Wisconsin Groundwater Coordinating Council

Report to the Legislature

Fiscal Year 2022

The Groundwater Coordinating Council (GCC) prepares an annual report each year that summarizes the operations and activities of the council, describes the state of the groundwater resource and its management and makes recommendations.

2022 GROUNDWATER COORDINATING COUNCIL MEMBERS

- Department of Natural Resources – Jim Zellmer, Chair
- Department of Agriculture, Trade & Consumer Protection – Sara Walling *
- Department of Safety & Professional Services – Bradley Johnson
- Department of Health Services – Jonathan Meiman, MD
- Department of Transportation – Robert Pearson
- Geological and Natural History Survey (State Geologist) – Ken Bradbury **
- Governor's Representative – Steve Diercks
- University of Wisconsin System – James Hurley

**   Recently moved on from agency*
*** Recently retired*

SUBCOMMITTEES

Research & Monitoring

- Geological and Natural History Survey - Dave Hart*(Co-Chair) & Mike Parsen*
- Department of Natural Resources – Bill Phelps*(Co-Chair), Shaili Pfeiffer* & Matt Silver*
- Department of Agriculture, Trade and Consumer Protection – Stan Senger* & Ken Potrykus*
- Department of Safety and Professional Services – Tim Vander Leest*
- Department of Health Services - Sarah Yang* & Curtis Hedman*
- University of Wisconsin System - Maureen Muldoon*, Tim Grundl & Jennifer Brand*
- U. S. Geological Survey - Andy Leaf* & Cheryl Buchwald*
- UWSP Center for Watershed Science and Education - George Kraft*

** Member of Standing Joint Solicitation Work Group*

Outreach & Partnership

- Department of Health Services – Sarah Yang (Chair)
- Department of Natural Resources – Bruce Rheineck
- University of Wisconsin System – Moira Harrington
- Department of Agriculture, Trade and Consumer Protection – Mark McColloch
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- Geological and Natural History Survey - Dave Hart
- Department of Transportation - Robert Pearson
- Center for Watershed Science and Education – Kevin Masarik
- State Laboratory of Hygiene – Jocelyn Hemming
- Wisconsin Rural Water Association – Andrew Aslesen

State of Wisconsin \GROUNDWATER COORDINATING COUNCIL

Tony Evers, Governor

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August 12, 2022

To: The Citizens of Wisconsin
The Honorable Governor Tony Evers
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Assembly Chief Clerk
Secretary Craig Thompson - Department of Transportation
Secretary Dawn B. Crim - Department of Safety & Professional Services
Secretary Randy Romanski - Department of Agriculture, Trade & Consumer Protection
Secretary-designee Karen Timberlake - Department of Health Services
Secretary Preston D. Cole - Department of Natural Resources
President Jay O. Rothman - University of Wisconsin System
State Geologist Vacant - Geological and Natural History Survey

The Groundwater Coordinating Council (GCC) is pleased to provide its 2022 Report to the Legislature. The GCC was formed in 1984 to help state agencies coordinate non-regulatory activities and exchange information for efficient management of groundwater. For over 30 years, the GCC has been a model for interagency coordination and collaboration among state agencies, local and federal government, and the university. It is one of very few examples of effective statewide coordination of groundwater efforts from an advisory position.

The level of coordinating effort and investment in groundwater is particularly appropriate as Wisconsin depends so heavily on groundwater for its drinking water. Wisconsin also relies on groundwater to irrigate crops, water cattle, and process a wide variety of foods, as well as feed trout streams and spring-fed lakes - all of which are vital to our state economy. New challenges and new ideas continue to warrant the GCC's collaborative approach.

This *online report* summarizes and links to information on the GCC and agency activities related to groundwater protection and management in FY22 (July 1, 2021 to June 30, 2022). Search "GCC" on dnr.wi.gov to find the full report. Click on the picture tabs for chapters of the report, beginning with the GCC's recommendations. The Executive Summary is attached.

We hope you will find this report to be a useful reference in protecting Wisconsin's priceless groundwater supply.

Sincerely,

James A. Zellmer, Chair
Groundwater Coordinating Council

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PURPOSE OF THE GCC AND ANNUAL REPORT

In 1984, the Legislature enacted Wisconsin's Comprehensive Groundwater Protection Act, to improve the management of the state's groundwater. The Groundwater Coordinating Council (GCC) was created and is directed by s. 160.50, Wis. Stats., to "serve as a means of increasing the efficiency and facilitating the effective functioning of state agencies in activities related to groundwater management. The Groundwater Coordinating Council shall advise and assist state agencies in the coordination of non-regulatory programs and the exchange of information related to groundwater, including, but not limited to, agency budgets for groundwater programs, groundwater monitoring, data management, public information and education, laboratory analysis and facilities, research activities and the appropriation and allocation of state funds for research."

The GCC is required by s. 15.347, Wis. Stats., to prepare a report which "summarizes the operations and activities of the council…, describes the state of the groundwater resource and its management and sets forth the recommendations of the council. The annual report shall include a description of the current groundwater quality of the state, an assessment of groundwater management programs, information on the implementation of ch. 160, Wis. Stats., and a list and description of current and anticipated groundwater problems." This report is due each August. The purpose of this report is to fulfill this requirement for fiscal year 2022 (FY22). The report includes webpages with links to extensive supporting information.

The GCC's role in facilitating inter-agency coordination includes the exchange of information regarding Wisconsin's Comprehensive Groundwater Protection (Act 1983 Wisconsin Act 410), Wisconsin's Groundwater Protection Act (2003 Wisconsin Act 310), the Great Lakes Compact (2007 Wisconsin Act 227), the federal Safe Drinking Water Act's Wellhead and Source Water Protection provisions, and many other programs.

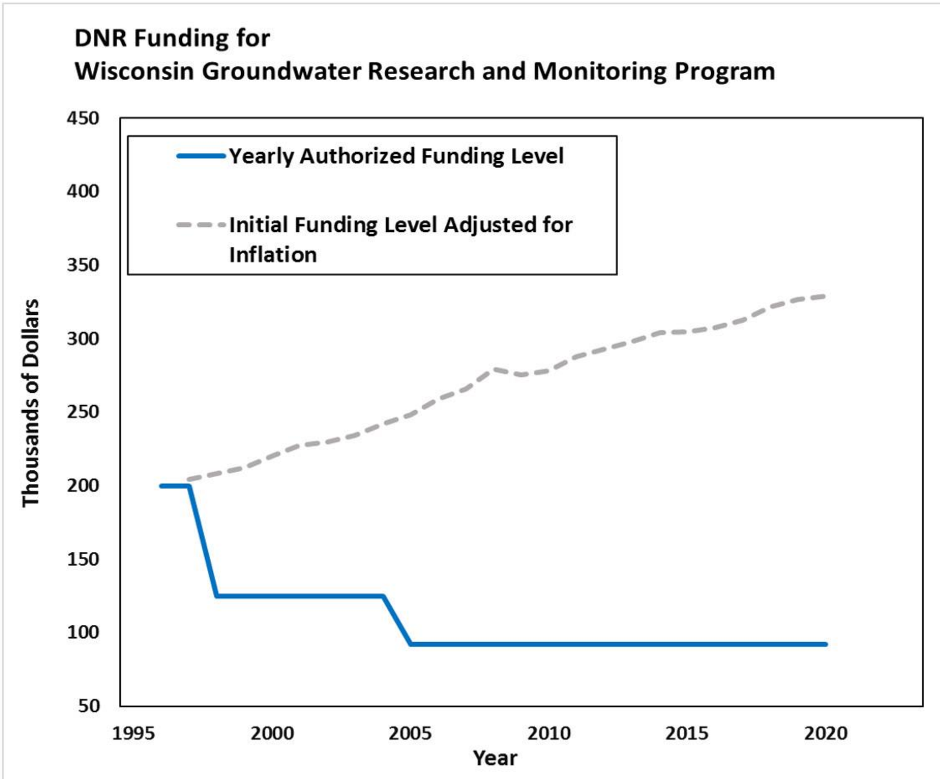
GROUNDWATER COORDINATION ACTIVITIES

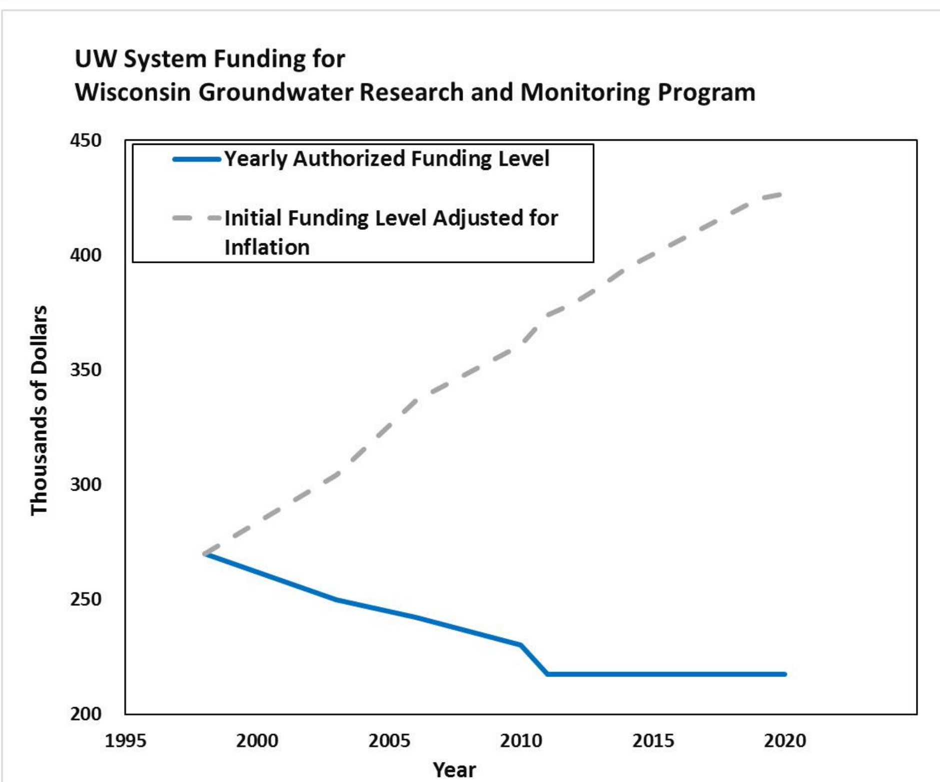
In addition to the council of agency leaders, the GCC is authorized to create subcommittees on "the subjects within the scope of its general duties…and other subjects deemed appropriate by the Council." A list of GCC members and subcommittees is included in this executive summary.

The GCC and its subcommittees regularly bring together staff from over 15 different agencies, institutions and organizations to communicate and work together on a variety of research, monitoring and data management, educational, and planning issues. A strong network among GCC and subcommittee members leads to coordination across agency lines on a variety of groundwater-related issues. These activities regularly avoid duplication, create efficiencies and provide numerous benefits to Wisconsin's taxpayers.

Coordination of Groundwater Research and Monitoring Program

The GCC is directed to "advise the Secretary of Administration on the allocation of funds appropriated to the Board of Regents of the University of Wisconsin under s. 20.285(1)(a) for groundwater research." Since 1992, a joint solicitation process has facilitated selection and funding of sound scientific research and monitoring to answer state priority needs. The history of DNR and UW System state legislative groundwater research funding levels (funding source created in 1996) are shown below. The solid blue line shows the actual authorized funding level through time, the dashed gray line shows the inflation adjusted value of the initial funding level in today's dollars.





The GCC, the UWS, DNR and the Groundwater Research Advisory Council (GRAC) again collaborated on the annual solicitation for groundwater research and monitoring proposals as specified in the Memorandum of Understanding. After a multi-agency effort spearheaded by the UW Water Resources Institute (WRI), the GCC approved selected projects for the annual program of research to answer current groundwater management questions.

A comprehensive review process including the GRAC, the GCC's Research & Monitoring Subcommittee, and outside technical experts resulted in recommendations that were used by the UWS and DNR in deciding which groundwater-related proposals to fund. From 16 proposals, five new projects were selected for funding in FY23 - two by UWS, two by DNR and one by Department of Agriculture, Trade & Consumer Protection (DATCP). The GCC approved the proposed UWS groundwater research plan as required by s. 160.50(1m), Wis. Stats., and a letter to this effect was sent to the UWS President and the Department of Administration. Current groundwater research and monitoring projects are listed in the report as well as all Wisconsin Joint Solicitation groundwater research and monitoring projects.

The UW Water Resources Institute provides access to summaries and reports of GCC-facilitated groundwater research, as well as cataloging all WRI research reports into WorldCat and MadCat, two library indexing tools that provide both worldwide and statewide access to this research. The Water Resources Library has partnered with UW Libraries' Digital Collections Center to digitize and post UWS and DNR final project reports. As a result of this partnership, full-text reports are also available through the UW Ecology and Natural Resources Digital Collection. Progress continues in making older final reports and summaries accessible online.

Information and Outreach Activities

Since 1994 annual groundwater workshops for teachers have been taught jointly by GCC Outreach and Partnership Subcommittee members from the DNR, Wisconsin Geological and Natural History Survey (WGNHS) and the Center for Watershed Science and Education (CWSE) at U.W. Stevens Point. Teacher applications to participate continue to fill all available workshop space and equipment. The workshop leaders instruct teachers on using a groundwater sand-tank model and provide additional resources to incorporate groundwater concepts into their classroom. Educators who attend the workshops receive a free model. With funding from a U.S. Environmental Protection Agency (EPA) wellhead protection grant, over 475 groundwater models have been given to schools and nature centers since 2001 and over 900 educators have received hands-on training in using the model effectively. Educators are regularly surveyed to promote continued use and evaluate educational benefits.

Other Coordination Activities

The GCC continued to promote communication, coordination and cooperation between the state agencies through its quarterly meetings. In addition to identifying collaboration opportunities, making decisions about research and guiding report development, the GCC received briefings and discussed a variety of current topics at its FY22 meetings:

- WGNHS: Northeast WI airborne electromagnetic (AEM) depth to bedrock mapping project

- DNR: Nitrate Aquifer Penetration Graphs
- DNR: WI Groundwater Retrieval Network (GRN) upgrades
- DOT: Chloride reduction through innovative road salt management
- WGNHS: Aerial thermal imaging applied to Wisconsin’s groundwater, springs, thin soils, and slopes

More information on these topics and the coordinating efforts of the GCC can be found in the FY22 GCC meeting minutes. Through these activities, the GCC plays an important role in ensuring agency coordination, increasing efficiency, avoiding duplication and facilitating the effective functioning of state agencies in activities related to groundwater protection and management. As a result, groundwater is better protected, which benefits public health, sustains our economy and preserves Wisconsin's natural resources for future generations.

SUMMARY OF AGENCY GROUNDWATER ACTIVITIES

State agencies and the University of Wisconsin System addressed numerous issues related to groundwater protection and management in FY22. Detailed discussions of the groundwater activities of each agency can be found on the agency activities webpage of the online report.

CONDITION OF THE RESOURCE: GROUNDWATER QUALITY

Major groundwater quality concerns in Wisconsin are summarized below and detailed in the online report.

Nitrate

While nitrate in agricultural use has benefits such as larger crop yields, high concentrations in groundwater lead to public health concerns. Nitrate is Wisconsin’s most widespread groundwater contaminant and is increasing in extent and severity. Statewide various studies show about 10% of private well samples exceed the 10 milligrams per liter (mg/L) health-based standard for nitrate-N. Nitrate levels in groundwater above 2 mg/L indicate a source of contamination such as agricultural or turf fertilizers, animal waste, septic systems and wastewater. Approximately 90% of total nitrate inputs into our groundwater originate from agricultural sources.

According to the Wisconsin Department of Health Services (DHS), high levels (above 10 mg/L) of nitrate in drinking water can affect everyone. Nitrate can cause blue baby syndrome and may cause birth defects. Nitrate may cause thyroid disease and may increase the risk for certain kinds of cancer.

More than 200 public water supply systems (mostly systems like mobile home parks, restaurants and taverns) exceeded the nitrate drinking water standard of 10 mg/L in FY 22, requiring them to post notices, provide bottled water, replace wells, install treatment or take other corrective actions. Concentrations of nitrate in private water wells have also been found to exceed the standard. A 2017 DATCP survey estimated that 8% of private wells exceeded the 10 mg/L enforcement standard for nitrate. GCC member agencies are working on multiple initiatives related to reducing the risk of high nitrate levels in groundwater and drinking water.

Per- and Polyfluorinated Alkyl Substances (PFAS)

(PFAS) are a large group of human-made chemicals that have been used in industry and consumer products worldwide since the 1940s. Their ability to repel water and oil and withstand high temperatures has made PFAS a particularly useful ingredient in industrial and commercial products, including non-stick products, stain- and water-repellent clothing and aqueous film forming foams (AFFFs). These chemicals do not easily break down in the environment and have been known to accumulate in the environment and humans.

Currently, there is limited regulatory authority regarding PFAS at the federal level. In 2016, the EPA issued a non-enforceable Lifetime Health Advisory level (HAL) for PFOA and PFOS of 70 parts per trillion (ppt) in drinking water. In June 2022, the EPA issued Interim updated lifetime HALs for PFOA and PFOS of 0.004 ppt and 0.02 ppt, respectively (four to five orders of magnitude lower than the previous HAL of 70 ppt). These health advisories are applicable to non-cancer health outcomes (the evaluation regarding cancer outcomes is still ongoing). EPA also issued (June 2022) HALs for GenX chemicals, which refers to hexafluoropropylene oxide dimer acid (HFPO-DA) and its ammonium salt, and perfluorobutanesulfonic acid (PFBS) of 10 ppt and 2,000 ppt, respectively.

Under the Safe Drinking Water Act's third Unregulated Contaminants Monitoring Rule (UCMR-3), select municipal water systems were asked to test for PFOA and PFOS, between 2013 and 2015. PFAS were detected in public water systems in La Crosse, West Bend and Rhinelander. Testing has also been conducted voluntarily by several municipal water systems and included a more comprehensive list of PFAS (i.e. additional compounds such as those included as part of EPA's Method 537.1). These testing efforts identified PFAS in varying concentrations in municipal water systems in Marinette, Peshtigo and Madison.

PFAS have also been found in groundwater near Department of Defense sites in Wisconsin, such as Wisconsin Air National Guard facilities at Truax Field and Volk Field. PFAS are present in many consumer products and AFFFs and can also be released from industrial facilities that manufacture or use the compounds. Therefore, PFAS are potentially present at fire departments, industrial facilities, landfills and wastewater treatment plants due to the diverse waste streams accepted from industrial and municipal parties. PFAS have also been identified in municipal wastewater treatment plants' biosolids. As biosolids are put to beneficial reuse via agricultural landspreading, this may be an important pathway for the substances to enter groundwater.

At present, the DNR is continuing to identify PFAS sources and their potential impacts to groundwater and other environmental media in Wisconsin. The DNR has begun sampling initiatives for PFAS in drinking water and ambient groundwater. These efforts include municipal drinking water sampling, open to all municipal systems, and a groundwater research study sampling up to 450 private wells. Both projects are occurring on a basis of voluntary participation.

Currently, there are no state or federal groundwater protection standards for PFAS. To address this regulatory gap, the DNR initiated rulemaking to implement DHS recommendations for groundwater enforcement standards for two PFAS, PFOA and PFOS, in accordance with State law. However, while the NRB moved forward with state drinking water maximum contaminant levels higher than DHS recommendations, it stopped rulemaking which would have set groundwater standards.

Bacteria, viruses and other pathogens

Bacteria, viruses and other pathogens often occur in areas where the depth to groundwater is shallow, in areas where soils are thin or in areas of fractured bedrock. These pathogens can cause acute illness and result in life-threatening conditions for young children, the elderly and those with chronic illnesses. An estimated 17% of private water supply wells statewide test positive for total coliform bacteria, an indicator species of other biological agents (Knobeloch et al., 2013). Approximately 3% of these wells tested positive for E. coli, an indicator of water borne disease that originates in the mammalian intestinal tract.

Viruses in groundwater are increasingly a concern as new analytical techniques have detected viral material in private wells and public water supplies. Research conducted at the Marshfield Clinic indicates that 4-12% of private wells contain detectible viruses. Other studies showed virus presence in four La Crosse municipal wells, in the municipal wells in Madison and in five shallow municipal wells serving smaller communities. A recent study in Wisconsin, designated the Southwest Wisconsin Groundwater and Geology (SWIGG) study, looked at the presence of total coliform bacteria and waste source and pathogen genetic markers in private water supply wells in Grant, Iowa and Lafayette Counties (Stokdyk et al. 2022). 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.

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. However, recent findings 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 as well as emergency response on this issue.

Pesticides

Pesticides are a broad class of substances designed to kill, repel or otherwise disrupt living things that are considered pests. They include insecticides, herbicides, fungicides and anti-microbials, among other types of biocides. In Wisconsin, the main source of pesticides in groundwater is agricultural herbicide and insecticide applications. For this reason, detection is more common in highly cultivated areas where agriculture is well established, notably in the south-central, central and west-central parts of the state.

In 2016, DATCP conducted a statewide statistical survey of agricultural chemicals in groundwater that found an estimated 41.7% of private wells in Wisconsin contained a pesticide or pesticide metabolite, up from 33% of private wells in a similar survey conducted in 2007 (DATCP, 2008; DATCP, 2017). The primary metabolites of metolachlor and alachlor, metolachlor ESA and alachlor ESA, were the two most commonly detected pesticide products. Atrazine and its metabolites, known collectively as the total chlorinated residues of atrazine (atrazine TCR), were also prevalent and occurred in about 23% of wells.

Many sampling programs initiated by DATCP, DNR and other agencies in the mid-1980s to early 1990s are still ongoing today. The longest running sampling program for pesticides began in 1985 and is designed to evaluate the potential impact of agriculture on groundwater quality by sampling monitoring wells near selected agricultural fields in areas with high groundwater contamination potential. Testing in this program confirms that the metabolites of metolachlor and alachlor are the two most common pesticides products detected in groundwater near the monitoring well sites. A DATCP review of data from samples it collected statewide from 2008 through 2016 revealed an increased occurrence of detections of neonicotinoid insecticides in samples collected from monitoring wells, irrigation wells, private wells and surface water samples.

DATCP has also conducted a statewide, statistically designed survey of agricultural chemicals in Wisconsin groundwater five times since the early 1990s (1994, 1996, 2001, 2007 and 2016). In 2016, nearly four hundred samples from private drinking water wells were analyzed for 101 pesticide compounds, including 70 herbicides, 26 insecticides, 4 fungicides and 1 pesticide safener. Health standards have been established for 27 of the compounds analyzed. In addition to capturing the current picture of agricultural chemicals in groundwater, this series of studies relates these findings to land use and compares results of the 2016 survey to those of previous surveys. The final report of the results of the 2016 survey was published in early 2017 (DATCP 2017).

Arsenic

Arsenic is an odorless and tasteless, naturally occurring element present in soil and rock. Under certain environmental conditions, arsenic can dissolve and be transported in groundwater. It can also be released as a by-product from agricultural and industrial activities. Everyone is exposed to small amounts of arsenic since it is a natural part of the environment, but under some geologic conditions elevated amounts of arsenic can be released to groundwater.

In Wisconsin, most arsenic found in groundwater is naturally occurring, released from minerals in bedrock and glacial deposits. Arsenic has been detected above the enforcement standard (ES) in the groundwater in every county in Wisconsin. Arsenic contamination of groundwater is common in northeastern Wisconsin in areas around Winnebago and Outagamie County and moderately high levels of arsenic (10 ppb – 30 ppb) are also common in some parts of southeastern Wisconsin.

The extensive research completed in Wisconsin over the past 20 years illustrates the highly variable nature of Wisconsin's geologic sources of arsenic to groundwater. A well with no detectable arsenic can be right across the street from a well that tests well above the 10 ppb MCL. Arsenic concentrations can vary over time, too. This makes regular testing – with efficient, accurate and affordable methods – critical. In 2014, DNR began requiring testing for arsenic when pump work was being done on existing wells. The data is being analyzed to determine if additional Special Well Casing Depth Areas should be developed.

GCC member agencies and partners continue to proactively address arsenic concerns through well drilling advisories, health studies, well testing campaigns, studies aimed at improving geological understanding and developing practical treatment technologies.

Volatile Organic Compounds (VOCs)

Volatile Organic Compounds (VOCs) are a group of common industrial and household chemicals that evaporate, or volatilize, when exposed to air. Examples of products containing VOCs include gasoline and industrial solvents, paints, paint thinners, air fresheners and household products such as spot and stain removers. Chemical names for the VOCs in these products include benzene, Trichloroethylene (TCE), toluene and vinyl chloride, among others. Improper handling or disposal of VOCs is often the reason why they occur in groundwater.

Sources of VOCs in Wisconsin's groundwater include landfills, underground storage tanks and hazardous substance spills. Thousands of wells have been sampled for VOCs and about 60 different VOCs have been found in Wisconsin groundwater. Trichloroethylene is the VOC found most often in Wisconsin's groundwater.

Radionuclides

Radionuclides are radioactive atoms. It is possible for radionuclides to be manmade, as is the case with some materials from nuclear power reactors, but they also occur naturally in rock formations and are released to groundwater over millions of years by geochemical reactions. Common naturally occurring radionuclides in groundwater include uranium, radium and thorium. Naturally occurring radionuclides are a concern for groundwater quality, particularly in the Cambrian-Ordovician aquifer system in eastern Wisconsin. The water produced from this aquifer often contains combined radium activity in excess of 5 pCi/L and in some cases in excess of 30 pCi/L. Historically, about 80 public water systems exceeded a radionuclide drinking water standard, causing these communities to search for alternative water supplies or treatment options. The vast majority of these systems are now serving water that meets the radium standard. The DNR continues to work with the remaining water systems to ensure that they develop a compliance strategy and take corrective actions.

A study of radium in groundwater, in the Cambrian-Ordovician aquifer system, was conducted in the vicinity of Madison in 2016 - 2017 (Mathews et al. 2019). This study evaluated radium occurrence in groundwater relative to several geochemical parameters, as well as the presence of naturally occurring radium "parent elements", uranium and thorium, in aquifer bedrock units. The Wisconsin State Laboratory of Hygiene and other WGRMP-funded (Wisconsin's Groundwater Research and Monitoring Program) researchers have also made advances in sampling techniques and laboratory testing for radionuclide parameters, which tend to be very sensitive to collection and analysis methods. Following these findings, researchers have developed corrections and guidelines to ensure reported test results are as accurate as possible.

CONDITION OF THE RESOURCE: GROUNDWATER QUANTITY

Groundwater quantity conditions are summarized below and detailed in the online report.

Groundwater is available in sufficient amounts throughout most of Wisconsin to provide adequate water supplies for most municipal, industrial, agricultural and domestic uses. What is frequently missed is that groundwater pumping lowers water levels in aquifers and connected lakes, wetlands and streams; and diverts flow to surface waters where groundwater would have discharged naturally. The amount of water level lowering and flow diversion is a matter of degree. At certain amounts of pumping in an area, streams, lakes and wetlands can dry up and aquifers can be perilously lowered.

