine disrupting chemicals in water. Minneapolis, MN. National Groundwater Association. 13-15 Oct. pp. 158-172.

7. Walczak, J.J., Xu, S., 2011. Manure as a Source of Antibiotic-Resistant Escherichia coli and Enterococci: a Case Study of a Wisconsin, USA Family Dairy Farm. Water. Air. Soil Pollut. 219, 579–589.

https://doi.org/10.1007/s11270-010-0729-x

8. Bradford, S.A., Morales, V.L., Zhang, W., Harvey, R.W., Packman A.I., Mohanram, A., Welty, C. 2013. Transport and Fate of Microbial Pathogens in Agricultural Settings. Critical Reviews in Environmental Science and Technology, 43:775−893.
9. Knobeloch, L., P. Gorski, M. Christenson, H. Anderson. 2013. Private drinking water quality in rural Wisconsin. Journal of Environmental Health, 75(7):16-20.
10. US GAO. 1997. Information on the quality of water found at community water systems and private wells. United States General Accounting Office/RCED-97-123, June 1997. Available *www.gao.gov/assets/rced-97-123.pdf*
11. Kewaunee Co., 2014. Kewaunee County Public Health and Groundwater Protection Ordinance, Ordinance No. 173-9-14. Available *kewauneeco.org/i/f/files/Ordinances/Chapter%2030.pdf*
12. Stokdyk, J., Borchardt, M., Firnstahl, A., Bradbury, K., Muldoon, M., Kieke, B. 2022. Assessing Private Well Contamination in Grant, Iowa, and Lafayette Counties, Wisconsin: The Southwest Wisconsin Groundwater and Geology Study. Available at *https://iowa.extension.wisc.edu/natural-resources/swigg/*
13. Uejio, C. K., S. H. Yale, K. Malecki, M. A. Borchardt, H. A. Anderson, J. A. Patz. 2014. Drinking water systems, hydrology, and childhood gastrointestinal illness in central and northern Wisconsin. American Journal of Public Health, 104(4):639-646. Available at *http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4025711/*
14. DNR Well Compensation fund records
15. Borchardt, M. A., P. D. Bertz, S. K. Spencer, D. A. Battigelli. 2003a. Incidence of enteric viruses in groundwater from household wells in Wisconsin. Applied and Environmental Microbiology, 69(2):1172- 1180. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC143602/
16. Borchardt, M. A., S. K. Spencer, B. A. Kieke, E. Lambertini, F. J. Loge. 2012. Viruses in nondisinfected drinking water from municipal wells and community incidence of acute gastrointestinal illness. Environmental Health Perspectives 120(9):1272:1279. Available at ncbi.nlm.nih.gov/pmc/articles/PMC3440111/
17. Lambertini, E., M. A. Borchardt, B. A. Kieke, S. K. Spencer, F. J. Loge. 2012. Risk of viral acute gastrointestinal illness from nondisinfected drinking water distribution systems. Environmental Science & Technology 46(17):9299-9307.