Groundwater pumping shows a continued long-term increase. Numbers of high capacity wells, especially in the Central Sands region of the state (parts of Portage, Waushara, Waupaca, Adams and Marquette Counties), indicates pumping amounts will continue to expand.

Groundwater pumping issues have arisen in multiple regions of Wisconsin. Large scale drawdowns of the confined aquifer have been documented in the Lower Fox River Valley and southeastern Wisconsin. Surface water impacts have been well-documented in the Wisconsin Central Sands and Dane County. These impacts have included the drying of lakes and streams.

BENEFITS OF MONITORING AND RESEARCH PROJECTS

The GCC provides consistency and coordination among state agencies in funding Wisconsin's Groundwater Research and Monitoring Program to meet state agency needs. Approximately $20 million has been spent over 30 years by DNR, UWS, DATCP and DSPS (formerly Commerce) on more than 450 different projects selected to answer essential management questions and advance understanding of groundwater in Wisconsin.

Projects funded have helped evaluate existing programs, increased the knowledge of the movement of contaminants in the subsurface and developed new methods for groundwater protection. While the application of the results is broad, a few examples where the results of state-funded groundwater research and monitoring projects are successfully applied to groundwater problems in Wisconsin include:

- Detection and characterization of sources of microbial pathogens
- Extent of arsenic in Northeastern Wisconsin
- Evaluation of drawdown in Eastern Wisconsin
- Best practices for minimizing risk of groundwater contamination
- Methods for diagnosing causes of bacterial contamination in public water systems
- Understanding barriers to private well testing
- Statewide inventory and database of springs

RECOMMENDATIONS: DIRECTIONS FOR FUTURE GROUNDWATER PROTECTION

The GCC is directed by statute to include in its annual report a "list and description of current and anticipated groundwater problems" and to "set forth the recommendations of the Council" (s. 15.347(13)(g), Wis. Stats.). In this section, the GCC identifies its recommendations for future groundwater protection and management.

These recommendations include top priorities of immediate concern and ongoing efforts that require continued support.

Priority Recommendations

Set new and revised health-based groundwater standard recommendations

Wisconsin has a long and proud history of groundwater protection. Wisconsin's groundwater law adopted in 1983 is held up as one of the nation's model environmental laws in part because of its robust, science-based process for protecting the quality of our groundwater and public health. For nearly 40 years, this law has guided the process that DHS and DNR follow, ensuring a scientifically rigorous review of available technical information and clarity on how recommended groundwater standards are selected.

However, the DNR has not been allowed to make revisions or additions to groundwater standards for over 10 years. Since 2019, DHS has provided DNR with two sets of recommendations (Cycle 10 and Cycle 11) based on state regulatory program needs for 47 new or revised groundwater standards. These include standards for pesticides, per- and polyfluoroalkyl substances (PFAS), metals, volatile organic compounds (VOCs) and bacteria. However, in 2022 the Natural Resources Board (NRB) ended rulemaking before sending the rule package to the legislature which would have set standards for the 26 Cycle 10 recommendations.

Implement practices that protect groundwater from nitrate and other agricultural contaminants (microbial agents, pesticides and their degradates).

Nitrate that approaches and exceeds unsafe levels in drinking water is one of the top drinking water contaminants in Wisconsin, posing an acute risk to infants and women who are pregnant, a possible risk to the developing fetus during very early stages of pregnancy, and a chronic risk of serious disease in adults. In addition, pesticides are estimated to be present in approximately 40% of private drinking water wells in Wisconsin. Areas of the state with a higher intensity of agriculture generally have higher frequencies of detections of pesticides and nitrate. Agencies should develop and evaluate a strategy to promote practices that lead to efficient use of nitrogen and careful or reduced use of pesticides in order to protect drinking water sources.

Implementation of these practices should be supported with appropriate technical tools and incentives such as:

- Identifying sensitive areas of the state based on geology where elevated nitrate is present and making information available through an online mapping tool
- Assessing soil type specific nitrogen crop application rates and cropping best management practices to further minimize nitrogen losses to groundwater and encourage their use, especially in highly sensitive areas of the state
- Developing a broad outreach plan and educational materials for farmers and nutrient management planners, and agricultural industry stakeholders that identify and encourage the use of specific alternate cropping and nutrient management practices to minimize agricultural nitrogen losses to groundwater
- Supporting research to assess the ability for alternative conservation practices, including saturated buffers and bioreactors, to minimize sources of nitrogen to surface and groundwater
- Developing strategies and outreach programs that encourage the full implementation of nutrient management plans

Address public health and environmental concerns regarding PFAS.

PFAS have been detected in both municipal and private drinking water sources in Wisconsin. PFAS have also been found in groundwater near Department of Defense sites in Wisconsin, such as Wisconsin Air National Guard facilities at Truax Field and Volk Field. PFAS are present in many consumer products and AFFFs. Current studies of these PFAS suggest exposure may affect childhood development, decrease female fertility, increase the risk of high blood pressure in pregnant women, increase cholesterol levels, increase the risk of thyroid disease and decrease antibody response to vaccines. EPA research suggests that some PFAS may have the potential to cause cancer.

The GCC recommends the following actions be supported to address PFAS concerns:

- Implement DHS recommendations for groundwater enforcement standards for two PFAS, PFOA and PFOS, in accordance with State law
- Pursue development of additional groundwater enforcement standards for PFAS compounds detected in Wisconsin
- Continue to identify PFAS sources and their potential impacts to groundwater and other environmental media
- Develop benchmarks for PFAS in other media such as surface water, biosolids and sludge to protect groundwater resources
- Support the Wisconsin PFAS Action Council (WisPAC) in developing and coordinating statewide initiatives around PFAS

Ongoing Recommendations

Without ongoing attention to the following needs, Wisconsin cannot address the priority recommendations (see above) or begin to understand emerging issues.

Evaluate the occurrence of viruses and other pathogens in groundwater and groundwater-sourced water supplies and develop appropriate response tools.

Viruses and other microbial pathogens have been found in municipal and domestic wells, challenging previous assumptions about their persistence and transport. Monitoring and assessment should focus on refining our understanding of pathogens in groundwater, in particular, where and when they pose threats to human health. Agencies should also work with partners to increase awareness of waste disposal choices, their risks and costs.

Support the sustainable management of groundwater quantity and quality in the state to ensure that water is available to be used, which will protect and improve our health, economy and environment now and into the future.

This includes:

- Supporting an inventory of information on the location, quantity and uses of the state's groundwater
- Supporting targeted monitoring and modeling of the impact of groundwater withdrawals on other waters of the state
- Supporting identification and evaluation of options for areas with limited groundwater resources
- Supporting research relating to changes in land-use development patterns and the resulting increase in groundwater use and changes to recharge

Continue to catalog Wisconsin's groundwater resources.

Management and protection of Wisconsin's groundwater resources requires publicly-accessible and up-to-date data in order to foster informed decisions, not only on state policy matters but also for sound business decisions on siting or technology investments. State agencies and the University should continue to collect, catalog, share and interpret new data about Wisconsin's groundwater so that it can be used by health care providers, people seeking business locations, homeowners and local governments. Options for sharing data about groundwater and groundwater vulnerabilities should include accessible formats like online mapping tools. Wisconsin should improve the accessibility of current data and continue to encourage research efforts that will provide information.

Evaluate potential impacts of climate change on Wisconsin's groundwater.

Climate change is increasing the frequency and severity of weather patterns that may produce unprecedented flooding or drought conditions. More severe flooding can affect groundwater quality, wells and water system operations. Public drinking water supplies as well as water-dependent industries need reliable estimates of these effects in order to develop practical emergency response and adaptation strategies. Additionally, land and water use patterns may also change and affect the groundwater supply. These may include biological or chemical contamination issues, or an increased demand for groundwater by agricultural, municipal and commercial users. More work is needed to determine the range of possible climates in Wisconsin's future. Work is also needed on feedback mechanisms between climate and groundwater to fully characterize possible changes to Wisconsin's groundwater resource. This research will help identify both flood and drought response and long-term management strategies for Wisconsin's groundwater supply.

Support applied groundwater research in Wisconsin.

Wisconsin is recognized as a national leader in groundwater research, which is appropriate given how uniquely important this resource is for public health, the economy and the environment in this state.

For example:

- Wisconsin leads the nation in the number of public water systems that rely on groundwater (more than 11,000).
- Over 97% of agricultural irrigation water and more than one third of the water used for commercial and industrial purposes come from groundwater supplies.
- Many ecosystems in Wisconsin are strongly dependent on groundwater availability and groundwater quality.

Wisconsin's reputation for groundwater research is largely due to the well–established joint solicitation process for groundwater research and monitoring projects coordinated by the GCC. This approach streamlines proposal writing and the review process and improves communication among agencies and researchers. The solicitation is a coordinated effort of the University of Wisconsin System and the Wisconsin Departments of Natural Resources; Agriculture, Trade and Consumer Protection; and Safety and Professional Services.

Collectively, since its inception this annual joint solicitation has funded 494 groundwater research and monitoring projects and has helped establish Wisconsin as an international leader in groundwater research. The GCC recommends the following actions be taken to support applied groundwater research in Wisconsin:

- Restoring the original authorized amounts of DNR and UW groundwater research funding (adjusted for inflation using U.S. Bureau of Labor Statistics Consumer Price Index calculator) to DNR $329,255 and UW $426,790 annually. Restoring funds to this level would allow nearly half of the submitted proposals to be funded each year instead of 1/6 to 1/4 typically funded over the last ten years. Alternatively, increasing the funding to $500,000 each for DNR and UW would allow the joint solicitation program to better attract qualified researchers to address concerns such as PFAS, which is more expensive to test for and research than most other groundwater issues facing Wisconsin.
- Additional consideration could be given to create dedicated funding mechanisms for the departments of Agriculture, Trade and Consumer Protection; Health Services; and Safety and Professional Services to conduct groundwater research targeting the needs of each respective agency.

DEPARTMENT OF NATURAL RESOURCES

Ozone generator inspection at a public water supply system.

The Wisconsin Department of Natural Resources (DNR) establishes groundwater quality standards for the state and coordinates the implementation of ch. 160, Wis. Stats. The department works with operators of landfills, entities that land spread waste, and those that oversee remediation and redevelopment of contaminated sites, to ensure standards are met to avoid increasing the concentration of pollutants in groundwater. The DNR works with public water systems across the state to protect groundwater quality and quantity to provide safe and reliable drinking water supplies. The DNR manages groundwater quantity (ss. 281.11, 281.12, 281.34, and 281.346, Wis. Stats.). The DNR staffs the Groundwater Coordinating Council and collaborates with the UW-System on the joint solicitation for groundwater research and with the Wisconsin Geologic and Natural History Survey (WGNHS) on an annual groundwater work plan.

Fiscal Year 2022 Highlights

- The DNR continues to implement elements of the Wisconsin PFAS Action Plan. In 2022 over 120 municipal systems voluntarily sampled using EPA Method 537.1 for PFAS in Drinking Water, which detects 18 different PFAS compounds. A report of findings will be created following completion of the program. More information at https://dnr.wisconsin.gov/topic/PFAS/PWSampling. In addition, effluent at select Wisconsin Pollutant Discharge Elimination System (WPDES) permitted facilities was sampled and the department is also drawing on the examples and experiences of other states as it develops an interim plan to address PFAS that may be present in municipal wastewater treatment facilities' biosolids that are regularly applied to agricultural lands throughout the state.
- The DNR received approval to set MCLs for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) in NR 809. These MCLs will be published in NR 809 on August 1, 2022. The MCL for PFOA and PFOS is 0.000070 mg/L (70 ppt). This level is set for the combined concentration of PFOA and PFOS.
- The DNR submitted a list of 27 substances, designated "Cycle 10," to DHS in March 2018 and also submitted a list of 40 substances, designated "Cycle 11", to the DHS in April 2019. On February 23, 2022, the Natural Resources Board considered and did not approve the Cycle 10 rule. The scope statement expired on March 3, 2022. The department is evaluating work on substances contained in Cycle 10 and have paused work on the Cycle 11 NR 140 Groundwater Pollutant Standards. At this time, rulemaking has been initiated to set a groundwater standard for E. coli and to revise the current standard for total coliform.The current status of NR 140 rulemaking can be found here: NR 140 Groundwater Quality Standards Update.

- Following the 2021 Supreme Court Decision (Clean Wisconsin, Inc., v. DNR), the DNR will continue its careful case-by-case analysis of high capacity well applications. The analysis will consider both the needs of the property and the environmental effects that the proposed high capacity well, when combined with existing environmental impacts, may have on waters of the state.
- The Drinking Water and Groundwater and Community Financial Assistance programs continue issuing grants to low-income private well owners. The grants provide funding to help replace contaminated wells or fill and seal unused wells.

Details of Ongoing Activities

The following DNR programs protect and manage groundwater:

Drinking Water and Groundwater (DG) – Regulates public water systems, private drinking water supply wells, well abandonment and high capacity wells. DG is responsible for adoption and implementation of groundwater quality standards contained in ch. NR 140, Wis. Adm. Code, and works closely with other programs and agencies to implement ch. 160, Wis. Stats., including groundwater monitoring, data management, hydrogeologic advice and staffing the Groundwater Coordinating Council. Groundwater quantity provisions (2003 Wisconsin Act 310, codified at s. 281.34, Wis. Stats. and ch. NR 820) and the Great Lakes Compact (2007 Wisconsin Act 227, codified at ss. 281.343 and 281.346, Wis. Stats.) are also implemented by DG. The program also coordinates the state's Wellhead Protection and Source Water Protection programs. See *https://dnr.wi.gov/topic/DrinkingWater,* *https://dnr.wisconsin.gov/topic/Wells*, *https://dnr.wi.gov/topic/Groundwater and* *https://dnr.wisconsin.gov/topic/WaterUse*.

Remediation and Redevelopment (RR) – Oversees response actions at spills, hazardous substance discharge sites, environmentally polluted sites, abandoned containers, drycleaners, brownfields (including grant programs that provide assistance with environmental assessment and cleanup), leaking underground storage tanks, closed wastewater and solid waste facilities, hazardous waste corrective action and generator closures and sediment cleanup actions, all of which are closely related to groundwater issues. In addition, the RR program provides temporary emergency water in instances where hazardous substances or animal waste have adversely affected private wells. See *https://dnr.wi.gov/topic/Brownfields/* and *https://dnr.wisconsin.gov/topic/cleanup*.

Waste and Materials Management (WA) – Regulates and monitors groundwater quality at proposed, active, and inactive solid waste facilities and landfills. WA reviews investigations of groundwater contamination and implementation of remedial actions at active solid waste facilities and landfills. WA also maintains a Groundwater and Environmental Monitoring System (GEMS) database of groundwater quality data from over 600 solid waste facilities and landfills and uses reports from GEMS to evaluate whether sites are adversely affecting groundwater quality. See *https://dnr.wi.gov/topic/Landfills/gems.html*.

Water Quality (WQ) - Regulates the discharge of municipal and industrial wastewater, by-product solids and sludge disposal from wastewater treatment systems and wastewater land treatment/disposal systems. WQ also issues permits for discharges associated with cleanup sites regulated by WQ for the RR program. See *https://dnr.wi.gov/topic/Wastewater* and *https://dnr.wi.gov/topic/TMDLs*.

Watershed Management (WT) – WT has primary responsibility for regulating stormwater and agricultural runoff, as well as managing waste from large animal feeding operations. See *https://dnr.wi.gov/topic/nonpoint/*, *https://dnr.wisconsin.gov/topic/cafo* and *https://dnr.wi.gov/topic/stormwater/*.

Office of Emerging Contaminants (OEC) - The Office of Emerging Contaminants (OEC) coordinates cross-program, division, and agency work around environmental contaminants and emerging topics such as PFAS. See *https://dnr.wisconsin.gov/topic/PFAS*.

Environmental Analysis and Sustainability Program (EAS) - The Environmental Analysis and Sustainability Program regulates metallic mining activity in the state. Issues related to groundwater quantity and groundwater quality are critical in determining whether a proposed mining project receives necessary approvals. See https://dnr.wisconsin.gov/topic/Mines/Metallic.html.

Drinking Water and Groundwater Program

Groundwater Quality Standards Implementation

Chapter 160, Wis. Stats., requires the DNR to develop numerous groundwater quality standards which consist of enforcement standards and preventive action limits for substances detected in, or having a reasonable probability of entering, the groundwater resources of the state. *Chapter NR 140, Wis. Adm. Code*, establishes these groundwater standards and creates a framework for their implementation. Groundwater quality standards are set for 138 substances of public health concern, eight substances of public welfare concern and 15 indicator parameter substances in ch. NR 140.

In accordance with *state groundwater law*, the DNR periodically submits a list of substances to the Department of Health Services (DHS) and requests that they review available toxicologic information and provide recommendations for new and/or revised groundwater standards. These lists submitted to DHS are designated as NR 140 "cycle" lists. The DHS then prepares and sends a Scientific Support Document back to DNR which describes the information and methodology used to develop each recommended standard.

The DNR submitted a list of 27 substances, designated "Cycle 10," to DHS in March 2018. The DHS responded with recommended standards to the DNR in June 2019. A plain language summary of each of the compounds in Cycle 10 is available at *DHS's Recommended Groundwater Enforcement Standards*. On February 23, 2022, the Natural Resources Board considered and did not approve this rule. The scope statement expired on March 3, 2022. The DNR also submitted a list of 40 substances, designated "Cycle 11", to the DHS in April 2019. The Cycle 11 list of substances includes 34 PFAS compounds detected, or potentially present, in Wisconsin groundwater. The department is evaluating work on substances contained in Cycle 10 and have paused work on the Cycle 11 NR 140 Groundwater Pollutant Standards. At this time, rulemaking has been initiated to set a groundwater standard for E. coli and to revise the current standard for total coliform.The current status of NR 140 rulemaking can be found here: *NR 140 Groundwater Quality Standards Update*.

The DNR continues to provide training to new staff in the runoff management and drinking water programs on the implementation of groundwater quality standards, including training for land spreading discharge permit writing and animal waste drinking water well contamination response. Groundwater and runoff program staff regularly consult on groundwater quality issues that arise in agricultural and urban runoff programs. Such coordination is critical in obtaining statewide consistency on how the DNR evaluates and reduces risk of groundwater contamination associated with regulated activities.

The DNR staff actively participate on the NRCS Source Water Protection Subcommittee. This subcommittee provides guidance to state conservationists and directors on how to comply with source water protection activities contained in the 2018 Farm Bill. Activities include identifying local priority areas for source water protection and practices to address water quality and quantity threats.

Groundwater Quantity Program Implementation

The DNR is authorized under ch. 281, Wis. Stats. to regulate wells, except for a residential well or a fire protection well that has a capacity of more than 100,000 gallons per day. Such wells are defined as high capacity wells. Any well, regardless of pump capacity, on a high capacity property is considered a high capacity well. 2015 Wis. Act 177 granted an exception for wells used for residential or fire protection purposes from being considered high capacity wells effective October 1, 2016. s. 281.34(1)(b) Wis. Stats.) Since 1945, the DNR has reviewed proposed high capacity wells for compliance with applicable well construction rules to determine whether the well would impair the water supply of a public utility well. The DNR review of high capacity wells has been evolving over the last decade as described in the paragraphs below.

In May of 2004, the statutes regarding high capacity wells were expanded through 2003 Wisconsin Act 310 to give the DNR additional authority to consider environmental impacts of proposed wells when the proposed well may significantly impact a large spring, results in 95% or greater water loss, or the well is located within 1,200-feet of a trout stream, exceptional resource water or outstanding resource waters. The DNR may deny or limit an approval to assure that proposed high capacity wells do not cause significant adverse environmental impacts to these valuable water resources. The Act 310 changes are implemented primarily through ch. NR 820, Wis. Adm. Code. The DNR water use section staff implement the programs created by Act 310 including reviewing applications, managing data and collecting water withdrawal reports.

The DNR changed its procedures in July 2011 in response to a 2011 Wisconsin Supreme Court decision. In Lake Beulah Management District v. State DNR (2011), the Wisconsin Supreme Court stated that the Public Trust Doctrine is a "fundamental tenet" of the Wisconsin Constitution and that it should be broadly construed to protect public rights in navigable waters. The court held that the WDNR has "the authority and a general duty to consider potential environmental harm to waters of the state when reviewing the high capacity well permit application."

If the DNR determined the proposed well could directly result in potential environmental harm, the DNR would either deny the well application or request that an applicant modify their proposed construction or operation of the well to prevent such impacts. The DNR based the need to modify or deny an application on the projected impacts to the affected water resource, e.g., estimated reductions in stream flow or lake level, and the resultant impacts to water temperature, the fishery and other ecological aspects of the stream or lake. In conducting these assessments, the DNR considered site-specific hydrogeology, separation distance between the well(s) and the water resource, the hydrology and characteristics of potentially affected surface waters, construction details of nearby wells, characteristics of the proposed wells such as construction, pump capacity, and the water use and pumping schedule for the proposed well and any other existing wells on the property. This version of the technical review methodology was in place from July 2011 through May 2016.

In May 2016 Wisconsin Attorney General Schimmel issued a formal opinion (OAG-01-16) regarding the DNR's authority to consider environmental impacts when reviewing high capacity well applications. Attorney General Schimmel concluded that section 227.10(2m), Wis. Stats., prohibits the DNR from conducting an environmental review of a high capacity well unless it is in one of the specific categories identified in Wis. Stat. § 281.34, such as a well in a groundwater protection area; with a water loss of more than 95% of the amount of water withdrawn; or that may have a significant environmental impact on a spring (these categories are specified in Wis. Stat. § 281.34(4)); or if it may impair the water supply of a public utility (as described in Wis. Stat. § 281.34(5)). 2017 *Wisconsin Act 10* took effect on June 3, 2017. The Act amended and created several statutes pertaining to replacement, reconstruction and transfer of approved high capacity wells. The new law allows well owners to conduct these activities without the DNR approval and without paying any additional fee, provided the statutory criteria are met. Please note that Act 10 does not affect any applications or approvals required for public or community water supply systems, or school or wastewater treatment plant wells under Wis. Adm. Code Chapters *NR 810*, *811,* and *812* and this guidance do not address requirements under those chapters. Act 10 also includes a study of specific navigable water resources of the Central Sands area of Wisconsin. A report on this study was due to the legislature in June 2021.

In May 2020, Wisconsin's *Attorney General Josh Kaul issued a letter* to the DNR withdrawing a 2016 Attorney General Opinion concerning the DNR's review of high capacity well applications and the ruling of the Wisconsin Supreme Court in Lake Beulah Management District v. Wisconsin Department of Natural Resources. In response to a May 1, 2020 letter from the Wisconsin Attorney General, the DNR no longer relied on a 2016 Attorney General opinion in evaluating high capacity well applications but rather acted in accordance with the Supreme Court's decision in Lake Beulah v. Wisconsin Department of Natural Resources by considering environmental impacts on a case-by-case basis when presented with concrete, scientific evidence of potential harm.

In 2021, the Wisconsin Supreme Court considered the application of 2011 Wisconsin Act 21 to the Lake Beulah decision and DNR's authority to conduct environmental review for all high capacity wells. In Clean Wisconsin, Inc., v. DNR (2021), the Wisconsin Supreme Court held that under the public trust doctrine, the DNR has explicit, broad authority and duty to consider environmental impact of a proposed high capacity well when presented with sufficient, concrete evidence of potential harm to waters of the state. Following the 2021 Supreme Court Decision, the DNR will continue its careful case-by-case analysis of high capacity well applications. The analysis will consider both the needs of the property and the environmental effects that the proposed high capacity well, when combined with existing environmental impacts, may have on waters of the state.

The DNR's High Capacity Well Application Review Process website (*https://dnr.wi.gov/topic/Wells/HighCap/Review.html*) describes the current technical approach.

Great Lakes Compact and Implementation of 2007 Act 227

The Great Lakes—St. Lawrence River Basin Water Resources Compact (Compact) took effect on December 8, 2008 following ratification in each of the eight Great Lakes States and Congress's consent. The water use section staff implement Compact-related programs including authorizing permits and approvals, implementing the water conservation and efficiency program, reviewing diversion applications and working in conjunction with groundwater quantity staff to collect annual water withdrawal reports.

The DNR has promulgated four administrative rules to implement the Compact and associated statewide water use legislation. Three of these rules took effect January 1, 2011: Water Use Registration and Reporting (ch. NR 856); Water Use Fees (ch. NR 850); and Water Conservation and Water Use Efficiency (ch. NR 852). The Water Use Permitting rule (ch. NR 860) took effect in December 2011. Three additional rules are still in the drafting stage. These rules include Water Supply Service Area Planning, Water Loss and Consumptive Use, and Water Use Public Participation.

In January 2018, the DNR received an application to divert water from Lake Michigan to the Village of Mount Pleasant. The Village of Mount Pleasant is partly in the Great Lakes Basin and partly in the Mississippi River Basin. Under the Great Lakes Compact, the Village of Mount Pleasant is eligible to receive a diversion of Great Lakes water if the Compact criteria for a straddling community diversion are met. The DNR approved the diversion on April 25, 2018 after holding a public comment period, public hearing and determining that the proposal met the Great Lakes Compact criteria. The diversion is approved to supply up to seven million gallons of water per day to the portion of the Village of Mount Pleasant in the Mississippi River Basin. The diversion area includes part of the area identified by Racine County as the future site of the Foxconn facility. The DNR's diversion approval was challenged on May 25, 2018 and the DNR's approval was upheld by the administrative law judge.

Water Use Registration and Reporting

Following implementation of the Compact, all new or increased withdrawers that have the capacity on their property to withdraw 100,000 gallons per day (gpd) or more for 30 days must register with the DNR prior to withdrawing groundwater or surface water. This is typically done in conjunction with other approval or permitting procedures.

The DNR continues to upgrade water use data management systems, improve existing registration data and expand data collection methods. These efforts resulted in an increase in withdrawal report response rates from below 50% in 2008 to 79% in 2010. These improvements continued so that the reporting response rate for 2013 – 2018 is 96% annually.

Water Withdrawal Registrations by Source Type and Major Basin (2022)

	Great Lakes Basin	Mississippi River Basin	**Total**
Groundwater	3,768	10,089	13,857
Surface Water	397	687	1,084
Total	4,165	10,776	14,941

Persons with registered withdrawals must measure or estimate their monthly withdrawal volumes and report the previous calendar year's monthly water use by March 1 of each year. These reports are collected and analyzed for errors and inconsistencies. The compilation of more than five years of water use reporting data has allowed the DNR to assess trends in water use over time. Summary analysis is conducted on reported withdrawals and an annual water withdrawal reporting summary is made publicly available on the *DNR website*. Individual reports are also provided upon request to governmental partners, researchers, businesses and private individuals.

Water Conservation and Water Use Efficiency

Ch. NR 852, Wis. Adm. Code, establishes a mandatory water conservation and water use efficiency program for new or increased Great Lakes Basin surface water and groundwater withdrawals. In addition, mandatory conservation is required for any new or increased diversions of Great Lakes water and water withdrawals statewide that would result in a water loss of two million gallons or more per day. The rule identifies conservation and efficiency measures that withdrawals subject to the mandatory program must meet.

The rule helps guide a statewide voluntary water conservation and efficiency program which focuses on providing information and education, identifying and disseminating information on new conservation and efficiency measures, and identifying water conservation and efficiency research needs. The program is coordinated with the Public Service Commission and the Department of Safety and Professional Services.

Water Use Permits

Water Use Permits are required for Great Lakes Basin groundwater or surface water withdrawals averaging 100,000 gallons per day or more in any 30-day period. General permits (valid until 2036) are required for withdrawals of 100,000 gallons per day averaged over 30 days up to 1,000,000 gallons of water for 30 consecutive days. Individual permits (valid for 10-years) are required for withdrawals of 1,000,000 gallons per day or more for 30 consecutive days. Ch. NR 860, Wis. Adm. Code prescribes a review process for the individual permits and requires additional environmental review. Since December 8, 2011, approximately 380 permits have been issued to new or increased withdrawals in the Great Lakes Basin. The original individual water use permits issued in 2011 were set to expire in December 2021. The DNR renewed 323 water use individual permits to property owners with no new or increased withdrawals since 2011, who consecutively withdraw more than 1,000,000 gallons per day. The renewed permits are valid until December 8, 2031. The DNR issued 222 water use general permits to property owners that had no change in withdrawals sources and no longer met the requirements of an individual permit. Only one property increased water use by 1,000,000 gallons per day (for 30 consecutive days over their 2011 withdrawal amount. The DNR reissued a modified water use individual permit for this property.

Water Use Fees

Wisconsin Act 28 contains statutory language directing the DNR to collect water use fees to fund Great Lakes Compact implementation and water use program development in Wisconsin. The statute directs all persons with water supply systems with the capacity to withdraw 100,000 gallons per day or more must pay an annual $125 fee per property. Act 28 also directs the DNR to promulgate a rule imposing an additional fee on Great Lakes Basin water users withdrawing more than 50 million gallons per year. That rule, ch. NR 850, Wis. Adm. Code, prescribes a tiered system for additional Great Lakes Basin fees on withdrawals exceeding 50 million gallons per year. Water use fee revenue is used to; document and monitor water use through the new registration and reporting requirements, implement the Great Lakes Compact through water use permitting and regulate diversion of Great Lakes Basin waters, help communities plan water supply needs, build a statewide water conservation and efficiency program and to develop and maintain a statewide water resources inventory.

Well Construction and Private Wells

DG sets and enforces minimum standards for well construction, pump installation and well filling and sealing through ch. NR 812, Wis. Adm. Code. The standards are intended to protect groundwater and ensure safe drinking water.

More than 10,000 new or replacement wells were constructed in Wisconsin in 2021. Advance notification to the DNR is required for all well construction. After construction, drillers submit Well Construction Reports to the DNR describing the construction of each well drilled. Private Water Supply staff enforce minimum well construction standards by conducting compliance inspections with a focus on private wells under construction, reviewing well construction reports and associated sampling results. During 2021, staff conducted 974 compliance inspections of wells under construction, and additional inspections of pump installation and well filling/sealing work. The DNR staff initiated enforcement action on multiple violations including failure to submit required reports and well drilling or pump installing without a license.

DG staff promote compliance through regular communication with drillers and pump installers, including in-person contacts, a Private Water Advisory Council with industry advisors, and a web page with industry-focused information and resources. The quarterly

"NewsBits" e-newsletter provides program updates, annual data and compliance reminders to drillers, pump installers and other interested parties.

Private Water Supply staff are often the first responders to reports of private well contamination. Well contamination by livestock waste has been an increasing problem in recent years. DG staff use field investigation and analytical tools to investigate the source of microbial contamination – known as MST (Microbial Source Tracking) sampling – and determine whether fecal contamination is due to grazing animal manure rather than human sources. Agency news releases to both the agricultural community and general media emphasize ways to avoid contamination and encourage regular sampling and well inspection by private well owners.

DG handles license renewal for well drillers, heat exchange drillers and/or pump installers each year under ch. NR 146, Wis. Adm. Code. New applicants demonstrate experience and take a one-time examination to obtain a license. New License Exam Study Guides are now available to assist applicants to prepare for the exam. All license holders must attend training each year to earn required continuing education credits. The DNR works with training providers to evaluate and approve all continuing education credits, ensuring that license holders are qualified to do their work in a way that meets standards and won't contaminate groundwater. More than 1,100 individuals hold an active Water Well Driller, Heat Exchange Driller and/or Pump Installer license in Wisconsin. During the pandemic, the DNR worked with continuing education providers to develop online training options and provided for the safe proctoring of in-person exams. The DNR has contracted with a third party to implement online examinations, which had not been an option before the pandemic. The third party examinations are conducted weekly instead of quarterly as before.

DG encourages private well owners to test their wells annually for bacteria and other contaminants of concern. DG maintains the popular webpage titled "What's Wrong with My Water?" to answer commonly-asked questions about private well water, to help well owners diagnose their aesthetic water quality problems and to provide suggested options. DG and Community Financial Assistance staff awarded a combined total of over $110,000 in well abandonment and well compensation grants in 2021. Well compensation grants provided cost-sharing funds to help six owners replace wells due to metals and other contamination. Additionally, 66 well abandonment grants were issued around the state to help fund filling and sealing of unused wells.

DG continues to develop new and enhance existing electronic tools to help well drillers, well owners and others find information and comply with well construction and well filling and sealing requirements.

The "*Well Driller Viewer*" tool provides a searchable map view of landfill setbacks, special well casing depth areas, remediation sites and other data to assist well drillers in planning projects and meeting requirements of NR 812, Wis. Adm. Code. The Well Driller Viewer – Mobile-Friendly App was added in 2019. With a few easy steps, anyone can download an app and access the Well Driller Viewer on a smartphone. The app provides screen views and easy navigation customized for mobile devices. In 2021, the Well Driller Viewer was enhanced with improved data layers to help drillers comply with construction requirements and provide the best well water quality possible.

"*Online WCR*" is the electronic system for submitting Well Construction Reports to the DNR. Online WCR checks for common errors to make sure the report is complete and submits the data directly to the DNR without the need to send in a paper report. A similar online *Well Filling and Sealing Report* system allows contractors to submit filling and sealing reports, which are required to be submitted electronically. Both systems reduce time and errors for both well professionals and the DNR staff and result in more accurate data available more quickly.

The Well Driller Viewer was launched in 2018.

Public water systems

The DNR's Public Water Supply (PWS) program oversees the drinking water quality provided by public water systems (ch. NR 809 (Safe Drinking Water), Wis. Adm. Code). Working in cooperation with owners and operators of water systems, the PWS program ensures that samples are collected, and analyses completed to determine if the water meets federal Safe Drinking Water Act (SDWA) standards. The PWS program also regulates the operation of public water systems through ch. NR 810 and the general design and construction of community water systems through ch. NR 811 and NR 812 for non-community systems. Additionally, the PWS program works to educate water system owners and operators concerning proper operation and maintenance of water systems to ensure safe drinking water for Wisconsin consumers.

The PWS program maintains data about Wisconsin's drinking water and groundwater quality through the *Drinking Water System database*. The Drinking Water System is an important tool used to efficiently enforce SDWA regulations for public water systems. It contains the monitoring and reporting requirements for each public water system and their drinking water sampling results. It also includes violations for any missing requirements and exceedances of the maximum contaminant levels (MCLs).

The DNR maintains an electronic monthly operating report (EMOR) data system to accept and store monthly operating report data from public drinking water systems. EMOR contains required documentation of a system's operations such as monthly pumpage, chemical treatment usage, chlorine residual, turbidity and temperature. EMOR generates data reports to monitor treatment operations and make efficient water quality and quantity management decisions.

Public water systems continue to face rising nitrate levels. Community and non-transient non-community water systems must take immediate action if a nitrate MCL of 10 mg/L is observed (e.g., take well off-line, blend, treat etc.). Transient non-community systems, which include taverns, restaurants, churches and campgrounds, are required to post notices warning customers of the exceedance and to provide bottled water to infants and pregnant women. Rising nitrate concentrations are a result of increasing concentrations in groundwater caused by land use activities and weather patterns. The public water supply program continues to work with other DNR programs and external partners to reduce nitrate in groundwater and surface water.

The PWS program is working with public water systems to implement the federal revised total coliform rule (RTCR). Wisconsin has adopted a "find-and-fix approach" so that when bacterial contamination potential is detected by the presence of total coliform, the DNR and water system operators investigate to find the cause, take action to fix it, and monitor to ensure public health protection. Among many RTCR implementation activities, water supply specialists tested new water supply sampling methods developed by the State Laboratory of Hygiene. The method will help public water systems distinguish whether the source of bacterial contamination is in the groundwater or due to a defect of the water system. For additional information about the Public Water Supply Program you can review the current *Annual Compliance Report*.

Under the Safe Drinking Water Act's fifth Unregulated Contaminants Monitoring Rule (UCMR5) select water systems will be asked to sample for 29 PFAS compounds and lithium. This will begin in 2023.

In 2022 over 120 municipal systems voluntarily sampled using EPA Method 537.1 for PFAS in Drinking Water, which detects 18 different PFAS compounds. A report of findings will be created following completion of the program. More information at *https://dnr.wisconsin.gov/topic/PFAS/PWSampling*.

The PWS program has also promulgated MCLs for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS). These will be published in NR 809 on August 1, 2022. The MCL for PFOA and PFOS is 0.000070 mg/L (70 ppt). This level is set for the combined concentration of PFOA and PFOS.

Wellhead protection

The goal of Wisconsin's Wellhead Protection (WHP) program is to reduce the risk of groundwater contamination in areas contributing groundwater recharge to public water supply wells, consistent with the state's overall goal of groundwater protection. A WHP plan is required for new municipal wells and must be approved by the DNR before the new well can be used. A WHP plan is voluntary for any public water supply well approved prior to May 1, 1992. DNR promotes and encourages, but does not require, wellhead protection planning for all wells. With planning assistance from Wisconsin Rural Water Association (WRWA), 12 communities completed WHP plans this year (a total of 25 wells).

The DNR and WRWA are working together on proactive strategic interventions to support wellhead protection actions in selected communities with wells susceptible to contamination. The DNR, WGNHS, WRWA and other partners are developing and using groundwater monitoring, modelling and related tools in Spring Green and Waupaca to demonstrate a voluntary community-based approach to rising nitrate levels. In response to contaminant plumes that have the potential to affect two municipal wells in the village of Luck, WI, the village has updated its WHP plan, participated in groundwater teacher workshops, and is evaluating new spill prevention and remediation and redevelopment opportunities with support from the DNR and WRWA.

The DNR continues to measure and report to US Environmental Protection Agency (EPA) on the percent of public water systems that are protected by substantial implementation of wellhead protection. In 2019, 40% of Wisconsin municipal public water systems were protected by implementation of a WHP plan. Over 400 communities now have a WHP plan for at least one of their wells and approximately 55% of the municipally served population is covered by source water protection plans with accompanying implementation ordinances.

The DNR maintains a *webpage* with information aimed at encouraging and supporting water utilities in protecting their water supplies from potential sources of contamination.

The DNR staff from a variety of water programs completed several collaborative projects to more effectively align management of both phosphorus and nitrogen losses to lakes, streams and groundwater. Different chemical behavior and separate Clean Water and Drinking Water federal laws make coordination somewhat challenging. Wisconsin's Nutrient Reduction Strategy and its newly-revised Nonpoint Source Program Plan now more thoroughly address both groundwater and surface water.

The DNR and WRWA staff continue to coordinate their assistance to local protection efforts. WRWA staff work on plans for individual communities and area wide plans for multiple water supply systems. DNR staff review draft plans and ordinances and provide technical advice to local officials responsible for carrying out wellhead protection.

Groundwater Information and Education

Since 1994, DNR staff have worked with the Groundwater Center at the Center for Watershed Science and Education (CWSE) and WGNHS to sponsor two groundwater workshops for teachers every year. Educators from 20 schools and nature centers are selected to attend the workshops and receive a free groundwater model for their school. Besides learning how to use the groundwater model, the educators received groundwater resources to incorporate groundwater concepts into their classroom. The intent of the workshops is to provide information for teachers to educate students – and their parents – on the importance of protecting groundwater in their own communities. With funding from an EPA WHP grant, groundwater models have been given to over 475 schools or nature centers since 2001 and nearly 900 educators have received hands-on training in using the model effectively.

Since the Groundwater Coordinating Council Report to the Legislature went online in an interactive format in 2014, web visits and time spent at the site have continued to increase. In FY19, the GCC report was accessed online over 5,000 times; in FY20, it was accessed online over 6,500 times.

Well drillers and pump installers, water testing providers, local health and conservation departments, health care providers and many individuals request and receive thousands of printed publications on groundwater each year. Among the most-frequently requested items are: Nitrate in Drinking Water, Groundwater: Wisconsin's Buried Treasure publication, and the Groundwater Study Guide packet.

Groundwater Monitoring and Research

Chapter 160 of the Wisconsin Statutes requires the DNR to work with other agencies and the Groundwater Coordinating Council (GCC) to develop and operate a program for monitoring and sampling groundwater to determine whether harmful substances are present (s. 160.27, Wis. Stats.). The DNR has also supported groundwater monitoring studies evaluating existing design and/or management practices associated with potential sources of groundwater contamination. The intent of these studies is to reduce the impacts of potential sources of contamination by changing the way land activities may impact groundwater.

Seven *new projects* were selected through the Joint Solicitation process for funding in FY22. Final reports and 2-page research summaries are available for many projects on the *Water Resources Institute website*.

The DNR commits $100,000 annually to operate and maintain the *Wisconsin Groundwater Level Monitoring Core Network* in collaboration with USGS and WGNHS. This 'Core Network' has been in existence since 1946 and currently includes 97 long-term monitoring groundwater wells and two spring flow gages. The long-term monitoring provides data that builds the history of water levels in an area or aquifer. Uses of the data include: assessing aquifers in drought or wet conditions, assessing groundwater divides and surface water impacts, calibrating groundwater flow models and other decision-support tools, determining the relationship between water resources and withdrawals and more.

In addition to supporting the statewide groundwater level monitoring network, the DNR also supports monitoring of streams, lakes and springs to understand groundwater influences on these surface water resources. In FY21, the DNR continued monitoring reference springs, a project begun by WGNHS, continued revisiting springs in the Wisconsin Spring Inventory, and surveyed newly identified springs. As part of the Central Sands Lakes Study, the DNR added 21 project groundwater level monitoring wells – or short-term monitoring wells – to the Central Sands region.

Groundwater Data Management

The DNR's consolidated Groundwater Retrieval Network (*GRN*) accesses groundwater data from database systems in the DG, Waste & Materials Management, and Watershed Management programs, including information on approximately 300,000 wells. These wells represent public and private water supply wells, piezometers, monitoring wells, non-potable wells and groundwater extraction wells. DG staff continue to improve the locational data associated with GRN's wells and the ease with which the data can be accessed.

The DNR's high capacity well and surface water intake data continues to improve. Since the database was developed in 2007, much of the previously existing locational and ownership information has been verified or updated to improve data quality. The improved data quality has helped increase response rates on annual water withdrawal reporting.

Between 2008 and 2013, reporting response rates increased from 60% to over 95%. The online reporting system has increased reporting accessibility and improved communication with the user community.

Office of Emerging Contaminants

The Office of Emerging Contaminants (OEC) coordinates cross-program, division, and agency work around environmental contaminants and emerging topics such as PFAS. OEC staffs the Wisconsin PFAS Action Council (WisPAC), which consists of nearly 20 state agencies working to address PFAS contamination in the state. The office monitors and advises on the implementation of the PFAS Action Plan, including sampling and ongoing monitoring, development of new methods and science-based standards, and enhanced risk communication infrastructure and resources. In alignment with recommendations from the Action Plan, OEC staffs additional advisory bodies such as the PFAS External Advisory Group and the PFAS Technical Group to help foster ongoing discussion and collaboration with stakeholders.

OEC coordinates with and provides technical assistance to stakeholders across the state, including the firefighting community around PFAS-containing firefighting foam through the development of best management practices, FAQs, and other resources related to Wis. Stat. 299.48 and ch. NR 159 regarding the prohibition of use to help prevent future contamination of Wisconsin's groundwater. OEC also staffs and coordinates work with sister agencies in the Great Lakes, and with partner organizations such as ECOS and ITRC, to share information, research, advisories, and other activities.

Remediation and Redevelopment Program

The Remediation and Redevelopment (RR) program has primary responsibility for implementing and aiding cleanups under the Spill Law, the Environmental Repair Law, the Land Recycling Law, federal programs (Superfund, Hazardous Waste Corrective Action and Closure, Leaking Underground Storage Tanks (LUST)), brownfields properties, the Drycleaner Environmental Response Program, contaminated sediments and at closed landfills. The RR program provides technical assistance, clarifies legal liability, provides financial assistance and provides technical project oversight of cleanup projects.

All cleanups are conducted according to the ch. NR 700 rule series, Wis. Adm. Code, Investigation and Remediation of Environmental Contamination, and ch. NR 140, Groundwater Quality. The majority of cleanups are done by persons responsible under the law, or persons or groups involved in the redevelopment of potentially contaminated properties. Program staff provide technical assistance on cleanups conducted by consultants at the direction of responsible parties. In addition, RR staff contract and direct consultants on state- and federally-funded cleanups and assessments. The RR Program also provides assistance for spill response; and works with other agencies, particularly the U.S. EPA Removals Program, for conducting major spill response actions and removal of hazardous substances when the responsible party is unable or unwilling to do so and there is a risk to public health, welfare, or to the environment. The RR program is also responsible for assisting the EPA with the remediation of contaminated sediments in the Great Lakes areas of concern.

Cleanup of Groundwater Contamination

In FY21 the program spent approximately $1,500,000 in Environmental Fund dollars to initiate or continue environmental cleanup actions at over 30 locations where groundwater contamination is known or suspected. In FY22, this amount increased to approximately $2,000,000 due to temporary emergency water costs of approximately $500,000 per year for the town of Campbell beginning in March 2021. The Environmental Fund is used when contamination is significant, but no identifiable private party has legal responsibility for the contamination, the person(s) legally responsible do not have the financial ability to proceed, or the responsible person simply refuses to proceed. Private contractors conduct these investigations and cleanups with oversight by DNR staff. Whenever feasible, the RR program and legal staff attempt to recover costs from responsible persons after the cleanups are undertaken. In addition to these "state-lead" projects, the RR program uses Environmental Fund dollars to cleanup emergency spills to prevent additional groundwater contamination.

Investigation, Cleanup and Redevelopment of Brownfields

Brownfields are abandoned, idle or underused industrial or commercial facilities or sites whose expansion or development is adversely affected by actual or perceived environmental contamination. The RR program coordinates several efforts to encourage local governments and private businesses to cleanup and redevelop brownfield properties. At many brownfields sites, the release of hazardous substances threatens groundwater quality.

Program staff assist local governments and private businesses with the cleanup and redevelopment of brownfields by providing technical assistance. The RR program provides a number of different types of assurance, comfort, or general liability clarification letters related to properties with groundwater contamination, as well as other contaminated media, depending on the site-specific circumstances. Collectively, these letters facilitate the reuse and development of properties. Since 1994, the RR program has provided thousands of redevelopment assistant reviews – which can include liability clarification letters, off-site exemption letters, cleanup agreements for tax delinquent properties, building on abandoned landfill approvals, etc. – at brownfield properties throughout the state.

The RR program also continues to assist parties with voluntary investigations and cleanups of brownfield properties through the Voluntary Party Liability Exemption (VPLE) process. Many sites that follow the VPLE process have contaminated groundwater.

In the VPLE program, after a person has conducted an environmental investigation of the property and cleaned up contamination, the DNR can issue a "Certificate of Completion" which provides a release from future liability for any discharge that occurred on the property prior to approval of the investigation and cleanup of that discharge. Since 1994, the DNR has issued over 200 certificates of completion. One site, for which a Certificate of Completion was issued, discovered that additional hazardous substances existed. In this case, the owner chose to remove the contaminated material with the DNR approval.

Dry Cleaner Environmental Response Fund (DERF) Program

The DERF program reimburses dry cleaner owners and operators for eligible costs associated with the cleanup of soil and groundwater at sites contaminated by dry-cleaning solvents. Fees paid by the dry-cleaning industry provide program funding. Environmental cleanups at dry cleaner sites are conducted following the ch. NR 700 rule series. There are 221 sites in the program with 101 at various stages of investigation and cleanup and 120 sites closed. The program is implemented through ch. NR 169, Wis. Adm. Code.

Tracking System and GIS Applications

The program's main database on the status of sites undergoing investigation and/or cleanup is the Bureau of Remediation and Redevelopment Tracking System (*BRRTS*).

In 2001, revisions to ch. NR 726, 716, 749, 811, and 812 implemented requirements to list sites with residual groundwater contamination on the database to replace the requirement to record groundwater use restrictions at the County Register of Deeds Office. In 2002, additional rule revisions required the inclusion of sites with residual soil contamination on the database. In 2006, the spill law was amended (see s. 292.12, Wis. Stats.) to expand the use of the DNR's databases to track sites with residual contamination left in place at the time of case closure. The database currently includes locational information on open sites, sites closed with no residual contamination, sites closed with residual groundwater contamination above the ch. NR 140 enforcement standards and sites closed with soil contamination above ch. NR 720 soil standards, sites closed with other engineering or institutional controls, and brownfields properties, as well as site specific information pertaining to investigation and cleanup of each property.

Information in the database is available through BRRTS on the Web (BOTW). This internet-accessible application provides information to future owners or users of the property of the existence of soil and/or groundwater contamination, as well as any responsibilities of the property owner (or occupant in some cases) to comply with any conditions of closure. The site-specific information is attached to each site by a link to a pdf.

In 2005, an expanded GIS application was made available, called the *RR Sites Map*. This application shows the locations of the majority of sites available on BRRTS (open and closed). In 2008, additional data regarding financial tools and liability clarification actions were added. In June of 2013, RR Sites Map was migrated to Geocortex where it obtained a new look but kept the same functionality.

RR Sites Map is linked to BRRTS on the Web and is useful for locating potential contamination sites when evaluating new municipal well placement or for property transactions. The database makes site specific information on open and closed remediation sites much more available and accessible to the public and specific interested groups, particularly those wanting to install or replace a potable well on an affected property, as well as those buying properties. Sites regulated by the Department of Agriculture and Trade and Consumer Protection (DATCP) are also included in BRRTS on the Web and RR Sites Map.

A well driller or well constructor should consult with the department prior to drilling in areas where the driller has been notified or determines that there are contaminated formations or groundwater contamination levels in excess of the standards specified in s. NR 812.06, or prior to drilling a well on a property identified by the department as having residual contamination and continuing obligations requiring listing on the department's database to determine if additional casing or other construction techniques may be required.

The RR Program continues to make improvements to both BOTW and RR Sites Map. In addition to the ongoing programming efforts, work continues on quality assurance and quality control (QA/QC) of existing data.

Waste and Materials Management Program

Monitoring Groundwater Quality Around Landfills

The Waste and Materials Management Program (WA) implements the DNR's Groundwater Standards Program in several ways during the life of a landfill. When staff review an applicant's "Feasibility Report," which proposes to site a landfill at a particular location, they review baseline groundwater data submitted by the applicant to determine whether exemptions and alternative concentration limits (ACLs) to the established ch. NR 140 groundwater standards are needed for the public health and welfare parameters, based on the concentrations of those substances present in the groundwater before landfill development. In addition, reviewers establish preventive action limits (PALs) for indicator parameters based on statistical calculations of the baseline concentrations.

During the active life of a landfill and after closure, staff review routine groundwater detection monitoring data, collected and submitted by the landfill owner at sites where monitoring is required to determine compliance with ch. NR 140 standards and site-specific ACLs and PALs. Ch. NR 140 provides a list of response actions that the DNR may require a facility to take after a groundwater standard exceedance is confirmed. When conditions warrant, staff require groundwater investigation reports that include proposals for further evaluations and recommendations for remediation at landfills that cause groundwater standards to be exceeded. Staff review results of site investigations triggered by the exceedances of groundwater standards and evaluate the effectiveness of remedial actions at active solid waste facilities and closed landfills by comparing results to groundwater standards and by looking at concentration trends over time.

WA accepts only electronic submittal of environmental monitoring data from landfill owners, labs and consultants. The electronic data submittals are currently uploaded by the DNR to the WA Groundwater and Environmental Monitoring System (GEMS) database. WA provides public access to the environmental monitoring data contained in GEMS through "GEMS on the Web." In addition to enhancing GEMS on the Web to allow more flexibility in choosing a specific date range and particular monitoring points, WA is seeking resources to program a web interface, possibly using the department's Data Portal or Web Access Management System, so that facilities can upload environmental monitoring data into GEMS.

The WA Program is placing stronger emphasis on having facilities collect water samples for VOC analysis, rather than for indicator parameters, in exchange for a reduced sampling frequency. VOCs are a key contaminant used to determine water supply well vulnerability to contamination and set monitoring requirements.

Bags of pharmaceuticals collected by Jefferson County as part of an effort to keep pharmaceutical waste out of the groundwater. *Photo credit: Barbara Bickford*

The WA Program updated its guidance titled, Reducing or Terminating Monitoring at Landfills, in 2020 (Pub-WA-1013-2019). More closed landfills in the state are reaching the end of their owner financial responsibility period. Groundwater monitoring data has been collected for decades at these sites and for those sites which the groundwater data show little to no impact to groundwater quality from the landfill, owners often express an interest in reducing or terminating monitoring to reduce costs. This guidance provides information to landfill owners and consultants on how to evaluate whether the monitoring data collected from their landfill and site-specific conditions support reducing or terminating monitoring, and it discusses whether additional data should be collected. The guidance provides a consistent and objective process and set of criteria for evaluating whether reducing or terminating monitoring is warranted so that it can be done in a manner protective to the groundwater.

The WA has been placing landfill locations on a GIS mapping program called the *WA Sites Viewer*, which includes delineating waste boundaries and locating monitoring wells where known. This information is shared with the DG Program and licensed well drillers to aid well drillers in siting a water supply well. At this time, almost all of the known landfills have been placed on the GIS mapping program. This GIS program has been an important tool to increasing compliance with the 1,200 foot set-back requirement to a landfill and for the NR 812 well variance application requirement, if the set-back cannot be met.

WA continues to be a participant in the Interagency Pharmaceutical Waste Working Group, with the DATCP and other partners. Keeping pharmaceuticals out of household and industrial waste streams is the main way to reduce the risk that the substances will reach groundwater through land spreading or septic systems.

Environmental Analysis and Sustainability Program

Monitoring Groundwater Quality Around Metallic Mines

The Environmental Analysis and Sustainability Program regulates metallic mining activity in the state. Issues related to groundwater quantity and groundwater quality are critical in determining whether a proposed mining project receives necessary approvals. State statutes have created separate approval processes for non-ferrous mining projects (Ch. 293, Wis. Stats.) and ferrous mining projects (Ch. 295, Wis. Stats.). The regulatory framework for ferrous mining projects includes provisions related to groundwater withdrawals, mining waste site design and operation and protection of groundwater quality. The law requires compliance with existing groundwater quality standards but establishes point of standards application and evaluation processes and criteria that are unique to ferrous mining projects.

Water Quality Program

The Bureau of Water Quality (WQ) is responsible for statewide implementation of the DNR's groundwater standards primarily through the issuance of discharge permits to facilities, operations and activities that discharge treated wastewater and residuals to groundwater.

Wastewater Discharges

WQ issues Wisconsin Pollutant Discharge Elimination System (WPDES) permits to all communities, industrial facilities and large privately-owned wastewater systems which discharge treated domestic or industrial wastewater to groundwater through land treatment/disposal systems. These systems are primarily spray irrigation, seepage cell, subsurface absorption systems and ridge & furrow treatment systems regulated under ch. NR 206, Wis. Adm. Code (domestic wastewater) and ch. NR 214, Wis. Adm. Code (industrial wastewater). WPDES permits issued to these facilities contain groundwater monitoring and data submittal requirements that are used to evaluate facility compliance with ch. NR 140, Wis. Adm. Code (groundwater quality standards). Groundwater monitoring systems at existing facilities are evaluated and upgraded as necessary at permit re-issuance.

The DNR also regulates the land application of organic industrial wastes, municipal biosolids and septage (chapters NR 214, 204, and 113) through approval of land spreading sites and requirements on locations, loading rates, nutrient levels and time of year. In recent years, as the quantities of these materials and agricultural manure have increased, competition for acceptable land spreading sites has increased, particularly in some areas of the state. Some instances of unacceptable impacts to groundwater have occurred associated with these activities. In addition, the DNR has pushed land spreading entities to provide for more storage capacity to minimize winter and spring runoff to surface water. As a result, wastewater generators and haulers have sought to utilize existing tanks and lagoons, and in some cases, substandard earthen manure pits or substandard storage tanks. The industrial wastewater program has affirmed code requirements to ensure older structures meet the standards needed to assure storage is environmentally sound, protective of both groundwater and surface water.

WQ maintains a database, designated the System for Wastewater Applications, Monitoring, and Permits (SWAMP), for holders of specific WPDES and general permits. This database system stores facility-specific information such as address, contacts, location, permit requirements, monitoring results and violations of permit requirements for private and municipal wastewater treatment facilities. The system contains current information on groundwater, wastewater and biosolids treatment and management. Historical sampling data from groundwater monitoring wells is available through the system and current sample results are added on a monthly basis. Sampling results and site loading information are also available for land application of municipal biosolids, septage and industrial sludge, by-product solids and wastewater.

WQ assists and participates in local planning efforts for existing developed areas (served by onsite wastewater treatment systems) that are investigating the possibility of providing a public sewerage system.

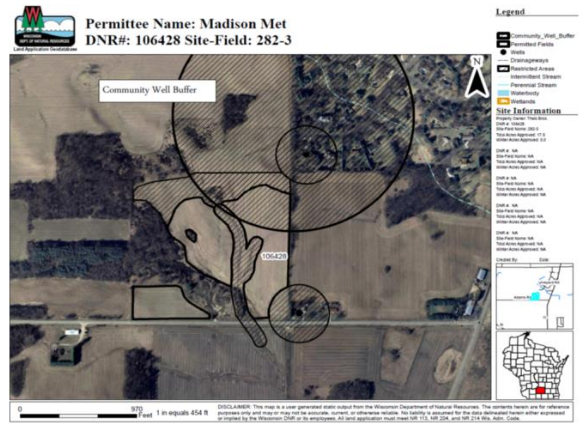
WQ issues WPDES general permits to a group of facilities with similar low-flow nondomestic wastewater, domestic wastewater, or mixed wastewater discharges to a subsurface soil absorption system pursuant to s. NR 205.08, Wis. Adm. Code. These facilities can apply coverage under either one of the following generals permits: Domestic Wastewater to a Subsufurce Soil Absorption System or Industrial Liquid Waste to a Subsurface Soil Absorption System. Both of these general permits were reissued in 2019. These general permits together currently cover 41 facilities. The requirements for requesting coverage under the general permits require the DNR to review the facility operating conditions (e.g. flow volume and pollutants), site restrictions and setback distance requirements of the systems to determine if the facility is applicable under these general permits. Also any proposed new or modifications to these systems are required to have the design plans reviewed and approved by the DNR pursuant to s. 281.41, Wis. Stats. Facilities covered under the general permits are required to monitor the discharges for flow and other pollutants. These general permits are renewed every five years. The renewal process for general permits allows the DNR to reevaluate if the facilities are still eligible for coverage under the permit and review land use changes that may have occurred. For instance, if there were changes due to installation of new water supply wells in the area during the previous permit period. These review processes and permit required monitoring allow the DNR to track protection of groundwater quality and public health and could also identify future concerns and permit needs.

Septage and Sludge Management

WQ implements the regulations in chapters NR 113, NR 204, and NR 214, Wis. Adm. Code. Ch. NR 113 relates to septage management and ch. NR 204 govern the treatment quality, use and disposition of municipal wastewater treatment plant sludge. Ch. NR 113 and ch. NR 204 incorporate federal septage and sewage sludge standards. WQ regulates the land application of industrial sludge, liquid wastes and by-product solids through ch. NR 214. Chapters NR 113, NR 204, and NR 214 contain treatment quality standards and land application site requirements and restrictions that are designed to prevent runoff to surface water or leaching of nutrients and pollutants to groundwater.

Results of federal and state septage audits identified the need for compliance training in the area of septage management. Cooperation with the U.S. EPA led to the on-going creation of better training tools and implementation of numerous compliance classes. Recent septage operator certification code changes in ch. NR 114 now require minimum compliance training of all certified septage operators in their continuing education requirements cycles to ensure a compliance focus. New classes and training segments are currently offered through various associations, county updates and stand-alone classes.

Inter-division work with the Bureau of Law Enforcement will continue to be necessary and likely increase as the industry continues to explore more options for waste disposal and re-use during these difficult economic times and “green” transformation. Unfortunately, many of these options can cause significant harm to waters of the state. Continued enforcement efforts are necessary to deter further significant environmental harm. Increasing the number of audits is intended to preempt significant operations that create long-term harm of the environment. Also, efforts are underway to systemize audits to minimize the intrusion to the permitted community, but allow ample discussion to provide educational opportunities if needed.



Clearer, more easily-produced maps in permits to land-apply wastes now help protect community and school water supply wells.

WQ continues to implement a statewide computer system that records and monitors treatment and disposal of municipal sludge, septage and industrial land-applied wastes. This system includes an inventory and a history of all sites used for land application. Wisconsin became the fourth state delegated authority by U.S. EPA to implement municipal sludge regulations, through its delegated NPDES (WPDES) permit program, in July of 2000. WQ has improved land spreading staff review for land spreading sites with current computerized mapping data provided by the Natural Resource Conservation Service(NRCS). The site evaluation and approval process now includes providing maps to the land application entities land applying septage, sewage sludge and industrial land-applied wastes. These maps show clear boundaries for approved areas to further protect surface and groundwaters.

Wisconsin Act 347 provides incentives for more wastewater treatment plants to accept and treat septage. This is accomplished through the offer of a zero percent Clean Water Fund loan for the planning and construction of receiving facilities and additional capacity provided for septage. Facilities which are upgrading capacity by more than 20% must evaluate septage generation and available disposal options in their planning area during facility planning. Although they are not mandated to provide such capacity, they are offered the zero percent loan if they do so. Structures are provided by which publicly owned treatment works establish costs for receipt of septage and a process is laid out for dispute resolution when such costs are questioned. Land application also remains a viable option when appropriate and Act 347 provides explicit pre-emptive authority to the state by disallowing restrictive local ordinances if they are not identical to state regulations.

Watershed Management Program

The Bureau of Watershed Management (WT) is responsible for statewide implementation of the DNR’s groundwater standards primarily through the issuance of discharge permits to concentrated animal feeding operations (CAFO) and dischargers of contaminated storm water. Field staff carry out compliance and enforcement activities using policies, codes, and guidelines intended to meet groundwater quality standards. Integrated basin planning, carried out in the field under guidelines developed by WT, assess and evaluate groundwater (as well as surface water) and provide general and specific recommendations for the protection and enhancement of the basin's groundwater.

Agricultural runoff and groundwater quality

Chapter NR 243 Wis. Adm. Code covers WPDES permit requirements for livestock operations and contains provisions to protect surface water, groundwater and wetlands in Wisconsin. Revisions made to ch. NR 243 have improved groundwater protection associated with CAFO land application practices by increasing setback requirements from community/non-community public wells and karst features and by further restricting winter applications of manure. Nutrient management plans submitted as part of the issuance of WPDES permits to CAFOs address how, when, where, and in what amounts CAFOs apply manure, process wastewater, and associated nutrients to cropped fields to protect surface waters and groundwater. Groundwater monitoring has been conducted voluntarily and required at selected production sites and land application fields. The DNR also promotes groundwater protection through the implementation of agricultural performance standards and prohibitions in ch. NR 151, Wis. Adm. Code, the issuance of Notices of Discharge under ch. NR 243, and response to acute manure related groundwater impacts (e.g., well contaminations).

By the end of 2021, there were 321 permitted CAFOs – 310 large CAFOs, 10 medium CAFOs, and 1 small CAFO. Over 90% of the permitted CAFOs are dairy operations. The trend of growing numbers of permit applications for larger-scale livestock operations is expected to continue.

Sections NR 151.07 and ATCP 50.04(3), Wis. Adm. Code, require all crop and livestock producers to develop and implement nutrient management plans. Technical Standard NRCS 590 contains planning and implementation requirements for all nutrient management plans. In 2015, DNR staff participated in a NRCS effort to update its technical standard for nutrient management plans to reflect new federal water quality protection criteria, including a nitrogen loss risk assessment.

Federal, state, and local agencies maintain technical resources and expertise to implement NRCS Standard 590, including development and dissemination of the field-based Soil Nutrient Application Program (*snapplus.wisc.edu*) in cooperation with the University of Wisconsin. Implementation of the Chapter NR 151 performance standard cannot be required without cost sharing in many situations. A multi-partner conservation consortium was effective in securing cost share resources from the Legislature to help farmers meet nutrient management plan requirements. DATCP administers these funds through its Soil and Water Resource Management Program. In addition, the NRCS provides cost sharing for development and implementation of comprehensive nutrient management plans, including 590 compliant planning and implementation. In other situations, cost sharing does not have to be provided to require compliance. This includes compliance for farms operating under a WPDES Animal Feeding Operation Permit, farms receiving state farmland preservation tax credits under the state's Farmland Preservation Program, livestock operations obtaining local permits under the state Livestock Siting Law, and livestock operations required by county regulation to develop and implement a nutrient management plan when voluntarily applying for a manure storage permit to cover new or altered manure storage facilities.

As part of the effort to protect drinking water and public health in areas of the state vulnerable to pathogen contamination of groundwater, the Department of Natural Resources worked with key public and agriculture industry stakeholders, state agencies, the State Legislature, the governor and the general public to update ch. NR 151, Wis. Adm. Code. The NR 151 rule modification developed the Silurian Bedrock performance standards to address land spreading of manure on soils in sensitive areas of the state - i.e. where depth to bedrock is shallow and the bedrock is fractured (also described as karst topography).

Storm Water and groundwater quality

Storm water discharges are regulated as required under the federal Clean Water Act under ch. NR 216, Wis. Adm. Code. Chapter NR 216 requirements include: 1) permits for about 245 municipalities in Wisconsin to control polluted runoff that may enter their municipal separate storm sewer systems (MS4s); 2) permits for owners of construction sites with one or more acre of land disturbance to control erosion during construction and to install practices to limit post-construction pollutant discharge after construction is completed; and 3) permits for certain industrial facilities to address potential contamination of storm water from outside activities and outdoor storage of materials.

In addition, under ch. NR 151, Wis. Adm. Code, the DNR has developed runoff performance standards for MS4s and construction sites that are implemented through the storm water permit program. Chapter NR 151 was updated and those changes became effective on January 1, 2011.

Provisions to implement Chapter NR 216 and the performance standards in Chapter NR 151 are included in several general permits. The MS4 general permit for municipal storm water discharges was first issued on in January 2006. The MS4 general permit was reissued in May 2014.

In 2020, six general storm water permits expired requiring revisions and reissuance. Five of the industrial general permits expire including the scrap metal and auto recycling permits at the end of March, the Tier 1 and Tier 2 industrial permits May 31, the non-metallic mining general permit August 31 and the construction site general permit August 31. The urban runoff team worked extensively with internal staff, external stakeholders and the US EPA to develop general permits that meet the standards of the Clean Water Act and Wisconsin Statues in compliance with the department's delegated Wisconsin Pollutant Discharge Elimination System (WPDES) authority.

Chapter NR 216, Wis. Admin. Code establishes criteria defining those storm water discharges needing WPDES storm water permits, as required by s. 283.33, Stats., and to implement the appropriate performance standards of sub chs. III and IV of ch. NR 151. Chapter NR 216 identifies which industrial facilities, construction sites and municipalities require WPDES storm water permits, application requirements, and storm water discharge permit criteria for each type of facility. In 2020, the department undertook an effort to re-write certain parts of NR 216. Specific efforts were made to finalize concerns raised by the US EPA in its 2011 75 issues letter related to legislative authority, to respond to the federal “remand rule” and proposes a realignment of the fee structure for construction site erosion control permits. The department is preparing the final rule package for review by the Natural Resources Board.

For more information

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DEPARTMENT OF AGRICULTURE, TRADE AND CONSUMER PROTECTION

Protecting Wisconsin's groundwater is a priority for the Department of Agriculture, Trade and Consumer Protection (DATCP). DATCP's major activities in this area include management of pesticides and nutrients, research, and funding of local soil and water resource management projects.

In compliance with Chapter 160, Wisconsin Statutes, DATCP manages pesticides and pesticide practices to ensure that established groundwater standards for contaminants are not exceeded. This may include prohibition of certain activities, including pesticide use. DATCP regulates storage, handling, use, and disposal of pesticides, as well as the storage and handling of bulk quantities of fertilizer. DATCP has authority to develop a statewide nutrient management program through section 92.05 Wis. Stats. The program includes compliance, outreach and incentives.

Enforcement standards have been established in Wisconsin for many known and potential groundwater contaminants, including over 30 pesticides. DATCP helps landowners comply with these standards and the Groundwater Law.

FY 2022 Highlights

- Performed annual groundwater sampling of private wells in agricultural areas using a targeted sampling approach and annual sampling of field-edge monitoring wells located on or near agricultural fields.
- Received a $50,000 supplemental grant from EPA for installation of additional monitoring wells at existing field edge monitoring sites in Adams, Iowa, Sauk, and Waushara counties in 2021.
- Analyzed about 324 groundwater and 82 surface water samples for more than 100 pesticide compounds plus nitrate in 2021.
- Provided cost-sharing for the installation and implementation of 1,123 conservation practices in 2021. These practices provided soil erosion control and helped manage manure and nutrients.
- Finalized and adopted DATCP 01 Technical Standard Verification of Depth to Bedrock for use in verifying and documenting land features, particularly the depth to bedrock of cropland, specifically for the purposes of applying manure as a crop nutrient to reduce the risk of pathogen contamination in areas with Silurian dolomite in eastern Wisconsin.
- Completed the airborne electromagnetic (AEM) survey of karst bedrock features to develop updated maps that identify the 5 foot and 20 foot depth to bedrock in the Silurian dolomite area of northeast Wisconsin.
- Awarded grants to 36 producer-led groups for FY 2022 funding, totaling $1,000,000.
- Continued a project to track estimated water quality outcomes and analyze benefits of conservation adoption in 13 of the 33 Producer-Led groups.

- Awarded $258,858 in 16 Nutrient Management Farmer Education grants in 2021. These grants go to counties and technical colleges which provide nutrient management training to producers and plan writers for development of nutrient management plan in compliance with state standards.

Details of Ongoing Activities

Nonpoint Source Activities

Pesticides

DATCP's primary effort related to nonpoint contamination of groundwater from pesticides includes regular sampling of private wells and monitoring wells across the state for herbicides, insecticides and nitrate. The agency uses statistically random and targeted sampling designs to compare and contrast pesticide and nitrate occurrence in private wells statewide to that found in predominantly agricultural areas. DATCP shares sample data for pesticides with well owners, EPA, counties, DNR and others to improve knowledge and awareness of pesticide contaminants in drinking water, and uses the data to inform decisions involving new policy or regulations.

One example of how DATCP uses groundwater data to ensure compliance with Chapter 160, Wisconsin Statutes, involves the herbicide atrazine. Atrazine is a corn herbicide that has been found to cause nonpoint groundwater contamination. Several revisions to Ch. 30, Wisconsin Adm. Code have been made in response to detections of atrazine in groundwater, with the latest revision being put into effect in April 2011. Maps for 101 prohibition areas are available from the Agricultural Chemical Management Bureau covering about 1.2 million acres that have been incorporated into the rule. The maps were updated with new base mapping software in 2012 to 1) update roadway names and other manmade features that have changed over the years, and 2) provide a consistent look for maps that had been created using different map software since the early 1990s. Pesticide use surveys indicate that atrazine use has declined from peak levels in the late 1980's but remains one of the top corn herbicides used. Its decline in use may be in-part a result of the atrazine management rule and concerns about groundwater contamination. Prohibition areas total about 1.2 million acres, but DATCP estimates the actual area effected by use prohibitions is less than 300,000 acres per year when non-cropland (woodland, developed land, roads, water, etc.) and cropland not used for growing corn is removed from the 1.2 million-acre land total.

Nutrients

Through its Land and Water Resources Bureau's programs, DATCP assists in the protection of water resources through nutrient management and related conservation practice implementation. The DNR's NR 151 rule on runoff management establishes agricultural performance standards intended to protect both groundwater and surface water. DATCP identifies the practices and procedures to implement and enforce compliance with these standards, including nutrient management. The nutrient management rules apply to all Wisconsin farmers who engage in agriculture and mechanically apply nitrogen, phosphorus, or potassium (N-P-K) nutrients from manures or commercial fertilizers to cropped fields or pastures. Under Wisconsin Statutes, cost-share funds must be made available to producers to compel compliance. However, as many as half of Wisconsin farms may comply with nutrient management standards and other performance standards without cost-sharing because they fall into one of the following categories:

- Concentrated Animal Feeding Operations (operations with 1,000 animal units or greater);
- Farms regulated by local manure storage or livestock siting ordinances; or
- Participants in Wisconsin's Farmland Preservation Program.

A Wisconsin nutrient management (NM) plan is an annually updated record that follows NRCS's 590 Nutrient Management Standard. A NM plan manages nutrient applications to ensure that crops receive the right amount of nutrients at the right time while minimizing degradation of both surface water and groundwater. A NM plan accounts for all N-P-K applied, and planned to be applied, to each field over the crop rotation, and identifies all crop management practices for each field.

The objective of the 590 NM Standard is to decrease the opportunity for nutrient losses to occur, decrease the total residual amount of nutrients in the soil and to keep those residual nutrients within the soil-crop system by limiting the processes (leaching, runoff, erosion and gaseous losses) that carry nutrients out of the system. The 590 NM Standard contains criteria for surface and groundwater protection that manages the amount and timing of all nutrient sources.

To learn more about DATCP's nutrient management program, visit: https://datcp.wi.gov/Pages/Programs_Services/NutrientManagement.aspx. For a summary of the water quality protection features of the 590 standard, visit: https://datcp.wi.gov/Documents/NM590Standard2015.pdf.

2021NMP Numbers	
NM Plans Reported	7,236
NM Acres Reported	3.23 million
Percent of WI Cropland Covered by NMP	35%
Farmer-Written Plans	1,663
Agronomist-Written Plans	5573

The DATCP allocated its annual appropriation of funds to counties through its annual allocation process. This process provides "for cost-sharing grants and contracts under the soil and water resource management program under s 92.14." In 2021, the allocation provided nearly $6 million to counties for landowner cost-sharing. This cost-sharing includes bond funds and SEG funds and supports the implementation of diverse conservation practices from manure management systems, to erosion control and nutrient management planning. The allocation also provided $258,858 in grants for farmer training (Nutrient Management Farmer Education grant program), and nearly $950,000 to support partners, including the University of Wisconsin System institutions, to enhance the statewide infrastructure fundamental to implementing state conservation activities, with an emphasis on development of the SnapPlus nutrient management planning software.

The DATCP also provided an annual appropriation of $3,027,200 in GPR funds and $6,411,900 in SEG funds "for support of local land conservation personnel under the soil and water resource management program." DATCP would need an increase of over $3 million in its annual appropriations to reach the statutory goal of funding 3 positions at 100, 70 and 50 percent, respectively. DATCP's 2021 final allocation plan under the Soil and Water Resource Management Grant Program is summarized in Table 1 below. In most cases, the available appropriations are not able to meet the total requests of the counties for cost-sharing and staffing support.

Table 1. Summary of Requests and Allocations for Grant Year 2021.

Funding Category	Total Requests	Unmet Requests	Final Allocations
County Staff/Support	$17,901,752	$8,462,652	$9,439,100
County LWRM Cost-Share (Bond)	$7,411,250	$3,911,250	$3,500,000
Bond Cost-Share Reserve (Bond)	$300,000	$0	$300,000
LWRM Cost-Share (SEG)	$2,953,972	$755,000	$2,198,972
Project Contracts (SEG)	$1,325,926	$383,756	$942,170
NMFE Training Grants (SEG)	$288,418	$29,560	$258,858
Total	**$30,181,318**	**$13,542,218**	**$16,639,100**

DATCP nutrient management program staff train farmers, consultants and local agencies on the principles of sound nutrient management, how to comply with performance standards and how to use available tools to create and evaluate an ATCP 50-compliant nutrient management plan. DATCP also maintains a Manure Management Advisory System (MMAS), which helps farmers develop a clear understanding of field-specific soils and their ability to accept nutrients and manure for optimal crop production while protecting water quality. The system includes web-accessible tools, including: WI "590" Nutrient and Manure Application Restriction Maps, a map service for geographic information system (GIS) users, and the Runoff Risk Advisory Forecast (RRAF) model.

The RRAF provides Wisconsin's farmers with an innovative decision support tool which communicates the threat of undesirable conditions for manure and nutrient spreading for up to 10 days in advance. The system uses data outputs from the National Weather Service including snow accumulation and melt, soil moisture content and temperature and forecast precipitation to create and display maps that provide the runoff risk for a 72-hour period. The 590 Restriction maps are available statewide to assist farmers in making sound decisions about how and where to apply nutrients on their cropland. The mapped data used to create the restriction maps are also available for GIS-users to download into their own mapping applications. All of these tools can be accessed at *http://www.manureadvisorysystem.wi.gov*.

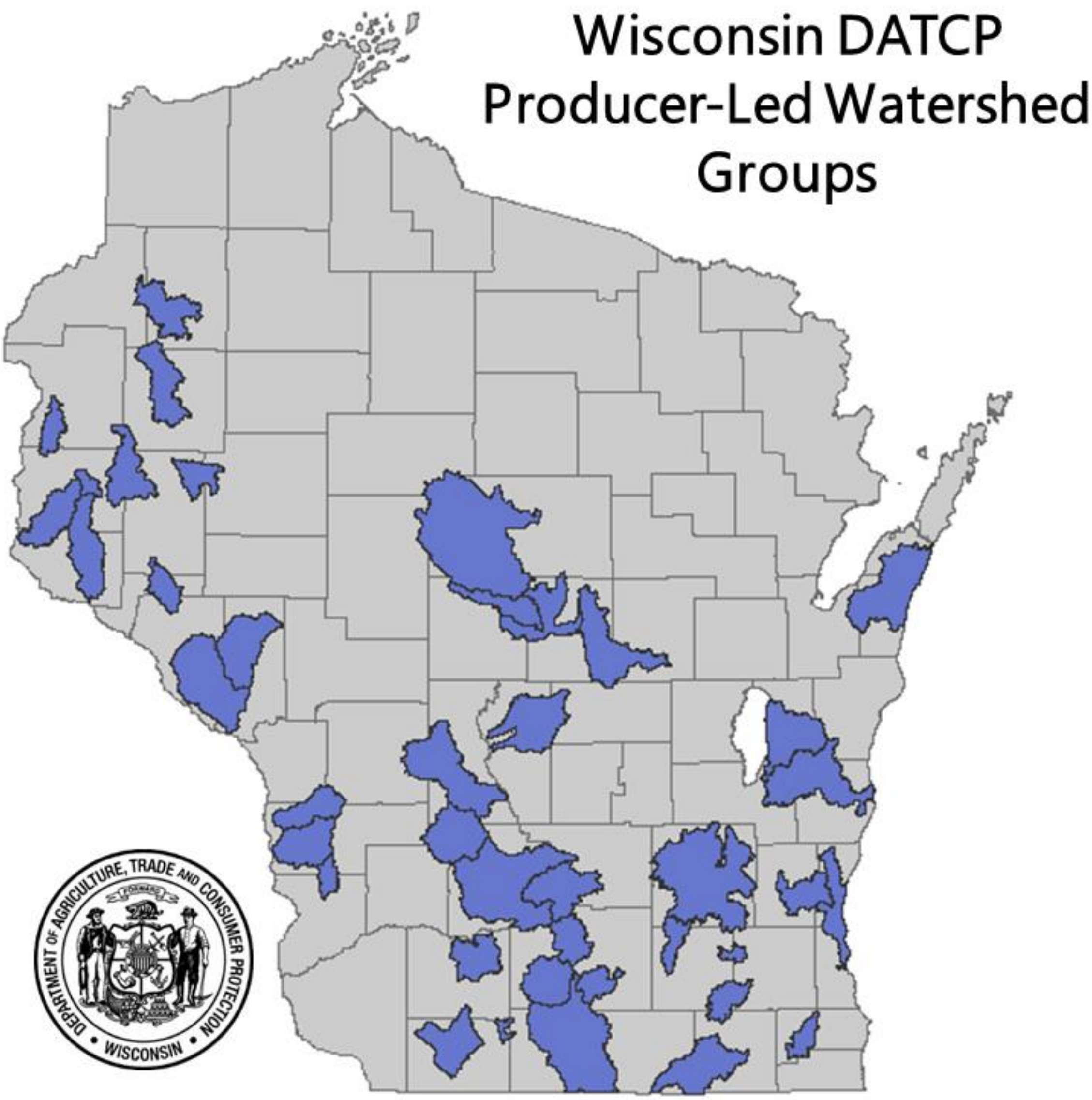
In 2017, DNR adopted a new targeted performance standard to reduce the risk of pathogen contamination to groundwater (NR 151.075). This new standard restricts manure application in designated areas where the bedrock consists of Silurian dolomite with a depth to bedrock of 20 feet or less. DATCP is responsible for the implementation of performance standards in NR 151 and assembled a team to develop a technical standard to support the implementation of the performance standard. The team met from February 2019 through August 2020 and drafted the Wisconsin DATCP Technical Standard 01 Verification of Depth to Bedrock. This standard is a new standard to define the criteria and procedures to verify and document the depth to bedrock when a landowner wishes to contest the current categorization of cropland specifically for the purposes of applying manure as a crop nutrient. The purpose of this standard is to provide appropriate methods for verification of depth to bedrock to support implementation of s. NR 151.075 in areas where the bedrock consists of Silurian dolomite with a depth to bedrock of 20 feet or less. A final version of the technical standard was adopted in July 2021 and associated guidance is available on the DATCP website. ATCP 50 is currently being revised to adopt the technical standard into administrative code.

In 2020, DATCP contracted with the U.S. Geological Survey (USGS) to update depth to bedrock maps of the Silurian/Karst bedrock region of northeastern Wisconsin. Current depth to bedrock maps are based on limited data and professional judgement, often from over 40 years ago. This project collected airborne geophysical data that encompasses selected areas of interest in Northeastern Wisconsin and focuses on the 5 and 20ft depths identified in the targeted Silurian bedrock performance standard. The data was collected using airborne electromagnetics, or AEM, which is a geophysical technology originally developed for use in the mining industry to locate and map ore bodies but more recently used to map groundwater resources. This work provided accurate, belowground properties that are otherwise difficult to assess and made public vital information for local water users and managers, farmers, conservation staff and agronomic professionals to better understand their groundwater resources and aquifer systems. The Wisconsin Geologic and Natural History Survey is using the data collected as part of the AEM Survey to update existing maps.

Program to Address Agricultural Nonpoint Contributions (ATCP 52)

Producer-Led Watershed Protection Grants are awarded by the Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) to help farmers address the unique soil and water quality challenges of their local landscapes with innovative and collaborative approaches.

Producer-Led groups focus on nonpoint source abatement activities which benefit both surface and groundwater quality. The program-wide 2021 Cover Crop and No-Till Analysis shows that farmers in the program planted 83,932 acres using no-till technology — a 34% increase from 2020. This resulted in an estimated reduction of 94,125 tons of soil erosion and prevented 66,053 pounds of phosphorus loss. Cover crop implementation followed a similar trend, with 100,440 acres planted (a 20% increase from 2020). The estimated outcomes of these improvements are a reduction of 87,919 tons of erosion and 58,081 pounds of phosphorus from leaving farm fields. More information about this project can be viewed at our website: [DATCP Home Producer-Led Tracking Project (wi.gov)]().



Point Source Activities

Previous work by DATCP identified pesticide and fertilizer operations as possible point sources of groundwater contamination. Past problems included improper disposal of unwanted agricultural chemicals, lack of containment for spills, outdated product handling methods, and poor understanding by workers in the industry of how small actions, when continued over time, lead to large problems. DATCP has worked to address these problems through point source prevention. In cases where environmental degradation has already occurred, DATCP oversees environmental cleanup of contaminated soil and groundwater.

Beginning in 1990, the Agricultural Clean Sweep grant program helped farmers dispose of unwanted pesticides, farm chemicals and empty pesticide containers. In 2003, DATCP also began operating and managing the state's household hazardous waste grant program and Agricultural Clean Sweep became Wisconsin Clean Sweep. In fall 2007, prescription drug collection was added to the grant and the annual program budget expanded to $1 million. In 2009 the program budget was reduced to $750,000 annually and program management reduced to 75 percent FTE.

In 2021, 82 grants were issued: 26 for agricultural waste, 37 for household hazardous waste and 19 for the collection of unwanted prescription drugs. Farmer and agricultural participation in collection events brought in slightly more than 70,000 pounds of agricultural waste in total. Farm participation can vary greatly depending on the weather or the frequency of collections within a county. Some counties hold a farm collection every other year or every few years. Farm participation for 2021 appears to be lower than the long-term average agricultural waste collected, which has historically ranged between 100,000 and 150,000 pounds collected annually. Many counties report declining collections as more farmers are using custom application and pesticides are becoming more concentrated. Much of the old stockpiled pesticides were collected during the early years of the program. However, Clean Sweeps still see old, banned or cancelled pesticides like DDT and chlordane. The added difficulties of health and safety concerns due to COVID-19 during 2021 contributed further to the decrease in collected waste as some counties made decisions to not host collection events scheduled for the early portions of the year, or entirely.

The amount of household hazardous waste collected in 2021 was about 2 million pounds, compared to 3.2 million pounds collected in 2020. This decrease in the amount of household hazardous waste collected may be attributed to some of our larger applicants (Milwaukee county for example) not hosting collection events sponsored by DATCP. The "Safer From Home" initiative implemented due to COVID-19 in 2020 gave residents the opportunity to remove hazardous waste from their homes and already disposed of the hazardous waste via 2020 Clean Sweep, resulting in less waste product to be collected in 2021. Lead and oil-based paints remain the most common waste collected from households, followed by latex paint, solvents/thinners, and pesticides/poisons as the fourth most collected waste brought in for disposal.

Wisconsin residents also turned over unwanted prescription drugs at various collection events or through permanent drug drop boxes located in law enforcement offices throughout the state Drug collections netted just over 12,000 pounds of unwanted pharmaceuticals, a decrease of about 14,000 pounds from the previous year. Again, the decrease may be due to cancelled collection events or limited disposal opportunities as a result of health and safety concerns with COVID-19. Drug collections supported by clean sweep grants are only a portion of the drug drop boxes and take back events in the state. The Wisconsin Department of Justice also coordinates and pays for the collection and disposal of unwanted drugs. The pharmaceuticals collected through Clean Sweep projects are included in this program.

Fourteen local DATCP specialists perform compliance inspections and work with facilities across the state to help keep them in compliance with the ATCP rules designed to protect the environment. Agency staff also educates facility managers and employees about how routine practices may affect the environment.

Since 1993, the Agricultural Chemical Cleanup Program (ACCP) addresses point sources of contamination and reimburses responsible parties for a portion of cleanup costs related to pesticide and fertilizer contamination. To date, over 780 cases involving soil and/or groundwater remediation related to improper storage and handling of pesticides and fertilizers have been initiated at storage facilities. Over this same time period DATCP assisted cleanups at more than 1,350 acute agrichemical spill locations. The ACCP has received over 1,500 reimbursement applications totaling almost $49 million in reimbursement payments.

Groundwater Sampling Surveys

DATCP manages a number of sampling programs to investigate the occurrence of pesticides in groundwater resulting from nonpoint sources. Three programs commonly used to assess drinking water quality are the annual targeted and exceedance sampling programs, and the less frequent statewide random sampling survey. DATCP also works with growers to assess water quality beneath agricultural fields by testing a network of field-edge monitoring wells at several locations across the state.

The most recent statistically random sampling survey of private wells statewide occurred in 2016. The results of the survey were published in early 2017, providing a comparison of pesticide and nitrate results to an earlier statewide random survey, published in 2008. DATCP is planning the next survey for 2023. Publications of DATCP surveys are available on the web at: *https://datcp.wi.gov/Pages/Programs_Services/GroundwaterReports.aspx*.

Research Funding

DATCP currently funds groundwater research at about $150,000 and fertilizer research at approximately $200,000 per year, respectively. The UW coordinates groundwater research project funding through the *Wisconsin Groundwater Research and Monitoring Program*. Reports for past DATCP-funded research projects can be found in the *WGRMP Repository*.

Recently completed research projects funded by DATCP include:

- *Assessment of Pesticide Contamination in Suburban Drinking Water Wells in Southeastern Wisconsin*
- *Aerial Thermal Imaging Applied to Wisconsin's Groundwater, Springs, Thin Soils, and Slopes*
- *Integrative Monitoring of Neonicotinoid Insecticides in Baseflow-Dominated Streams on the Central Sand*

Titles of ongoing projects funded by DATCP include:

- **Sublethal Effects of Chronic Exposure to Neonicotinoid Pesticides on Aquatic Organisms**. Report anticipated October 2022.

- **Neonicotinoid Contaminants in WI Groundwater: Relationships to Landscape Cropping Systems**. Report anticipated September 2022.
- **Geophysics-informed Transport & Shallow Bedrock Topography in Northeast and Southcentral WI Counties**. Report anticipated December 2022.
- **Advancing the Use of Nitrate Findings to Inform Groundwater Protection and Improvement Strategies**. Report anticipated November 2022**On-farm Research and Local Partnership to Reduce Nitrate Loading From Agriculture in Pepin County**. Report anticipated September 2023.

In June 2022, DATCP will begin funding one new two year project to further evaluate neonicotinoid use in the Central Sands. This project, *Neonicotinoid Groundwater Leaching Potential from Potato and Management Impacts at Field Scale,* will evaluate pesticide leaching if field scale seed treatment and soil applied neonicotinoid pesticides coupled with the impacts on pesticide leading by farm management practices.

Groundwater Data Management

DATCP maintains its groundwater data in a database that is linked to a geographic information system (GIS) web-mapping application. The system allows the user to search the database and plot maps that show data within a user-defined geographic area. The database was placed on-line in 2012. It contains contact and location information, well characteristics, and pesticide and nitrate sample results for private and public drinking water wells and combines that data with monitoring well data collected from hundreds of agricultural chemical cleanup cases. The database includes samples analyzed by DATCP, Wisconsin State Lab of Hygiene (WSLH), as well as other public and private laboratories. DATCP's groundwater database currently contains information for over 62,000 wells and nearly 800,000 pesticide and nitrate-N sample analytical results.

DATCP uses GIS tools to analyze groundwater data and prepare maps for public hearings, DATCP board meetings, presentations and other uses. DATCP prepares and maintains data in GIS of well locations, atrazine concentrations, atrazine prohibition areas and other pesticide and nitrate-N data. This database information is used to generate maps of statewide pesticide and nitrate-N detections in wells, as well as maps for chapter ATCP 30, Wis. Adm. Code (Pesticide Product Restrictions). Other GIS analyses involve identifying groundwater wells that may be impacted by point sources of pesticide and nitrate-N contamination by allowing comparisons of groundwater results with other features in GIS, such as locations of agrichemical dealership sites and spill sites that may affect groundwater quality.

For further information:

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DEPARTMENT OF HEALTH SERVICES (DHS)

FY 2022 Highlights

- The Groundwater Program assisted the Department of Natural Resource (DNR) in FY2022 in a project to sample public water systems across the state for per and polyfluoroalkyl substances (PFAS). DHS worked with DNR's Drinking Water and Groundwater Program to develop public notice language for public water systems with high levels of PFAS. The DHS Groundwater Program also provided advisory letters to residents with concerns about their water quality on various hazards.
- Multiple DHS programs, including the Groundwater Program and the Site Evaluation Program, provided technical assistance and health education related to more than a dozen groundwater contamination sites in Wisconsin. In FY2022, these programs addressed PFAS contaminants at several locations within the state (e.g., Marinette, La Crosse, Eau Claire, Wausau, Peshtigo, French Island, Madison, Rhinelander). The Site Evaluation Program also assessed groundwater contamination at other sites for polycyclic aromatic hydrocarbons; benzene, toluene, ethylbenzene, and xylene (BTEX) compounds; and chlorinated volatile organic compounds (VOCs) such as TCE, PCE, and 1,2-DCA.
- Wisconsin's Environmental Public Health Tracking Program released a request for applications in FY2022 for local and tribal health departments (LTHDs). Funds are used by grantees to explore data from the County Environmental Health Profiles and the tracking data portal to identify an environmental health concern in their jurisdiction. Six LTHDs were funded and one of those projects focused on water quality, specifically testing of manganese in private well water. In addition, Wisconsin Tracking will be working with the DNR and two LTHDs to streamline data flow of private well water results to the DNR.
- The Climate and Health Program (CHP) and Wisconsin Sea Grant piloted the Flood Resilience Scorecard (FRS) during the pandemic in summer 2020 to evaluate the City of Washburn's flood vulnerabilities. FRS is a comprehensive tool designed to help communities identify what makes them most vulnerable to flooding and what actions they can take to increase their resilience. FRS has been published online and will be available in an interactive format in late summer 2022. CHP will continue to evaluate flood vulnerability using FRS in an estimated 30–40 communities in 2022 to improve local flood resilience and health equity in Wisconsin communities. CHP also continued to promote its Risk Assessment Flood Tool (RAFT), an interactive flood planning and response map, to LTHDs and flood and emergency management professionals. DHS flood planning and response tools can help identify flood-prone areas of the state and identify populations at greatest risk to drinking water contamination resulting from flooded wells.

Overview

DHS serves as a primary resource for information about the health risks posed by drinking water contaminants and is charged with investigating suspected cases of waterborne illness. Toxicologists, public health educators, epidemiologists, and environmental health specialists employed in the DHS Division of Public Health work together to:

- Develop recommendations for groundwater standards for the protection of public health upon request by the DNR.
- Present information on water quality and human health implications of groundwater and drinking water contamination to the public through town meetings and conferences, as well as a wide variety of informational materials.
- Provide direct assistance to families via home visits, letters to well owners, and telephone consultations.
- Educate residents who have contaminated water supplies on the health effects of specific contaminants and recommend strategies for reducing exposure until a safe water supply can be established.
- Provide advice and assistance in cases of vapor intrusion when shallow groundwater is contaminated with volatile organic chemicals, such as benzene and vinyl chloride, which are released as vapors from groundwater directly into buildings through foundations.
- Improve understanding of current and potential groundwater and drinking water issues related to human health in Wisconsin through disease surveillance, health assessment, and capacity and vulnerability assessment. Information from these activities assists project development, focuses area prioritization, and supports academic research. This information also aids local and state agency work on groundwater-related public health issues.

Detail

Reviewing Scientific Information to Develop Public Health Recommendations for Groundwater Contaminants

Wisconsin Stat. ch. 160 directs DHS to recommend health-based standards for substances found in groundwater and specifies the protocol for developing these recommendations. Recommended standards are sent to the DNR and are submitted through the rulemaking process as amendments to Wis. Admin. Code ch. NR 140.

In FY2022, DHS continued to support DNR's rulemaking efforts for the Cycle 10 groundwater standards by responding to public comments and presenting at the Natural Resources Board meeting. The DNR is currently working to determine next steps for these standards. To learn more about these recommendations, please visit DHS' Cycle 10 website.

Working with Partners to Address Drinking Water Concerns

The DHS Groundwater Program also continues to work with other DHS programs to support state, local, and community partners in response to groundwater contamination issues in collaboration with the Site Evaluation Program (see Environmental Cleanups section).

The Groundwater Program also interacts directly with members of the public to address issues affecting their drinking water and increase public awareness of groundwater and drinking water health issues. In FY2022, the Groundwater Program provided advisory letters to residents with concerns about their water quality on hazards including bacteria, manganese, and strontium and worked on several outreach materials related to evaluating risk from PFAS in drinking water. For instance, the Groundwater Program worked with a graphic designer to develop a short video describing how we evaluate risk from exposure to mixtures of PFAS. The program also worked with the University of Wisconsin-Madison's Sea Grant Institute to develop an online tool that the public can use to evaluate their risk from PFAS in their drinking water.

Environmental Cleanups

Multiple DHS programs including the Groundwater Program and the Site Evaluation Program provided technical assistance and health education related to several groundwater contamination sites in Wisconsin.

In FY2022, these programs again had a large focus on PFAS contamination in groundwater across the state. DHS toxicologists and health educators assessed the human health risks of PFAS exposure at many sites, including Marinette, La Crosse, Eau Claire, Madison, Rhinelander, and Wausau. Additionally, these programs assisted the DNR in a project to sample public water systems across the state for PFAS. As part of this project, DHS worked with DNR's Drinking Water and Groundwater program to develop public notice language for public water systems with high levels of PFAS and served as a liaison between DNR and LTHDs on these sites. The team routinely provided technical assistance to concerned citizens, impacted water systems, and contamination sites through the assessment of multiple interconnected exposure pathways, including groundwater, surface water, and biota (such as fish or deer consumption), providing appropriate recommendations to reduce or halt exposure to reduce PFAS levels in the body.

Beyond PFAS, the Site Evaluation Program has also worked to assess groundwater contamination at several other sites across the state. These assessments included evaluating exposure pathways; performing hazard assessments; and mitigating risk for PAHs, BTEX compounds, and chlorinated VOCs such as TCE, PCE, and 1,2-DCA through risk communication.

Taking Action with Data: Use of the Environmental Public Health Data to Improve Environmental Health in a Community

DHS continuously seeks to provide data and resources to LTHDs to assist them in making public health improvements in their communities. In FY2022, Wisconsin Tracking released a request for applications (RFA) for LTHDs, *Taking Action with Data*, for the sixth round of funding. Six LTHDs were funded through this mini-grant opportunity and one project focused on water quality. LTHDs often select private well water quality as a topic they wish to address within their jurisdictions, as this is a significant concern in Wisconsin. This year, Lincoln County's project aims to increase testing of manganese in private well water. To learn more about prior mini-grant LTHD success stories, please see our Environmental Public Health Tracking webpage.

Wisconsin Tracking and other DHS staff provide ongoing support, technical assistance, and guidance to LTHDs on epidemiology, communications, and evaluation throughout the project period. LTHDs carry out their projects with support and assistance from the Tracking Program as needed. Some examples of technical assistance we provide to LTHDs include sharing summaries of past projects focused on water topics completed by grantees; reviewing and providing feedback on surveys and data visualization; and assisting in their writing of project success stories.

Wisconsin Tracking recently submitted a competitive application to the Centers for Disease Control and Prevention (CDC) to continue the work our program started in 2002. The CDC is currently focused on data modernization as an essential component in the improvement of public health. We intend to continue our *Taking Action with Data* mini-grants project and are adding a data modernization pilot to the project. We will be working with the DNR and with two LTHDs to streamline the data flow of private well water testing results from the laboratory to the DNR.

Climate and Extreme Weather Vulnerability Assessment

The DHS Climate and Health Program (CHP), funded by the CDC, works to enhance statewide capacity to prepare for and respond to the public health impacts of climate change, including impacts to private wells from heavy rainfall and flooding events.

Gaps identified previously by the Wisconsin Climate and Health Profile Report have led to the development of several flood-related resources and tools, with the goal of enhancing understanding of flood risks in watersheds and populations vulnerable to flooding events. Flooding events can have negative effects on groundwater quality and public health. These effects can include well contamination and impacts to aquifers due to chemical releases and flood runoff that contains nutrients and other chemical pollutants from both urban and agricultural sources. These projects involve partnerships within DHS and with the University of Wisconsin Center for Climatic Research, Wisconsin Sea Grant, the Association of State Flood Plain Managers, Wisconsin Emergency Management, and several LTHDs. The findings from these flood-related projects have helped inform LTHDs and local emergency management planning processes.

The CHP is currently working on two flood-related tools to help LTHDs, local emergency management, tribal emergency management, and municipal government officials and planners better understand flood vulnerability in Wisconsin:

- A Flood Resilience Scorecard has been published as a document online and will be available in an interactive format later this summer. The tool has been created to aid communities in flood vulnerability assessment. The scorecard identifies institutional, social, environmental, and infrastructure vulnerabilities that could hinder a municipality’s ability to prepare for and respond to flood events. The scorecard will provide recommendations for improvements that will ultimately reduce the negative health impacts from flooding events.
- The Wisconsin Flood Toolkit has been recently revised to include specific considerations for priority populations, those who are particularly susceptible or vulnerable to flooding events. This update will help municipalities better tailor their response and messaging to those most in need during a flooding event. This tool has also been translated into Spanish.

- A third flood-related tool was launched in March 2019 and is undergoing continuous updates. The Risk Assessment Flood Tool (RAFT) provides an online customizable graphic interface for assessing a community's higher risk areas during flood events by overlaying critical infrastructure and vulnerability data with live river gage data from National Oceanic and Atmospheric Administration (NOAA). RAFT assists local emergency management, local emergency preparedness, tribal health centers, and Local Public Health Agencies plan and prepare for flooding events. It will also inform future outreach efforts targeted at private well owners in vulnerable areas.

Environmental Radiation Monitoring

Wisconsin Stat. ch. 254 directs the DHS Environmental Monitoring (EM) Program to collect various types of samples for environmental radiation monitoring, including surface and well water from selected locations at planned sampling intervals near nuclear power plants. The EM Program provides an ongoing baseline of radioactivity measurements to assess any Wisconsin health concerns from the operation of nuclear power generating facilities in or near Wisconsin, or other radiological incidents that may occur within Wisconsin or worldwide.

DHS' ongoing EM Program will provide assurances to the citizens of Wisconsin that the environment surrounding nuclear power facilities and other monitoring areas will continue to be evaluated.

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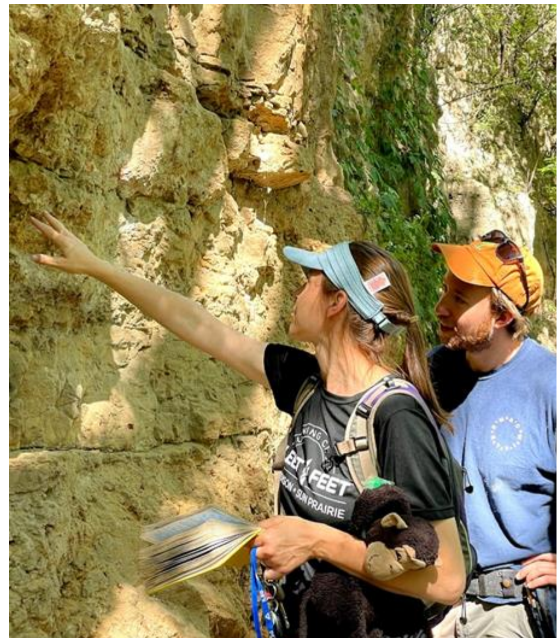
WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY

The Wisconsin Geological & Natural History Survey (WGNHS), part of the University of Wisconsin-Madison's Division of Extension, performs basic and applied groundwater research and provides technical assistance, maps, and other information and education to aid in the management of Wisconsin's groundwater resources. The WGNHS groundwater program is complemented by the Survey's geology programs, which provide maps and research-based information essential to the understanding of groundwater recharge, occurrence, quality, movement and protection. The Survey distributes maps, reports and data related to Wisconsin's geology and groundwater. The Director of the WGNHS is a permanent member of the Wisconsin Groundwater Coordinating Council (GCC) and several WGNHS staff members serve on GCC subcommittees.



Examining an outcrop in southwest Wisconsin (photo by Carsyn Ames).

FY 2022 Highlights

(See the WGNHS 2021 Year In Review; also see this interactive project map describing the projects in more detail.)

- Investigating groundwater quality in southwestern Wisconsin
- Evaluating methods to determine depth to bedrock in Wisconsin
- Acquiring airborne electromagnetic (AEM) geophysical data over large parts of northeast and southwest Wisconsin
- Investigating groundwater and water-level fluctuations in the Bayfield Peninsula and the Chequamegon-Nicolet National Forest
- Investigating Neonicotinoids in groundwater and surface water in Central Wisconsin
- Understanding relationships between bedrock structure and folding and arsenic and other contaminants in groundwater
- Conducting new bedrock geologic mapping in Dodge, Jefferson, Lafayette, and Grant Counties
- Conducting new Quaternary geologic mapping in Wisconsin's Driftless Area and in Jefferson and Bayfield Counties
- Conducting hydrogeologic research in southwest Wisconsin
- Investigating groundwater-surface water relationships in Wisconsin streams, lakes, and wetlands

- Upgrading Wisconsin's statewide groundwater monitoring network
- Upgrading and enhancing geoscience information delivery

Details of Ongoing Activities

Groundwater-Level Monitoring Network

The WGNHS continues to cooperate with the Department of Natural Resources and U.S. Geological Survey in the operation and maintenance of Wisconsin's statewide groundwater-level monitoring network. The WGNHS supports evaluation and maintenance of the monitoring network, aids in data collection, interpretation, and provides information to public and private clients. Recent grants from the U.S. Geological Survey's National Groundwater Monitoring Network program have injected over $550,000 in new funding to repair and evaluate old wells, replace failing wells, and drill new wells in areas of the state lacking monitoring coverage. By 2022, these investments will have resulted in repairs or evaluations to 38 monitoring wells and the drilling of 17 new wells across 30 of Wisconsin's 72 counties. Of the roughly 100 wells in the long-term network, nearly half will have been evaluated, improved, or added thanks to this funding source, representing a generational upgrade to the monitoring network. The WGNHS' webpage dedicated to the monitoring network has also recently been updated and a new video documents the current activities and value of the network. Visit: http://wgnhs.wisc.edu/water-environment/groundwater-monitoring-network.

County and Local Groundwater Studies

Geologic and groundwater studies at county and local scales continue to be an important part of WGNHS programs. With funding from the federal STATEMAP program or local sources, WGNHS scientists initiated or carried out county or locally focused geologic and/or groundwater studies during 2021 in ten Wisconsin counties. New geologic mapping is the fundamental starting point for understanding groundwater resources in Wisconsin. Many of these studies will generate or have generated water-table maps or depth-to-bedrock maps. (Maps: https://wgnhs.wisc.edu/maps-data/maps/)

- ***Southwest Wisconsin groundwater and geology (SWIGG) project***. The purpose of this project is to improve our understanding of groundwater quality in southwest Wisconsin (Iowa, Lafayette, and Grant Counties) and how groundwater quality is related to local hydrogeologic properties and well construction characteristics. Southwest Wisconsin is an area of shallow carbonate bedrock beneath generally thin soils. Due to the shallow fractured bedrock and the presence of minor karst features this area is considered very vulnerable to groundwater contamination, but prior to this study regional groundwater sampling has been sparse. Project objectives are to (1) evaluate private well contamination in three counties using indicator bacteria (total coliform and *E. coli*) and nitrate based on randomized synoptic sampling events; (2) assess well construction and geological characteristics (e.g., well age, depth to bedrock) that affect total coliform and nitrate contamination; and (3) identify the source of contamination in a subset of total coliform- and nitrate-positive wells using microbial tests that distinguish between human, bovine, and swine fecal sources. This project was completed in early 2022 and the administrative report is freely available. Additional information about the project is at https://wgnhs.wisc.edu/southwest-wisconsin-groundwater-and-geology-study-swigg/.

- ***Hydrogeology and groundwater flow model of Columbia County.*** This multi-year study is a cooperative effort between the WGNHS and USGS, sponsored by the Columbia County Department of Land Conservation and the Wisconsin DNR. The project involved characterization of the county's groundwater system and included development of a groundwater flow model. The model is used extensively at the request of county officials to evaluate potential sources of poor groundwater quality in many private and public groundwater supply systems. A technical report on the model and hydrogeology of the county was released in 2021.
- ***Bedrock controls over arsenic contamination in southeast Wisconsin.*** WGNHS geologist Eric Stewart and colleagues published research showing a relationship between arsenic detection in groundwater and proximity to bedrock folds in the Beaver Dam area of Dodge County. The statistical approach they used is encouraging because it can not only be used to assess variables impacting arsenic detection, but can also be used to model the impact of well construction strategies that could reduce arsenic risk. This research was also featured in a news story on UW–Madison's website. A better understanding of bedrock arsenic sources will be useful for potential casing regulations that could dramatically lower the percentages of wells that produce drinking water with low to moderate levels of arsenic within the southeast Wisconsin study area (Fond du Lac, Dodge and Jefferson Counties).
- ***Bayfield County Groundwater.*** The thick sands in the central Bayfield uplands comprise an important groundwater recharge area, but the remote location and a water table more than 200 ft below land surface pose challenges to studying the local hydrogeology. In 2021, we continued to monitor two groundwater wells installed in the Bayfield County uplands in order to better understand regional groundwater flow there.
- ***Depth-to-Bedrock Map of Dodge County, Wisconsin.*** This new map, a companion to the recently released bedrock geology map of Dodge County, Wisconsin (M508), shows thicknesses of deposits of unconsolidated materials above the bedrock. Across the county, depth to bedrock ranges from 0 feet, where bedrock is exposed, to over 250 feet within bedrock valleys. Areas with bedrock depths shallower than 20 feet are of particular importance for land-use planning and to the construction stone industry. Such areas are more susceptible to groundwater contamination and underlie about 17 percent of Dodge County, including the more-populated areas of the county. The accompanying report describes how the map was compiled and outlines limitations of the map.

- ***Nitrate in groundwater at Waupaca, Wisconsin.*** The City of Waupaca, Wisconsin, uses groundwater pumped from a network of seven high-capacity wells as its municipal water supply. Recent increases in the concentration of nitrate in the municipal water supply raised questions about the source of this contamination and whether it might eventually exceed standards for drinking water. This study combined geologic, hydrologic, land-cover, water-use, and water-quality data from the area with a groundwater-flow model to simulate and predict the effects of different land and water use on the concentration of nitrate in groundwater pumped from two of the city's municipal wells. The resulting tool supports decision makers who are tasked with land-use management and demonstrates a study design that could be applied to well-head-protection efforts elsewhere in Wisconsin's Central Sands region. The WGNHS released a report on this work in early 2022.

Regional Groundwater Studies

Regional groundwater studies usually span multiple counties. During 2021 the WGNHS was involved in several regional projects, including the following:

- ***Depth-to-Bedrock Mapping in Wisconsin.***
  Depth-to-bedrock maps show the thickness of unconsolidated materials overlying bedrock. These maps provide a key link between the underlying geology, groundwater flow, and land use and are important in guiding activities such as permitting, bridge construction, and the land application of waste products in sensitive areas. Given their role in guiding decision-making, the production of accurate depth-to-bedrock maps is critical. A new WGNHS report describes techniques for making the maps, identifies sources of data and evaluates their strengths and weaknesses, describes available tools and best practices for using them, and explains the concept of uncertainty—how it's measured, its importance in decision making, and ways of displaying it.

- ***Hydrogeology of the Chequamegon-Nicolet National Forest (CNNF)*.** WGNHS continued several groundwater studies in the CNNF. These include characterizing groundwater-surface water interactions of recently flooded seepage lakes near Drummond, WI, and, as mentioned above, studying groundwater recharge in the sandy uplands portion of the Bayfield Peninsula. We also began a project along the North Fork of the Yellow River in Taylor County to improve understanding of the local hydrogeology and to document baseline water chemistry. Over the course of the year, the project team made regular visits to this

Collecting water samples in the CNNF. Photo by Anna Fehling.

area to sample water, monitor water levels, and collect other varied hydrologic and geophysical measurements. In the fall, WGNHS sampled a combination of more than 150 lakes, streams, springs, and campground wells throughout the Chequamegon-Nicolet National Forest. This work contributes an updated reference point for establishing long-term records and for identifying trends of water quality conditions within the National Forest.

- ***Advancing the use of nitrate findings to inform groundwater protection and improvement strategies.*** UW-Extension agents in Wood and Portage counties, Portage County staff, and the WGNHS developed this study based on input from the Central Sands County Groundwater Collaborative (CSGCC). The overarching goal is to advance the use of historical nitrate and neonicotinoid findings to inform groundwater protection initiatives and improvement strategies by counties within the Central Sands Region of Wisconsin – particularly, Adams, Juneau, Marquette, Portage, Waushara, and Wood.

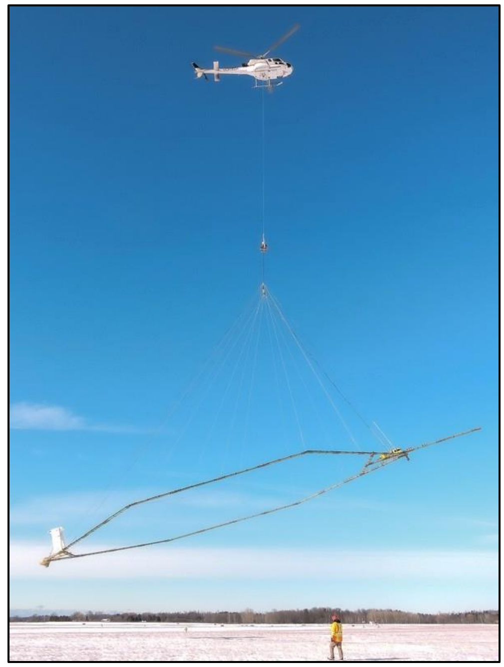
- ***Geology and hydrogeology of the Rountree Formation in southwest Wisconsin.*** The uppermost bedrock formations across much of SW Wisconsin are carbonate rocks of the Sinnipee and Prairie du Chien Groups. As those rocks chemically weather over geologic time, they produce a dense red residual clay known as the Rountree Formation. However, because the Rountree Formation is covered by younger sediment, very little is known about it. This project will evaluate the geographic distribution of this red clay layer across numerous counties in southwest Wisconsin; investigate its geologic and geochemical properties; and assess what—if any—role it plays in buffering the bedrock groundwater system from surface contamination. The results of this investigation will merge with water quality data from the Southwest Wisconsin Groundwater and Geology (SWIGG) study to better understand the interaction between human land use, underlying geology, and groundwater contamination susceptibility in southwest Wisconsin.

Core of material from the Rountree Formation in southwest Wisconsin.

Groundwater Research Activities

The WGNHS carries out specific groundwater research projects focused on understanding topics important to groundwater use and management in Wisconsin and elsewhere. Active research projects during 2021 included the following:

- ***Hydrogeology of Southwest Wisconsin.*** The hydrogeology and hydrostratigraphy of the Driftless Region of southwestern Wisconsin are complex due to the presence of multiple bedrock aquifers, rugged topography, bedrock structures, and fractures and karst features. To begin to better understand this region the WGNHS has undertaken groundwater monitoring centered on the Platteville Pioneer Farm, an Experimental Farm in Grant County operated by UW-Platteville. The goal of the Pioneer Farm work is to develop better conceptual models of the groundwater flow systems in SW WI.



Helicopter towing a geophysical array hoop used for AEM surveys. Photo by Maureen Muldoon.

- ***Mapping depth to bedrock.*** WGNHS scientists worked with DNR, DATCP, NRCS, and UW–Green Bay officials to develop and release new guidance for depth–to–bedrock mapping in the state. An exciting offshoot of this project was the acquisition and interpretation of airborne electromagnetic (AEM) geophysical data over large parts of eastern Wisconsin. This work utilizes a helicopter-towed geophysical array to cover large land areas rapidly. Based on its success in eastern Wisconsin, WGNHS and partners are conducting a similar survey in parts of southwest and southeast Wisconsin in 2022.
- ***Neonicotinoid contaminants in Wisconsin groundwater: relationships to landscape cropping systems.*** WGNHS hydrogeologists are collaborating with researchers at the UW-Madison Department of Entomology to better constrain the temporal and spatial dynamics of neonicotinoids in stream water across the Central Sands Region and analyze potential linkages between land-use activity and neonicotinoid concentrations in streams. Neonicotinoid monitoring results in streams will be evaluated using a calibrated groundwater flow model for the Central Sands to delineate groundwater contributing areas to these streams. Agricultural land use patterns within the groundwater contributing areas will then be analyzed to develop statistical relationships between land-use type and neonicotinoid concentration in streams. These results will provide stakeholders an additional tool to assess risk to aquatic invertebrates, better protect sensitive taxa, and inform regulatory and land-use management decisions.

Groundwater Data Management and Support

In 2021 the WGNHS continued to collect geologic and groundwater data and provide this data to a variety of users. Significant databases and data efforts include the following:

- ***Enhanced publications catalog***. The WGNHS maintains hundreds of reports, maps, and other records in digital form for free downloads to the public. During 2021 the Survey continued to upgrade the functionality of this service, allowing easier data searching, previewing and downloading of information related to Wisconsin's groundwater and geology.
- ***Collection of downhole geophysical logs***. The WGNHS continually collects and compiles downhole geophysical logs from research wells and "wells of opportunity," such as municipal wells. The logs, including natural gamma radiation, temperature, caliper, fluid conductivity, borehole diameter and optical imaging, are important tools for understanding water-quality problems in individual wells, and for correlating geologic units in the subsurface. In addition to municipal wells, geophysical logging has been used to troubleshoot problems in private wells and wells owned by state agencies including Department of Corrections, Department of Natural Resources and Departement of Transportation. The WGNHS maintains a publiclly-accessible data viewer for geophysical logs and Quaternary core, see https://data.wgnhs.wisc.edu/data-viewer/.
- ***Hydrogeologic Data Viewer maintenance***. The WGNHS continues to support the Hydrogeologic Data Viewer, a map-based application to access a statewide catalog of hydrogeologic data. The application provides DNR staff with online access to data and publications and includes several methods to search by area for data of interest, such as geologic and geophysical logs or well construction reports. Many of the geophysical logs are collected for the DNR in wells where water quality or lack of data is an issue.
- ***wiscLITH database***. When requested, the Survey provides updates of the digital database, wiscLITH, which contains lithologic and stratigraphic descriptions of geologic samples collected in Wisconsin. This is a publicly available database, and current work efforts focus on including more data for areas of the state with active geologic and hydrogeologic projects. Database: https://wgnhs.wisc.edu/pubs/wofr200903/.
- ***Well construction reports***. The WGNHS serves as the repository for well construction reports (WCRs) from wells installed between 1936 and 1989 and can provide digital or paper copies to those who request them. In addition, WGNHS serves as a point-of-contact for questions about WCRs and updates records when errors are found during project work.
- ***High-capacity well approval tracking***. WGNHS continues to track high-capacity well approvals in an internal database. This enables a more proactive approach for WGNHS researchers, in collaboration with the DNR, to work with well drillers, pump installers and consultants to collect samples and borehole geophysical logs from priority areas of the state.
- ***WGNHS Research Collections and Education Center.*** The WGNHS archives geologic records, rock samples, core samples and other materials in Mount Horeb, Wisconsin. Our core repository contains over 2.5 million feet worth of drillhole

cuttings, more than 650,000 feet of drill core and more than 15,000 individual hand samples of rock from across the state. Examination tables and basic laboratory facilities allow convenient analysis and study of these materials by qualified individuals. More about the repository: https://wgnhs.wisc.edu/research/core-repository/.

Groundwater Education

WGNHS groundwater education programs for the general public are usually coordinated with the DNR or the Central Wisconsin Groundwater Center at UW–Stevens Point or with the UW–Madison science outreach community as well as with the UW-Madison Division of Extension. WGNHS produces and serves as a distributor of many groundwater educational publications through our website (https://wgnhs.wisc.edu). We also distribute information about Wisconsin groundwater on our website at https://wgnhs.wisc.edu/water-environment. Our outreach efforts reach different and broader audiences through a variety of social media tools, including:

- *Facebook - https://www.facebook.com/WGNHS*
- *Twitter - https://twitter.com/wgnhs*
- *Pinterest – http://www.pinterest.com/WGNHS/*
- *YouTube –https://www.youtube.com/channel/UCwwucf9-W1qocovGx-uzs7w*

WGNHS presents groundwater educational activities at various museums and schools and at UW-Madison outreach events (such as at Science Expeditions and at the Science Festival).

In 2021, WGNHS staff members participated in groundwater educational meetings in counties where mapping and/or hydrogeologic studies are in progress. Staff members will continue to work with the DNR and the Central Wisconsin Groundwater Center on teacher-education programs connected to the distribution of groundwater sand-tank models.

The WGNHS maintains a long commitment to the continuing education of water well drillers, pump installers and plumbing contractors through participation in the programs of the DNR and the Wisconsin Water Well Association. Geologic and hydrogeologic field trips and presentations for DNR water staff and new DNR employees have been held in the past and will continue as requested.

The WGNHS Research Collections and Education Center is providing a locale for various groups to conduct related educational programs. Researchers and consultants also use our core holdings in that collection to better understand the subsurface and its aquifers. Staff of WGNHS organize and annually present papers at the Wisconsin Section of the American Water Resources Association reaching consultants, academics, and state and federal agency scientists with results of our research.

For more information:

Visit https://wgnhs.wisc.edu/
Contact the Wisconsin Geological & Natural History Survey
3817 Mineral Point Road
Madison, Wisconsin 53705-5100
tel. (608) 262-1705 email: info@wgnhs.wisc.edu

DEPARTMENT OF TRANSPORTATION

Because of the 1983 Wisconsin Groundwater Law, the Department of Transportation (DOT) regulates the storage of highway salt (ss. 85.17 and 85.18, Wis. Stats.) to protect the waters of the state from harm due to contamination by dissolved chloride. DOT is also responsible for potable well sampling at 28 rest areas and some seasonal waysides. Other DOT groundwater related activities include: groundwater investigation or remediation of contaminated properties; subsurface hydrogeologic investigations for infrastructure development; compensatory wetland restoration including hydrology performance monitoring (surface water/groundwater interaction); storm water management; and coordination with USGS and WGNHS for locational use and access for groundwater level monitoring points incorporated into the Wisconsin Groundwater-Level Monitoring Network.

FY 2022 Highlights

- Maintains new social media partnership with WI Salt Wise: https://www.wisaltwise.com.
- Continues to research the effectiveness of brine chemicals and brine application rates for varying weather conditions in partnership with Clear Roads (National Research Consortium https://clearroads.org) and the UW Traffic and Safety Laboratory (TOPS Lab).
- Created the Brine Technical Advisory Committee (TAC) in 2018 and provides ongoing training to County winter maintenance crews regarding Direct Liquid Application (DLA).
- 29 Counties used DLA and some Mostly Liquid Route (MLR) last season.
- Preliminary results of new brine application techniques are showing significant reduction in overall salt use while maintaining clear roads and level of service for the traveling public.

New fact sheet: Safe Highways – Less Salt.

- Less salt was used last winter season (236 million pounds) yielding cost savings ($10.1 Million).
- 14.3 million gallons of brine solution was used last season, most in Wisconsin history.
- 44 Counties have been provided with route optimization technology to date.

Details of Ongoing Activities

Salt Storage

Highway salt is stored statewide by suppliers, counties, cities, villages and private companies. Annual inspections occur and reports are provided for salt storage sites to ensure storage practices are in accordance with ch. Trans 277, Wis. Adm. Code (Highway Salt Storage Requirements). The intent of the Code is to help prevent entry of highway salts into waters of the state from storage facilities. All salt must be covered and stored on an impermeable base. The base for stockpiles is required to function as a holding basin and to prevent runoff. The covers must consist of impermeable materials or structures to prevent contact with precipitation. State funded facilities are being added to the DOT salt storage program to provide greater capacity of indoor storage. This will improve groundwater protection and create greater flexibility for scheduling salt purchase at optimal prices.

The DOT annually updates salt storage facility records into a database and assists the DNR Wellhead and Source Water Protection program in locating salt storage facilities for GIS mapping applications. There are currently 1,323 salt storage site locations listed in the database with a total of over 2,410 buildings, brine tanks and stockpiles identified in the state. Facility inventories, inspections, repairs and improvements are included in the database.

Salt Use

The DOT Bureau of Highway Maintenance produces the Annual Winter Maintenance Report describing statewide salt use based on weekly reports from each county. Current policy in the State Highway Maintenance Manual restricts the spreading of deicer salts to a maximum of 400 pounds per lane mile per initial application, and up to 300 pounds per lane mile for subsequent applications. Electronic controls for salt spreader trucks are calibrated to record and verify application rates and coverage effectiveness. Other technology is used on county highway patrol trucks to keep salt on pavement surfaces (e.g., zero-velocity spreaders, ground speed controllers and onboard liquid pre-wetting units). Additional efforts to minimize and conserve salt applications include the use of an in-situ weather monitoring system. Pavement temperature sensors on most trucks and at 75 weather stations along major highway routes are used to determine application rates and effectiveness. Annual training for snowplowing and salt spreading techniques is provided for county snowplow operators.

Salt Usage Tracking and Initiatives

The DOT is working to ensure the right materials and resources are available and used before, during and after each storm event. The department continues to identify best practices based on national studies, pilot winter projects involving salt and brine use, plowing practices and snow plow route optimization.

The newest DOT initiatives over the last 4 winter seasons in winter maintenance is called “Mostly Liquid Routes” (MLRs). Multiple Counties tested MLRs this past winter using brine or brine mixtures to keep the snow from sticking to the road between plow cycles, and rarely put rock salt on the road. These projects can result in a reduction of about 50% road salt application while still achieving the “time to bare/wet” goals.

Research and Additional Information

In December 2021 two research projects were completed in coordination with the Department:

1. *Evaluation of Winter Maintenance with Salt Brine Applications in Wisconsin*
   - https://topslab.wisc.edu/research/tse/evaluation-of-winter-maintenance-with-salt-brine-applications-in-wisconsin/
2. *Expanding Application Rate Guidance for Salt Brine Blends for Direct Liquid Application and Anti-icing*
   - Expanding Application Rate Guidance for Salt Brine Blends for Direct Liquid Application and Anti-icing | Clear Roads

DOT winter maintenance and response performance measures can be found at these webpage links:

- https://wisconsindot.gov/Pages/doing-bus/local-gov/hwy-mnt/winter-maintenance/default.aspx
- https://wisconsindot.gov/Pages/about-wisdot/performance/mapss/measures/mobility/winter.aspx

Explanations of liquid brine applications are provided on WisDOT podcast (Feb 25, 2020 – Transportation Connects – Clear Roads, Less Salt – Winter Road Maintenance) below and refer to the DOT social media for occasional postings and new information pertaining to Winter Maintenance and chloride reduction initiatives:

- https://wisdot.libsyn.com/clear-roads-less-salt-wisconsin-winter-road-maintenance-0

For more information

Visit https://wisconsindot.gov
Contact Robert Pearson,
Bureau of Technical Services - Environmental Services Section - Hydrogeologist
4822 Madison Yards Way, 5th Floor South
Madison, Wisconsin 53707-7965
Phone: 608-266-7980, email robert.pearson@wisconsin.gov

UNIVERSITY OF WISCONSIN SYSTEM

The University of Wisconsin System (UWS) maintains groundwater-related research, teaching, and outreach responsibilities. These three missions are integrated through cooperation and joint appointments of research, education, and outreach and extension personnel, along with postgraduate fellows, who address groundwater issues. UWS staff members work with state and federal agencies and other partners to solve groundwater resources issues. Research is coordinated through the University of Wisconsin Water Resources Institute, which conducts annual calls for proposals followed by rigorous peer and panel review of the proposed projects. Typically, four to seven projects are funded through the Institute each year. Citizen outreach is accomplished through publications, video and audio podcasts, social media, media relations, public meetings and presentations, teleconferences, and water testing and satellite programs. In the following sections, we describe the activities of several university programs, including the *University of Wisconsin Water Resources Institute*, the *Central Wisconsin Groundwater Center* (affiliated with UW-Madison's Division of Extension and UW-Stevens Point), the *Natural Resources Institute's Land and Water Programs* at UW-Madison's Division of Extension, the *University of Wisconsin Nutrient and Pest Management Program*, and the *Wisconsin State Laboratory of Hygiene*.

Details of Ongoing Activities:

University of Wisconsin Water Resources Institute (WRI)

The University of Wisconsin Water Resources Institute (WRI) is one of 54 water resources institutes located on universities across the nation with core funding provided and administered by the U.S. Department of the Interior through the U.S. Geological Survey. The Institute promotes research, training, and information dissemination focused on Wisconsin's and the nation's water resources problems. WRI is a UWS program administratively housed at UW-Madison's Aquatic Sciences Center, along with the University of Wisconsin Sea Grant College Program.

FY 2022 Highlights

- In support of the Wisconsin Groundwater Research and Monitoring Program, provided UWS funding to seven research projects focused on groundwater contaminants, including nitrate, radium, strontium and road salt; water quantity challenges in the Central Sands; geochemistry and microbiology; groundwater-surface water interactions; and economics of groundwater and water utilities and supported graduate and undergraduate students at UW-Milwaukee, UW-Madison, UW-Stevens Point, and UW-Platteville.
- Coordinated the Request for Proposals and the review process for the FY23 Joint Solicitation for the Wisconsin Groundwater Research and Monitoring Program.
- Supported five Water Resources Science-Policy post graduate fellows in partnership with the Wisconsin Department of Natural Resources (DNR), Wisconsin Department of Health Services (DHS), and University of Milwaukee Center for Water Policy to work on state priority groundwater and surface water challenges, including completion of a legislatively requested study on water in the Central Sands Region,

development of decision-support tools for high-capacity wells, the effect of a changing climate on brook and brown trout, and statewide public health tracking for harmful algal bloom toxin exposure. It also leveraged Aquatic Sciences Center funding to support ten additional post graduate fellows working on aquatic toxicology and PFAS, community flood resiliency, coastal hazards, coastal wetlands, and aquaculture.

- Organized and conducted a statewide workshop among university researchers and state scientists, resource managers and policymakers to determine gaps in understanding per- and polyfluoroalkyl (PFAS) in Wisconsin. This was in partnership with the State Laboratory of Hygiene and the University of Wisconsin Sea Grant College Program. A *white paper* from the workshop will assist in setting future priorities.

Per- and polyfluoroalkyl substances (PFAS) are chemicals used in everyday items like clothing and cookware. They can accumulate in fish, wildlife, and humans. Here, a Water Resources Institute-funded researcher is studying analyzing chemicals in her lab. *Photo: Bonnie Willison*

- In early summer 2022, kicked off the inaugural cohort of summer undergraduate research experiences for those on University of Wisconsin System campuses. The freshwater science explorations will pair students with researchers at campuses at Eau Claire, La Crosse, Madison, and Platteville. In future years, the program will expand to other campuses. It is funded by the Freshwater Collaborative, WRI and the Sea Grant College Program.
- Supported the annual Wisconsin Chapter of the American Water Resources Association meeting. This year, the Wisconsin Water Library and the Wisconsin Geological and Natural History Survey also collaborated to post digital copies of the meetings' proceedings from 1978 to the present on a University of Wisconsin-Madison library *website*. This will make the water science material widely available.
- Produced seven episodes of a podcast called *Wisconsin Water News* that explores relevant water topics through this easily downloadable and informative tool.
- Supported the production of 27 final project reports, 15 theses, and 87 peer-reviewed publications over the past five years.

Research

The WRI research portfolio is supported by UW System funding for the Wisconsin Groundwater Research and Monitoring Program and includes interdisciplinary projects in four areas: groundwater, surface water, groundwater-surface water interactions, and drinking water. Groundwater is a top priority and an area of particular strength at the WRI.

During FY22, the WRI directed a wide-ranging program of priority groundwater research consisting of four new projects and three continued projects. These included short- and long-term studies both applied and fundamental in nature. They provide a balanced program of laboratory, field, and computer-modeling studies and applications aimed at preserving or improving groundwater quality and quantity. Key areas of emphasis in FY22 included research focused on groundwater contaminants, including nitrate, radium, strontium, and road salt; water quantity challenges in the Central Sands; geochemistry and microbiology; groundwater-surface water interactions; and economics of groundwater and water utilities and supported graduate and undergraduate students at UW-Milwaukee, UW-Madison, UW-Stevens Point, and UW-Platteville.

Undergraduate assistant Dylan A. Childs completing chloride analysis using the chloride probe in University of Wisconsin-Milwaukee Paradis Lab, summer 2021. The project is funded by WRI.

Groundwater issues investigated during the past year included:

- Investigating in-season cover crops for reducing nitrate loss to groundwater below potatoes. Kevin Masarik and Jacob Prater, UW-Stevens Point. (continuing)
- Valuing groundwater quality: A cost function analysis of Wisconsin water utilities. James Price, UW-Milwaukee. (continuing)
- Investigating sources of salinity associated with Ra and Sr in the Cambrian-Ordovician aquifer system of eastern WI. Matthew Ginder-Vogel, Patrick Gorski, and Sean Scott, UW-Madison and Wisconsin State Laboratory of Hygiene. (continuing)
- Measurement of bacterial transport and immobilization in variably saturated geologic materials of WI. Christopher Zahasky, Eric Roden and Vy Le, UW-Madison. (new)
- Mass discharge of road salt via groundwater to surface waters in Southeastern Wisconsin. Charles Paradis, Laura Herrick, Cheryl Nenn, and Timothy Wahl, UW-Milwaukee and Southeast Wisconsin Regional Planning Commission. (new)
- Data-driven groundwater depth and risk forecasting in the Central Sands region of WI for sustainable management. Jingji Huang and Ankur Desai, UW-Madison. (new)
- Assessment of biochar application to reduce nitrate leaching through agricultural vegetative treatment areas. Joseph Sanford, UW-Platteville. (new)

For FY23 (July 1, 2022 - June 30, 2023), the UWS selected two new groundwater research projects from proposals submitted in response to the Joint Solicitation for Wisconsin Groundwater Research and Monitoring Program and will continue four projects selected from the previous years' solicitations. The projects are based at UW-Madison and include:

- Aligning the Wisconsin Idea on water: Interpreting public perspectives and values. Michael Cardiff, Ken Genskow, and Bret Shaw, UW-Madison. (new)
- Biomanipulation of Groundwater Flooding. Steven Loheide II, Kenneth Potter, UW-Madison. (new)

Additionally, the WRI receives an annual federal 104(B) allocation that can be used to advance groundwater and other water resources research and initiatives. This allocation is often used to fully support or augment a project selected through the state groundwater competition, freeing up state resources to invest in additional strong proposals submitted to the groundwater competition. In FY22, this allocation supported:

- Fate of groundwater phosphorus from septic systems near lakes. Paul McGinley, UW-Stevens Point. (continuing)

In addition, this federal allocation was matched by state agency partners and used to:

- Support a Water Resources Science-Policy postdoctoral fellow in partnership with DNR's Drinking Water and Groundwater Program to work on the Central Sands Lakes Study (study requested by the legislature). (Dr. Carolyn Voter, 2019-21).
- Support a Water Resources Science-Policy postdoctoral fellows in partnership with DNR's Fisheries Management Program to work on the state's streamflow model and effects of stream hydrology on fisheries. (Dr. Bryan Maitland, 2020-22).
- Recruit and support a Water Resources Science-Policy postdoctoral fellow in partnership with DHS to work on public health aspects of harmful algal bloom toxin exposure (Jordan Murray, 2021-22).
- Recruit and partially support two Water Resources Science-Policy legal fellows placed at the UW-Milwaukee Center for Water Policy to work on water policy and equity issues (Misbah Husain and Sarah Martinez, 2021-22)

Pictured is Dr. Carolyn Voter, one of WRI's Wisconsin Water Resources Science-Policy Postdoctoral Fellows, who was integral to the 2021 Central Sands Lake Study Report, as directed by the legislature.

Lastly, the Aquatic Sciences Center (home to WRI) successfully secured a grant from the U.S. Environmental Protection Agency to support three UW-U.S. Environmental Protection Agency Human Health and the Environment Postdoctoral Research Fellows. (Drs. Nathan Pollesch, Prarthana Shankar, and Sally Mayasich, 2019-22). And, through a variety of partnerships, the Aquatic Sciences Center was also able to support post graduate fellows to work on PFAS contamination of surface waters (Dr. Sarah Balgooyen, 2019-22), community flood resiliency (Jackson Parr, DHS, 2021-22), coastal hazards (Lydia Salus, Emily Rau, and Sarah Brown, Department of Administration, 2019-22), coastal wetlands (Dr. Nicole Ward, DNR, 2021-22), and aquaculture (Dr. Patrick Blaufuss, UW-Stevens Point and Milwaukee, 2020-22).

Teaching

Institutions within the UWS continue to offer undergraduate- and graduate-level courses and opportunities focusing on diverse issues regarding groundwater resources. Additionally, several campuses offer for-credit, field-oriented water curriculum courses for middle- and high school teachers during summer sessions. The WRI also views continuing education for P-12 teachers as an important component of its outreach and training effort. The Wisconsin Water Library, housed on the UW-Madison campus and funded by the WRI, maintains an extensive collection of curricula with innovative approaches and other educational materials for teaching water-related science in P-12 classrooms. Through the librarian's outreach to teachers last year, nearly 20,000 students were exposed to water-science learning. The library's curricula are available for checkout by all teachers and residents in Wisconsin. The librarian also has deep experience in working with children. She put that experience to use in developing kits based on field-tested science, technology, engineering, art, and math. The kits will eventually number 27 on topics such as the water cycle, art and water, and pond science. The kits contain several books, directions for a guided science experiment and other themed activities. Finally, the library provides checkout of an aquatic invasive species elementary and middle school curriculum collection known as an attack pack. The packs have been used to educate people about aquatic invasive species in the waters of Wisconsin and are being updated to include additional information about fish.

Grants Administration

The WRI conducts the annual outside peer review of all proposals submitted to the state of Wisconsin Joint Solicitation for Groundwater Research and Monitoring. In FY22, WRI continued to use a web-based proposal submission, review, and reporting system *eDrop*. The website enables seamless online submission and review of proposals. At the site, prospective investigators submit a proposal by filling out a series of forms and uploading their full proposal and budget. Assigned reviewers then complete their reviews through eDrop by answering a series of questions online. Once all the reviews are completed, the UW Groundwater Research Advisory Council is granted access to anonymous reviews and original proposals to help decide which proposals to recommend for funding. Agency partners also have access to the reviews to inform their selection processes as well. The website provides a framework for consistently capturing the same information from all the prospective investigators and reviewers, ensuring all proposals are treated equally.

Information-Sharing and Outreach Activities

The *University of Wisconsin Water Resources Institute website* offers research projects and publications. One of the site's main audiences is researchers. To that end, the site provides a clear navigational path to the WRI project listings, project reports, a groundwater research database, funding opportunities, and conference information sections. All of these areas are updated on a regular basis to ensure currency of information transfer. Additionally, WRI has a presence on Twitter, Facebook, and Flickr.

Video is a compelling way to share water-science information. The Institute's video catalog includes seven titles. The most popular one is "Testing well water for microorganisms." To date it has more than 13,000 views, which is a large number for a scientific topic.

The Pew Research Center, in a 2017 report, noted that the percentage of podcast listeners in America has substantially increased since 2006. At the time of the report, four in ten Americans ages 12 or older had listened to a podcast and 24 percent had listened to a podcast in the past month, up from just 9 percent in 2008. WRI capitalizes on this popular platform. It offers five multi-part *podcast* series on topics such as groundwater, mercury in aquatic environments, and aquifers and watersheds.

During this reporting period, WRI staff were integral to the leadership and content-population of Water@UW-Madsion located here - *https://water.wisc.edu/*. The site is a portal to the breadth and depth of water-related work on the state's flagship campus, the

UW-Madison, and serves as the first stop for anyone interested in water research. Graduate students can search for departments offering courses and degrees that fit their interests. Prospective graduate students can use the site to investigate potential faculty advisors. Finally, staff and faculty can search for colleagues working on topics complementary to their own to facilitate greater interdisciplinary collaboration and efficiencies. This year, Institute Associate Director Dr. Jennifer Hauxwell advised the Water@UW-Madison executive committee. Natalie Chin, the Institute's tourism and climate change specialist, and Moira Harrington, the Institute's communications lead, served on the committee. The group hosted a spring event that reached hundreds of viewers. Additionally, WRI Director Jim Hurley serves on the Steering Committee for the Freshwater Collaborative, another entity promoting collaboration, this time among University of Wisconsin System campuses.

Water Resources Publications

The program offers easily accessible publications through an *online site*, with free information or information available for a nominal cost. Topics include nitrates in groundwater, siting rain gardens, and arsenic in groundwater. The program also produces the *Aquatic Sciences Chronicle* on a quarterly basis. It circulates to roughly 5,500 electronic and print subscribers with an interest in WRI projects and related topics. The newsletters are also posted online.

Wisconsin's Water Library

Wisconsin's Water Library is a unique resource for Wisconsin citizens. It contains more than 30,000 volumes of water-related information about the Great Lakes and the waters of Wisconsin. The library includes a curriculum collection, dozens of educational videos, a children's collection, and more than five journals and 30 newsletters.

In addition to archival benefits, the library provides outreach by answering many in-depth reference questions on a wide range of water-related topics. In partnership with the Wisconsin Department of Natural Resources and the Wisconsin Wastewater Operator's Association (WWOA), the library offers assistance to current and future wastewater and drinking water operators of Wisconsin. The library catalogs the essential technical manuals and loans them to WWOA members around the state in support of required state license examinations.

Wisconsin's Water Library continues to catalog all groundwater research reports from projects funded by the WRI into WorldCat and MadCat, two library indexing tools that provide both worldwide and statewide access to WRI research. By having this information permanently indexed, the research results are easily available to other scientists throughout the University of Wisconsin System as well as across the nation and the world.

The library also maintains a digital archive of the entire collection *of Groundwater Research and Monitoring Program reports.* The archive was created in partnership with the UW Digital Collections Center and ensures a permanent and accessible electronic record of Wisconsin groundwater-related activities since 1984. Paper copies of the reports continue to be a part of the Wisconsin Water Library.

Technical Research Publications Resulting From Recent WRI Groundwater Research and Monitoring Program-Sponsored and Other WRI-Supported Projects (Past Five Years):

Water Resources Institute Reports

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Booth, E. G., S. P. Loheide II, D. Bart, P. A. Townsend, and A. C. Ryzak. 2019. Linking groundwater and nutrients to monitor fen ecosystems using airborne imaging spectroscopy. (University of Wisconsin-Madison). Final Report, University of Wisconsin Water Resources Institute. 20p. WR17R001/2018WI372B.

Choi, C.Y., D.J. Hart, J.M. Tinjum, and M.K. Harper. 2016. Assessment of environmental impacts of geothermal source heat exchange. (University of Wisconsin-Madison). Final Report, University of Wisconsin Water Resources Institute. 22p. WR14R002.

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Ginder-Vogel, M., and C. Remucal. 2016. Effect of source chemistry on Mn-bearing solid dissolution and reactivity in municipal water systems. (University of Wisconsin-Madison). Final Report, University of Wisconsin Water Resources Institute. 14p. WR14R004/2015WI335B. WR15R009.

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Kucharik, C.J., T. Campbell. 2020. Improving water and nitrogen use efficiency under changing weather variability in the Central Sands. (University of Wisconsin-Madison). Final Report, University of Wisconsin Water Resources Institute. 18p. WR18R001.

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Larson, E.R., and S.A. Allen. 2016. Establishing the long-term range of variability in drought conditions for southwest Wisconsin. (University of Wisconsin-Madison). Final Report, University of Wisconsin Water Resources Institute. 17p. WR13R003/2013WI313B.

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McLellan, S. 2021. Detection of Sewage Contamination in Urban Areas of the Great Lakes. . (University of Wisconsin-Milwaukee). Final Report, University of Wisconsin Water Resources Institute. 3 pp. WR16R005/2016WI354G.

Nitka, A., P. McGinley. 2017. Investigating the impact of nitrate contamination on uranium and other elements of emerging concern in Wisconsin groundwater. (University of Wisconsin-Stevens Point). Final Report, University of Wisconsin Water Resources Institute. 16p. WR16R002.

Noguera, D. M. Anderson, I. Tejedor, J. Wouters. 2017. Phosphorus and arsenic sensors for real time environmental monitoring. (University of Wisconsin-Madison). Final Report, University of Wisconsin Water Resources Institute. 15p. WR15R001.

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Ventura, S., and S. Cardiff. 2016. Advances in monitoring and analysis of trace metals: a workshop to address applications in the Upper Great Lakes. (University of Wisconsin-Madison). Final Report, University of Wisconsin Water Resources Institute. 15p. WR14R001/2014WI325B.

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Central Wisconsin Groundwater Center

The *Central Wisconsin Groundwater Center* is an affiliate of the Center for Watershed Science and Education. It is a partnership between the College of Natural Resources at the University of Wisconsin – Stevens Point and the University of Wisconsin – Madison, Division of Extension. The Central Wisconsin Groundwater Center provides groundwater education, research and technical assistance to the citizens and governments of Wisconsin. Assistance includes answering citizen questions, helping communities with groundwater protection, describing the extent and causes of groundwater pollution, assessing drinking water quality, and working on groundwater policy. More information can be found at *https://www.uwsp.edu/cnr-ap/watershed/*.

Well Water Testing & Outreach

In calendar year 2021, the center helped 6,323 households test their water in conjunction with the UW-Stevens Point Water and Environmental Analysis Laboratory along with partners in county Extension offices, county health departments, and county land conservation departments. Well water testing programs were conducted in the following counties: Dodge, Sauk, Green, Chippewa, Kewaunee, Monroe, Sheboygan, Richland, Vernon, Crawford, Burnett, Waushara, Marquette, Polk, Calumet, Trempealeau, Taylor, Pierce, St. Croix, and Douglas. Many of the educational programs had to be conducted via online webinars rather than in-person meetings. In-person educational programs have resumed for programs that have taken place in 2022.

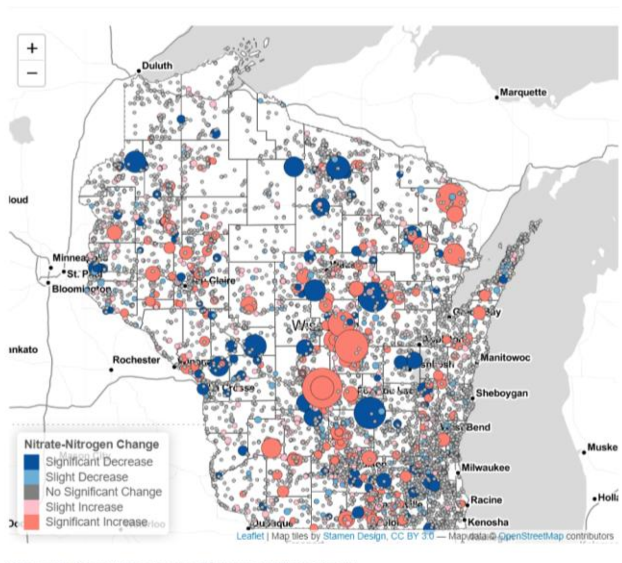
Water Quality Database

The Groundwater Center maintains a database of private well testing data from the Water and Environmental Analysis Regional Laboratory at UW-Stevens Point and conducts drinking water education programs. There are currently more than 875,000 individual test results for approximately 122,605 samples throughout the state. Chemistry data include pH, conductivity, alkalinity, total hardness, nitrate-nitrogen, chloride, saturation index, coliform bacteria, an atrazine screen, various metals and minerals including arsenic, lead, and copper. The database primarily covers the period 1985 to the present. The database can be queried, making it an easily accessible source of information for local communities and groundwater managers.

Interactive Wisconsin Well Water Quality Viewer

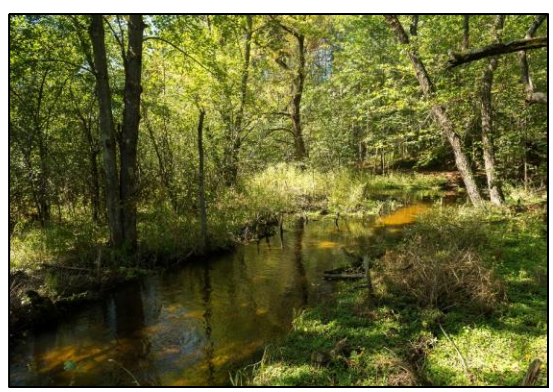
In July 2012, the Groundwater Center made publicly available an online mapping tool that allows people to search for groundwater quality information. The tool incorporates private well water data from the center's database, the Wisconsin Department of Natural Resources (DNR) Groundwater Retrieval Network and the Department of Agriculture, Trade and Consumer Protection. In 2014, data from the Eau Claire County Health Department were also integrated. [Summary maps] are available for 14 different water quality parameters and can be viewed or summarized into a table at a county, town or section level detail. Updated in 2019 to include nitrate/arsenic data from DNR well testing requirements for new wells and/or well pump work it now includes data for over 200,000 samples: with 105,381 samples from Extension efforts. It allows users to see water quality in their community and other parts of Wisconsin. In 2021, the Viewer was accessed by 7,509 people. The viewer was recently updated to include data thru December 31, 2021.

Nitrate in Groundwater



The Center launched a new app that investigates nitrate trends in Public Water Supply Systems. Using data from public water systems (i.e. Municipal, Other-than-Municipal, Transient, Non-community, and Non-transient, Non-community) the app summarizes publicly available data which can be viewed spatially or by Wisconsin Unique Well Number. The data reveal that 89.4% of wells have no trend, 6.8% have an increasing trend, and 3.9% have a decreasing trend. The app can be found online at: https://shiny.theopenwaterlog.com/nitrate_trends/

The Center is also investigating the impact of various cropping practices on groundwater quality in the Central Sands Region. Using a combination of lysimetry and wells, the study is collecting year-round data to better understand the timing of nitrate leaching losses from various crops. Because many leaching studies often focus only on the growing season, this data set will provide important insight into inter- and intra-annual variability of leaching that is necessary to calibrate and validate nitrate leaching models. An additional project was started in 2020 looking at the use of inter-planting to reduce nitrate leaching losses below commercial potato production. The work is a collaboration with Dr. Chris Kucharik and



The Little Plover River, one of the many streams in the Central Sands region affected by increased pumping. Photo: UW WRI.

students of his Lab at UW-Madison Department of Agronomy.

Central Wisconsin county-based volunteer streamflow monitoring

In a joint project with five county conservation offices and the DNR, the center launched a program that provides citizen volunteers with professional-grade streamflow monitoring equipment. This is part of an effort to better understand water conditions in the Central Sands Region affected by increased pumping. Staff members worked with county staff to recruit and train volunteers. Currently, staff are coordinating with 10 citizen volunteers to measure baseflow at 70 sites throughout the Central Sands Region. A quality control procedure is in place to independently verify a percentage of each citizen volunteer's measurements to ensure consistency and accuracy; results are extremely encouraging. These volunteers fill a large gap in baseline monitoring data of stream flow in the area.

Chemical Tracers for Identifying Sources of Groundwater Nitrate-Nitrogen

The center continues to refine chemical analysis methods for a suite of human wastewater tracers and agricultural pesticide metabolites to help trace the source of elevated groundwater nitrate concentrations in a well. This method study has resulted in a technique that has been applied to wells in Adams, Portage, St. Croix, Dunn, and Chippewa counties. Center staff worked with the DNR and the Wisconsin Department of Health Services to develop drinking water advisory levels for some of the compounds detected. Results from this study have been presented at the Wisconsin American Water Resources Association meeting and are available in a final report on the Groundwater Center's website.

PFAS in Private Wells

The Center is partnering with the Wisconsin Department of Natural Resources and Wisconsin State Laboratory of Hygiene on a statewide testing project of private wells for Per- and polyfluoroalkyl substances. Four limited-term employees hired by the Center will collect samples from up to 450 private wells selected by the DNR. The data will collect important data on ambient levels of these compounds in groundwater and private wells.

Groundwater and Lakes

The center is working with several Wisconsin counties on lake management planning that incorporates groundwater flow modeling and groundwater in hydraulic and nutrient budgets. These studies are useful ways to communicate the connection between groundwater and surface water resources and highlight the need for protecting groundwater quality. Ongoing center research includes the movement of phosphorus from septic systems and the influence of nitrogen on lakes.

5-Year County Well Water Quality Inventories

Starting in 2019, the Center began multi-year projects with Chippewa, Green, and Sauk counties to organize *citizen-based groundwater monitoring networks* in each county. Dodge County was added in 2020. Wells will be tested for the following parameters: nitrate, chloride, alkalinity, pH, hardness, and conductivity. The goal is to test the same wells for five years in a row for the purposes of understanding trends in rural groundwater quality over time. By testing the same wells annually, Center staff will be better able to assess where/why groundwater quality changes and what characteristics and/factors can be used to predict changes in well water quality over time. County-wide summary statistics are fairly consistent for all parameters from year to year. Individual wells however tend to have greater variability. Future years will investigate what factors contribute to variability/trends in individual wells.

County	Year		Alkalinity	Chloride	Conductivity	Nitrate-Nitrogen	pH	Total Hardness
		n	mg/L as $CaCO_3$	mg/L	umhos/cm	mg/L		mg/L as $CaCO_3$
Chippewa	2019	79	62.1	22.9	256	5.0	6.78	96.2
	2020	79	66.6	24.1	274	4.9	7.33	91.7
	2021	79	69.3	24.8	268	4.9	6.95	100.7
Dodge	2020	354	333.0	34.0	792	1.7	8.03	383.1
	2021	354	339.3	34.4	783	1.5	8.07	348.1
Green	2019	307	304.6	19.1	649	5.4	7.52	341.9
	2020	307	298.6	18.9	665	5.8	8.12	340.5
	2021	307	307.2	19.1	661	5.8	8.09	346.3
Sauk	2019	351	207.4	16.6	470	4.2	7.58	233.2
	2020	351	204.9	17.1	479	4.3	8.02	227.3
	2021	351	214.8	16.8	474	4.1	7.82	233.8

Policy

The center continues to play pivotal roles in a number of state groundwater issues. Working with partners in the private and public sectors on groundwater quantity policy and law has been a continuing priority. Center staff routinely present information on the science of groundwater quality and groundwater pumping and associated impacts to local and state government officials. Staff recently participated in the Wisconsin DNR Central Sands Lake Study and the NR151 Nitrate Technical Advisory Committee.

Recent Publications and Reports (past 5 years)

Nitka, A.L., DeVita, W., McGinley, P.M. 2019. Evaluating a Chemical Source-Tracing Suite for Septic System Nitrate in Household Wells. Water Research 148(1):438-445 http://dx.doi.org/10.1016/j.watres.2018.10.019

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University of Wisconsin-Madison Division of Extension: Natural Resources Institute's (NRI) Land & Water Programs

The Division of Extension Natural Resources Institute's (NRI) Land & Water Programs include state and local specialists addressing water resources, land and water conservation, forestry, conservation professional training, citizen engagement, and volunteer monitoring. NRI also coordinates a number of regional and national programs addressing water resources and water-education initiatives related to groundwater.

NRI Regional Water Programs and Conservation Professional Development

NRI coordinates the *North Central Region Water Network (NCRWN)*, a 12-state collaboration among Land Grant universities, including partnerships with state and federal agencies across the Upper Midwest region. Through this network, Extension researchers and educators share programs and coordinate on an array of water resource issues, including groundwater quantity and quality. Currently, multi-state teams are active around soil health, watershed leadership, harmful algal blooms, drought, climate, and green infrastructure.

NRI also coordinates the *Conservation Professional Training Program*, which develops and hosts multi-state professional development for conservation professionals. Wisconsin programs have included issues of conservation lands management such as manure management and fractured bedrock geology, including:

- Classroom and field training for local elected officials (town, county) both on the basic geology of local resources and localized research on groundwater quality and land use impacts in both the northeast and southwest regions of the state.
- Training public- and private-sector professionals to help farmers more effectively manage manure and commercial nitrogen fertilizers that can negatively impact groundwater.
- Training for manure applicators on manure application in karst areas.
- Providing conservation planning training and farmer training that includes karst issues.
- Offering projects that help water resource managers understand farmer awareness of, and capacity to adopt, conservation practices that are most likely to fit into farm management systems.

NRI Water Outreach and Education

The *Water Action Volunteers* stream monitoring program educates both children and adults about stream ecology and stream health. Volunteers continue to monitor more than 500 stream sites statewide for a variety of parameters, including stream flow, which is directly affected by groundwater. Volunteer-collected data is helping to characterize water quality and quantity across the state and to identify streams where impairments may exist. This program engages volunteer monitors in partnership with schools, nature centers, and many others to provide educational experiences and important data regarding streams and hydrological systems.

Northland College Professor Tom Fitz teaching Master Naturalist volunteers about artesian wells found in northern Wisconsin.

The *Wisconsin Master Naturalist* program, active since 2012, follows a train-the-trainer approach to engage Wisconsin citizens in resource management. The course curriculum covers a variety of natural resources issues specific to Wisconsin, including groundwater quality and use. Certified volunteers are expected to provide 40 hours of natural-resource-related service annually to Wisconsin host organizations, such as nature centers, state parks, or museums. Areas of service include education/interpretation, stewardship, and citizen science. The Wisconsin Master Naturalist Program has resulted in over 178,000 volunteer hours providing nearly $5.1million dollars in value to the state since the program began. Fifty-eight host organizations have partnered with the program by having 162 individuals trained as instructors who have trained 1,115 volunteers statewide. There is a presence of Master Naturalists in 64 of Wisconsin’s 72 counties. The course provides a broad overview of Wisconsin’s natural resources and the processes that affect them. This program continues to grow in cooperation with partners across Wisconsin.

Master Naturalist volunteer providing water quality monitoring on a stream in Rock County.

Regional Natural Resource Education Program

Extension’s Natural Resources Institute cooperates on community-focused educational programs with other state agencies involved with water resources and natural resource issues. The *Regional Natural Resources Education Program* uses locally based natural resource educators to develop and conduct programs that reach local and statewide audiences by accessing state-level support for educational material development and program evaluation. The educational programs address a broad range of groundwater-related topics, including drinking water, threats to groundwater quality, impacts of land-use changes, and land management decisions on groundwater quantity, information about localized groundwater problems such as karst geology, water conservation, and efficiency, along with a variety of other issues associated with nutrients in surface water and groundwater. Educators have actively engaged with and facilitated the development and growth of farmer-led groups that learn about and implement conservation practices designed to address a host of water quality issues.

For more information on NRI/Land & Water programs related to groundwater:
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University of Wisconsin Nutrient and Pest Management (NPM) Program

Mission Statement

The University of Wisconsin's Nutrient and Pest Management (NPM) Program works with farmers, researchers, agricultural professionals, and citizens to provide research-based agricultural nutrient and pest management education on crop production practices that protect water quality, farm profitability, and resilient landscapes.

Overall, in 2021, the NPM program staff collectively educated 13,225 people, at 548 events, giving 189 unique (original, first-time) presentations. In addition, they provided 16,573 individual consultations via email, phone, and in-person contacts. Educational products developed in 2020 include 36 videos, 47 print publications, and 125 nutrient management training manuals.

NPM Program outreach products are available for viewing and downloading at: https://ipcm.wisc.edu/

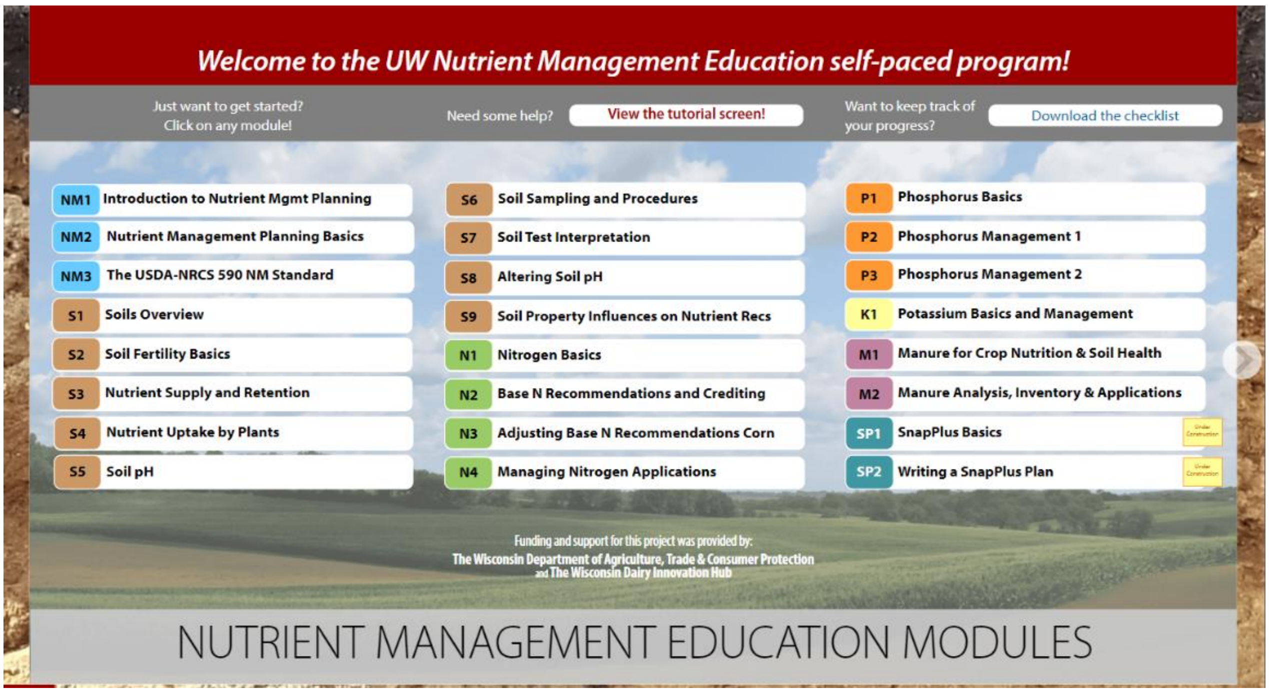
Nutrient Management

The NPM Program is part of a team that develops, distributes, evaluates, and implements nutrient management education programs. Partners include University of Wisconsin-Madison College of Agriculture and Life Sciences (UW-CALS) faculty/staff; county-based UW-Extension staff; land & water conservation departments; Wisconsin technical colleges; the Wisconsin Department of Agriculture, Trade and Consumer Protection; and the U.S. Department of Agriculture-Natural Resources Conservation Service, along with private-sector agri-businesses and Wisconsin farm producers. Activities include:

- *Nutrient Management Farmer Education Curriculum* (NMFEC) development and implementation. The NMFEC is an essential tool used throughout the state to teach farmers about crop nutrient management practices that improve profitability and reduce adverse impacts of nitrogen and phosphorus pollution. The NPM Program staff maintain, update, produce, distribute, and implement the NMFEC. The curriculum combines classroom instruction, individual consultation, and on-farm field trials to deliver education on the preparation and understanding of farmer-written nutrient management plans. The curriculum is delivered statewide through collaborations with partners identified in the previous paragraph. Participation in a NMFEC project is the **only** mechanism for Wisconsin farmers to become certified to prepare their own nutrient management plans.

Cumulative accomplishments numbers from 2000 to 2021 show that as a result of local delivery of the curriculum, more than 9,178 producers farming approximately 2,683,770 acres in 55 counties have received in-depth education on nutrient management planning. In 2021, approximately 362 farmers operating about 118,745 acres in more than 20 Wisconsin counties added to this accomplishment list. Data are currently being collected for 2022 accomplishments.

- *Release of a new platform* *and* *updated content for the NMFE Curriculum*. An online, video-based instruction version was developed in 2021 and released in early 2022. The new NMFE allows for self-paced learning by users. The new curriculum is available at: https://nmfe.webhosting.cals.wisc.edu/. (*Please allow a few minutes for the initial*



download.) Content of the digital curriculum is displayed in a modular format. Each module deals with a specific component of a nutrient management plan and features multiple, short, instructive videos along with linked resources. This project was in response to challenges with the traditional delivery of the NMFE curriculum including COVID-19 restrictions as well as staff and budget reductions. This digital remote delivery method will: i) Eliminate or greatly reduce the need for physically close instructor-student contact, ii) Allow for self-paced, self-instruction, and iii) Increase the number of Wisconsin farms possessing and implementing NM plans. Support for this project is provided by WDATCP and the UW-Madison Dairy Innovation Hub.

- *SnapPlus nutrient management planning software* assistance and refinement in conjunction with the SnapPlus team (UW-Madison Soil Science). NPM staff assist in developing educational online videos (11), updating the SnapPlus online help system, refining output reports to meet the needs of end users and the creation of a SnapPlus training manual with more than 125 copies requested and delivered in December of 2021. In addition to creating SnapPlus educational products, NPM staff actively train farmers, agronomists, and others to use SnapPlus. In 2020, NPM staff members continue to assist the SnapPlus team in the development of a new SnapPlus user interface as well as quality control reviews of the software program.

- *Educational support to Wisconsin watershed projects*. Activities include coordination and delivery of individual nutrient management plans, on-farm demonstrations (nutrient crediting, nitrogen rates for corn, soil health, cover crops, soil erosion control, etc.). Support activities include planning, advice, coordination, grant preparation, and reporting. In addition, NPM staff serve on the selection committee for DATCP-sponsored farmer-led watershed projects. NPM Program staff serve as key members of watershed projects (producer-led, federal NRCS, and other) in 22 watershed projects in 39 Wisconsin counties.

- *On-farm demonstrations, field plot research and subsequent educational programs* on various topics including: adaptive nitrogen management for corn, cover crops, conservation tillage, manure applications, etc. occurred in six counties in 2021.

Pest Management

NPM, in conjunction with numerous partners including UW-Madison-CALS faculty, county-based UW-Extension, the UW Integrated Pest Management (IPM) Program, and others, delivers timely educational programming on topics associated with pest management. Activities include:

- *Waterhemp weed control project* involves statewide field trails evaluating control techniques for herbicide-resistant waterhemp. Waterhemp is a very aggressive weed that is wreaking havoc across the nation's cropland fields. In 2021 NPM conducted on-farm research waterhemp trials in Dane, Grant, Shawano, and Oconto counties.

- *Soil conservation and weed management.* NPM working with the UW-Madison Dept. of Agronomy conducted on-farm research aimed at managing weeds while improving soil conservation. These trials look at using cover crops, no-till, residual herbicides, and system-based programs for the management of waterhemp and other troublesome weeds in Wisconsin.

- *Strategies for avoiding herbicide resistance in weeds.* The NPM program delivers educational outreach materials and trainings to Wisconsin producers and agri-businesses on strategies for avoiding the development of herbicide resistance in weeds. Strategies include awareness and diversification of herbicide modes of action used on a given farm/field, equipment sanitation to avoid transport of weed seeds, and identification of weed species likely to be resistant to popular herbicides.

- *White mold and waterhemp management using winter rye.* NPM conducted on-farm research aimed at managing white mold and waterhemp in soybean while improving soil conservation. These trials looked at using winter rye vs. conventional approaches to managing white mold on farms in Wisconsin.

- *On-farm roller crimper studies.* Three on-farm studies were conducted to investigate the on-farm utility of using the rye/roller-crimper system for white mold and waterhemp management while reducing pesticide inputs. Locations included Lafayette, Portage, and Calumet Counties.

Cropping Systems

- *Cover crops research, education and outreach.* NPM partnered with county Extension educators, USDA-NRCS, County Land Conservation Departments, non-governmental organizations, and CALS specialists to deliver cover crop education programs in person and virtually across the state and Midwest. Activities included on-farm field days, on-farm research and demonstration, development of educational videos, factsheets, publications, and training farmers and agronomists. NPM outreach specialists provided active leadership in the Wis. Cover Crops Conference and Cover Crops Research and Outreach Project (CCROP). Cover crop demonstration and research plots were continued at Peninsular, Lancaster, and Arlington Agriculture Research Stations.

- *Soil health education.* More than 70 soil health presentations were given in-person and virtually to farmers, lake & watershed groups, tribal communities, and youth throughout the state, region, and nation. NPM staff worked closely with community and farmer-led watershed groups to develop demonstration/research projects and field days to highlight the impact of agricultural practices on soil health and water quality. NPM staff, with Extension and agency collaborators, defined soil health indicators for cranberry production systems in Wisconsin. Additionally, NPM staff assisted the Wisconsin Natural Resources Conservation Service in delivering soil health education to new and existing agency staff, attendees at Farm Technology Days, and high school agriculture educators.

- *Badger Crop Connect.* NPM staff were part of a team of educators within the Crops & Soils Program of the Division of Extension that organized and delivered a new series of webinars containing timely Wisconsin crop management information from March through October 2021. These webinars were a successful alternative to in-person fields days. Three NPM staff delivered four unique presentations at four different sessions. Collectively, there were over 1,122 viewer logins for these discussions.

- *Healthy Grown / Healthy Farms.* NPM working cooperatively with the WI Potato and Vegetable Growers Association (WPVGA) has developed a national model of sustainable production systems, exemplifying integrated pest management. In addition, the program includes a nationally recognized ecosystem restoration effort. In 2021, ten growers were certified and over 12,800 acres of fresh market potatoes (about 40% of Wisconsin's fresh market acres) were verified as "Healthy Grown." NPM has worked with the WPVGA to expand "Healthy Grown" to carrots and onions.

- *Water quality and conservation expansion programs*. NPM staff have worked to expand water quality programs with state potato and vegetable growers. The inclusion of water modules into Healthy Grown was developed and piloted in 2021. This led to an expanded role for NPM staff including the WDNR proposed NR 151 rule change comprehensive economic analysis project, outreach coordination for the USDA-SCRI Potato Soil Health Project, work with the Central Wis. Farmer Cooperative Producer-Led Watershed, lead for the Central Wis. Water Quality Working Group, and continued work as a liaison with the Water Task Force.

- *First Nation sustainable food production and food sovereignty initiatives*. Through programming efforts of the College of Menominee Nation, Menominee Indian Tribe, the Stockbridge-Munsee Community, and Wisconsin Farm Bureau, NPM's Dr. Jamie Patton provided educational outreach on culturally-relevant, sustainable food production practices to indigenous communities in the Great Lakes Region, as well as northeast Wisconsin non-native agricultural producers. Additionally, NPM supported youth STEM education by providing multiple presentations on environmental topics to the College of Menominee Nation-Sustainable Development Institute's Summer Sustainability Leadership Cohort, a program for Menominee high school youth.

- *UWEX Agricultural Institute Climate Change Team.* The NPM Program is part of a leadership group guiding the UWEX-Agriculture Institute Climate Change Education Team. The team's mission is to provide professional development and educational resources to enhance the ability of Extension agricultural educators to address current and expected challenges associated with climate change. In 2021, three professional development webinars were held, attended by 60 educators and specialists from three UWEX Institutes.

<u>Outreach and Communication</u>

- *Mobile applications*. The NPM Program creates mobile applications (apps) for hand-held devices (Apple and Android). Maintenance and updating of the NPM Program's apps occurred in 2021. Currently available mobile apps include: *Tarspotter*, *Sporebuster, Manure Tracker, Sporecaster, Nitrogen (N) Price Calculator, Corn N Rate Calculator, Integrated Pest Management Toolkit, Corn Crop Calculator, Manure and Legume Nutrient Credit Calculator*, and *BeanCam* (*https://ipcm.wisc.edu/apps/*). Collectively, these apps have been downloaded by more than 140,000 users from across the world. All apps are created in collaboration with UW-Madison faculty and are promoting agricultural best management practices.

- *YouTube videos*. The NPM Program produced 36 new videos on a range of crop management topics in 2021. Over 330 YouTube educational videos featuring UW-Madison-CALS specialists have been prepared and released by the NPM Program over the past nine years. A complete listing can be found at *https://www.youtube.com/user/uwipm*. A conservative estimate of the number of views is greater than 1,200 worldwide per day with over 2.2 million total views as of November 2021.

- *Wisconsin Crop Manager newsletter and IPCM website*. The NPM and IPM Program website delivers the popular *Wisconsin Crop Manager* newsletter featuring contributions from faculty and staff across UW-CALS departments. *Wisconsin Crop Manager* is produced weekly during the growing season with semi-monthly and monthly releases during the winter months. The weekly e-mail distribution list contains 1,244 recipients, with 14,000 PDF downloads in 2021. Available online at: *https://ipcm.wisc.edu/wcm/*.

- *NPM publications*. The NPM Program has a long history of collaborating with CALS faculty specialists to create timely, pertinent, high-quality publications promoting the adoption of agricultural management practices to improve water quality and farm profitability. In 2021, 47 new publications were produced. Formats range from simple pocket-sized cards to extensive manuals and workbooks. NPM staff roles include author, editor, and designer. A listing of NPM's print publications can be found at https://ipcm.wisc.edu/downloads/.

- *NPM Resource Highlights.* An online, digital newsletter created in 2020 is sent monthly to the UWEX Agricultural Institute (AI) list serve. Its purpose is to inform AI affiliates of new and existing NPM Program resources that are seasonally pertinent. Publications, videos, mobile applications, etc. are featured. The original intent was to inform new county educators of NPM Program educational products; however, feedback from UW/UWEX faculty and staff indicate that they, also, find the information useful in their local programming efforts.

- The NPM Program won three Certificate of Excellence Awards in 2021 from the American Society of Agronomy (ASA) Extension Education Materials Competition. The NPM Program has won a total of 24 awards from ASA in ten years! Year 2021 awards include: *Small Grains in Wisconsin* (award category: pubs. <16 pages); *Tarspotter Corn Disease Forecast Tool (*digital decision aids); *Bumper Crops video series* (audiovisuals).

For more information on the NPM program:
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Wisconsin State Laboratory of Hygiene (WSLH)

At the Wisconsin State Laboratory of Hygiene (WSLH), a great deal of effort is focused on identifying and monitoring chemical and microbial contaminants in groundwater through testing, emergency response, education and outreach, and specialized research. The activities related to groundwater span several departments at WSLH. The mission of the WSLH is to protect the health of drinking-water consumers by providing analytical expertise, research, and educational services to the scientific and regulatory communities and the public.

The chemical and microbial groundwater contaminants routinely tested include all contaminants regulated by the federal Safe Drinking Water Act, as well as many emerging contaminants that appear on the USEPA Contaminant Candidate List. Examples include: fecal indicators (total coliform, *E. coli*, coliphage, *Bacteroides* spp., *Rhodococcus coprophilus*, sorbitol-fermenting Bifidobacteria), *E. coli* O157:H7, toxigenic *E. coli*, Salmonella, waterborne viruses (norovirus), human-adenovirus, parasites

(Cryptosporidium, Giardia, and microsporidia), radioactivity, inorganic compounds (mercury, nitrate, arsenic), and organic compounds (atrazine, PCBs, PBDEs). PFAS contamination has gained significant attention and significant resources are being directed toward testing and outreach to support the many PFAS related efforts. The water microbiology section of the WSLH currently has molecular capabilities to analyze for human adenovirus and distinguish between bovine and human *Bacteroides* spp. as part of the laboratory's toolbox approach to microbial source tracking in groundwater.

In addition to routine testing of fecal indicators and emerging contaminants, the WSLH now employs a "toolbox" of microbial and chemical source-tracking assays. Microbial and chemical source tracking is used to determine sources of fecal contamination in water, whether from human or animal sources, using multiple microbial and chemical agents. The data are then used for making management decisions regarding control of fecal pollution of groundwater.

Another important focus of the WSLH is emergency response to incidents involving groundwater. For example, WSLH works with the DHS and the DNR to investigate outbreaks of illnesses of unknown (possibly food or water) origin. Staff provides background information on the outbreaks for local public health officials, local media, and the general public. WSLH also responds to spills and incidents and supports state agencies in remediation and emergency cleanup activities.

WSLH also provides educational and outreach activities related to groundwater and drinking water including (1) instructional consultations for well owners and well drillers, (2) assistance and consultation for municipal water supply operators, and (3) tours for a variety of international, educational, regulatory, and governmental groups. Staff members have developed publications related to drinking water, including a well water activity sheet, *"Test your well water annually"* brochure, and other well water testing promotional materials. Staff members present papers at a variety of conferences and symposia and publish research findings in professional journals.

Summary of Groundwater-Related Work at WSLH

Organic Chemistry Section

- The State Laboratory has developed and is validating methods for measurement of PFAS chemicals in various matrices, including groundwater/drinking water. Significant coordination with state and federal partners occurs to ensure appropriate certifications are in place, which PFAS compounds to focus on, and matrix specific challenges such as limits of detection. As with many labs, capacity challenges exist so better and quicker ways to measure PFAS are continually being pursued. The State Laboratory is happy to partner with others and share information as appropriate to collectively advance understanding about these issues. State and Federal efforts are ongoing to support drinking water and groundwater testing for PFAS compounds.
- Interpretation of GC-MS and LC-MS analysis of petroleum compounds is done to aid in fingerprinting possible sources of contamination. Other source tracking tools and lists of compounds (human sources, animal sources) are also provided to assist in understanding source, fate, and transport of contaminants.
- Analysis of pharmaceuticals, personal care products, and antibiotics as tools to indicate pollution from humans and animals. This analysis in conjunction with the

Microbial Source Tracking “Toolbox” is used to support various activities toward groundwater protection and management.

Chemical Emergency Response Section

- The WSLH serves as the only public health emergency preparedness-supported chemical response laboratory in Wisconsin. The lab has extensive capabilities for testing human exposures to priority chemical agents, provides sampling materials and guidance for first responders, including hazardous material, drinking water, and natural resource entities, and performs any needed testing of environmental samples related to chemical incidents. One facet of this support has been the development of a drinking water collection kit, tailored to allow appropriate collection for assessing a wide range of chemical and microbiological contaminants in drinking water. These kits have been provided to all drinking water utilities serving more than 3,000 people, as well as to public health and other appropriate agencies. The emergency kit continues to be deployed to assist in characterizing a possible contamination and the system worked as designed.

Water Microbiology Section

- 2021 and 2022 continues to see the WSLH performing significant work with Sars-CoV2 (COVID) in wastewater. COVID in Wastewater has garnered significant attention and continues to be relevant and add value. This work was and continues to be a joint effort between the water microbiology section and environmental toxicology. COVID in wastewater has been a useful tool for communities to understand levels of the virus on a community level, thus indicating overall levels or trends of the virus on a broader scale.
- Source assessment requirement under the Revised Total Coliform Rule - WSLH continues to implement a scientifically based well assessment for wells testing positive for coliforms. This project is to develop and test a suite of microbial organisms that can determine the source of contamination by collecting a large volume sample using a hollow fiber ultra-filtration system.
- WSLH is researching changes to the fecal source tracking toolbox by implementing species-specific PCR assays for human, bovine, swine, and poultry Bifidobacteria; improving the PCR primer sets for human and bovine Bacteroides spp.; and determining the feasibility of using pepper mild mottle virus to determine human contamination in groundwater. The research includes collecting fecal samples from animals throughout the state to determine sensitivity and cross reactivity for microbial sources of contamination.
- As a part of a larger laboratory-wide preparedness program, WSLH is prepared to offer appropriate microbial water quality testing when needed. WSLH is a member of the Environmental Response Laboratory Network and the Water Laboratory Alliance for both chemical and biological response. This involves participation in nationwide preparedness drills coordinated by the Centers for Disease Control and Prevention in conjunction with the U.S. Environmental Protection Agency.
- The WSLH Flow Cytometry Unit coordinates and distributes samples for the only Cryptosporidium Proficiency Testing Program (PT) available in the United States. This WSLH program supports environmental laboratories testing water samples for the presence of this parasitic protozoan under the Long Term 2 Enhanced Surface Water Treatment Rule. The program has been designed to provide water-testing laboratories and accreditation agencies with a means of assessing a laboratory's performance of U.S. EPA Method 1622/1623. The program is accredited under ISO

17043 "general requirements for proficiency testing" and distributes samples twice annually. The program operates with support from the WSLH Water Microbiology Department, which evaluates the robustness of the parasites suspensions prior to and following distribution to participant laboratories.

- The Water Microbiology Section of the WSLH Environmental Health Division has developed a suite of testing and sampling methods called Large Volume Sampling (LVS) that is designed to detect organisms that can be present in low concentrations.

Inorganic Chemistry Section

- Instrumentation is in place to measure isotopic ratios of certain metals (i.e. lead) to identify the source of the particular metal, be it the source, piping, etc. Each case is different, but it is possible to deploy this technology to better elucidate the source of a metal in drinking water or other matrices. Lead and mercury are good candidates for testing in these regards. Radium in groundwater is another candidate for the application of a potentially better tool.
- A variety of nutrients are routinely measured in drinking water, surface water, and groundwater. People with health concerns regarding their drinking water, such as nitrates, can submit samples for evaluation. Results are sent to the clients and the DNR for their database. The DHS has worked with WSLH at the county level to provide drinking water kits to families with newborns to monitor for nitrates in well water.
- Most types of metals are also measured. Those of health concern and public interest, such as arsenic and hexavalent chromium, are important in monitoring because they have been associated with specific geological formations and conditions in northeastern Wisconsin.
- Ancillary inorganic tests are routinely performed to measure chloride, sulfate, pH, alkalinity, and conductivity—properties that are important in controlling the chemical conditions for groundwater systems.
- As with other sections of the WSLH, the Inorganic Section responds to both spills that would affect surface water and groundwater. The lab has worked extensively with both DNR and DHS to identify contaminates in well water that may have had surficial origins. The WSLH recently has added multi-collector ICPMS instrumentation that can be used to measure isotopic fingerprints of metals to source-track their origin.
- The inorganic section has a dedicated trace-level clean lab that routinely measures metals or elements in water at the parts per trillion (ppt) ranges for unique applied low-level research questions and monitoring.
- The WSLH works with and receives samples from the U.S. Geological Survey, researchers at UW campuses, and the Wisconsin Geological and Natural History Survey on specialized groundwater projects. The lab also routinely measures samples from drinking water utilities that rely on groundwater.

For more information on the WSLH:

Visit the website *http://www.slh.wisc.edu/*

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DEPARTMENT OF SAFETY AND PROFESSIONAL SERVICES

Within the Division of Industry Services, two programs have the responsibility of safeguarding public health and the waters of the State. The General Plumbing Program regulates plumbing installations including graywater reuse, stormwater plumbing systems, cross-connection controls and household water treatment devices. Private on-site wastewater treatment systems that receive domestic wastewater and discharge to the subsurface are regulated by the Private On-site Wastewater Treatment Systems (POWTS) Program.

FY 2022 Highlights

- Counties are operating a maintenance program for all POWTS in their jurisdiction.
- The Department continued offering training programs for the POWTS industry. This included monthly DSPS POWTS program updates provided virtually, technical training, and inspector training targeting new county inspection staff.
- The Department hired 2 project plan review positions authorized under WI Act 67. The positions are approved through June 2023.
- As allowed by law, the last Wisconsin Fund Grant application period was provided in January 2022. Unless the law is changed, this grant program will not be funded again.
- DSPS Announced Funding for UW-Stevens Point Study by Soil and Waste Resources Scientist to Update Septage Disposal Standards.

Details of Ongoing Activities

Plumbing – Reuse, Stormwater and Private Onsite Wastewater Treatment Systems (POWTS)

In addition to public health and safety, the water supply and quality issues facing Wisconsin are a focus of the General Plumbing and POWTS programs in the Department of Safety and Professional Services.

General Plumbing – Reuse and Stormwater Use

The Department plumbing code includes standards for reuse of wastewater and stormwater. Currently, the Chapter SPS 382 stormwater rules create the ability for plumbing to be integrally involved with the design and installation of storm systems complying with Chapter NR 151, Wis. Admin. Code. At this time, there are over 315 approved stormwater use or wastewater reuse plumbing systems in Wisconsin.

Private Onsite Wastewater Treatment Systems (POWTS)

The Department maintains regular contact with the Department of Natural Resources regarding mutual issues of interest such as large onsite sewage systems, mixed wastewater treatment systems, Underground Injection Control (UIC) regulations, septage disposal and water well regulations. The Department also communicates with the US EPA Region 5 office regarding POWTS related matters. Department staff participate when requested in the development of a regional and national model code related to on-site sewage systems.

Data Management

DSPS is continuing its data integration information technology (IT) initiative called eSLA which stands for the Electronic Safety and Licensing Application. The POWTS program was involved with Phase 1 of the initiative which was rolled out in fall of 2018. The General Plumbing program was part of Phase 2 rolled out in June of 2019. The database also stores information on activities associated with on-site sewage system design, installation and maintenance. The Department is working with county code administrators and POWTS industry members to upgrade the reporting and recording of inspection, maintenance and servicing events for onsite sewage systems. The department promulgated a rule revision in late 2008 that implements POWTS program related provisions contained in 2005 Wisconsin Act 347 and further modified in 2011 by Wisconsin Act 134. The revised rule required that counties conduct an inventory by October 1, 2017, to identify all POWTS within their jurisdictional areas. With inventories maintained, Counties are required to further maintain a reporting program related to inspection, maintenance and servicing events for all POWTS in their jurisdiction. Additional software upgrades include a new credentialing software programming incorporating artificial intelligence which will aid in processing applications. This program is called "LicenseE".

For further information:
Visit the following web site: https://dsps.wi.gov/pages/Home.aspx
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REPORT OF THE GOVERNOR'S REPRESENTATIVE

Steve Diercks, Coloma, WI

As a potato and vegetable grower member of the Wisconsin Potato & Vegetable Growers Association (WPVGA) and the Governor's Representative on the Wisconsin Groundwater Coordinating Council, I am pleased to report that the WPVGA continues to collaborate with multiple stakeholders to achieve sustainable groundwater quantity and quality.

Wisconsin's Central Sands region remains one of the most productive irrigated vegetable areas in the United States with top three rankings for potatoes, sweet corn, green beans, peas, carrots, beets for canning and cabbage for kraut. This production, which is valued at nearly $6 billion annually would not be possible without irrigation. At the same time, concerns have been raised over the potential impact of irrigated agriculture on the groundwater aquifer and surface waters of the Central Sands. In response, the WPVGA continues to bring together the people, organizations and expertise to foster the sustainable use of water resources. It is an example of collaboration involving GCC member agencies and the agriculture industry.

Voluntary conservation practices, groundwater monitoring, state-of-the-art technology and applied research are the focal points of the WPVGA's efforts. The Association continues to engage in activities that consolidate and build on the existing knowledge-base related to the hydrogeology of the Central Sands. Among these activities are the following:

- The WPVGA funds several applied research projects led by Dr. Yi Wang, UW Professor of Horticulture, and Dr. Matt Ruark, UW Professor of Soil Science, looking at nitrate concentrations in irrigation water as well as evaluating the performance of multiple potato varieties in low nitrogen environments. The research results will provide important information for growers to help them develop improved nutrient management programs that account for nitrogen being applied in the irrigation water, along with new varieties that use less nitrogen. This research also includes the study of slow release nitrogen products with a goal of reducing nitrate leaching into groundwater. These studies are being conducted on-farm as well as at the UW-Hancock Agricultural Research Station.
- Ongoing collaboration on a research project with the UW Atmospheric and Oceanic Sciences Department looking at newer, more accurate and advanced methods of measuring evapotranspiration (ET), which is the term used for crop water use. This project is being led by Dr. Ankur Desai and uses the latest technology of an eddy covariance flux tower system to measure ET in an irrigated vegetable field as well as using another flux tower system to measure ET in a nearby forest. Research results are being shared with growers to assist them in their irrigation management and scheduling regimes. Four years of data show that the ET rates are higher (reflecting greater water use) in the pine forest than the irrigated vegetable field. In 2022, the towers were moved to Plover into a potato

production field owned by Worzella & Sons; along with one tower in the adjacent Boston School Forest.

- Also in 2022, the WPVGA was successful in receiving a second Producer-Led Watershed Protection Grant from the Wisconsin Dept. of Agriculture, Trade and Consumer Protection. Seven member farms are participating in the project which is located in the Little Plover River/Wisconsin River watershed. Called the Central Wisconsin Farmers Collaborative, the group seeks to promote innovative conservation and stewardship practices that benefit the watershed, the landscape, and the land managers themselves through collaborative partnerships, farm-to-farm education programs and other strategic actions. Conservation practices employed by the group include the extensive use of cover crops, prairie and pollinator plantings, and no-till/minimum till practices. There were also extensive wetlands restoration practices employed in this watershed.
- An additional Producer-Led Watershed Protection group was formed in 2022 in the Central Sands: Farmers of the Roche-A-Cri. Farmers of the Roche-A-Cri has group members representing Coloma Farms, Signature Farms, ZanBria Artisan Farms, Heartland Farms, Horizon Cranberry Farms, Nathan Bula Farms LLC, Sterling Farms and Flyte Family Farms. The WPVGA continues to encourage more member farms to participate in the Producer-Led Watershed Protection Grant program.
- Funding software maintenance to keep the Wisconsin Irrigation Scheduling Program (WISP) and the Agricultural Weather Data Service operational. The existing WISP software tracks a daily soil water balance to assist growers with irrigation water management. The Desai lab is also working with Ben Bradford from UW Entomology to fine tune the WISP ET calculations.
- Collaboration with the Village of Plover, the Wisconsin Wetlands Association, the Wisconsin Wildlife Federation, Wisconsin DNR, UW-Stevens Point, and others on the Little Plover River Watershed Enhancement Project (LPRWEP). This multi-party collaboration has improved the health and flow of the Little Plover River (LRP) and the quality of life of the surrounding community. The WPVGA recognizes that restoring the health of the river requires an array of on-the-ground practices and voluntary landowner participation, and is committed to utilizing a combination of protection, restoration and management practices that ensure the project’s success.
- Maintaining and monitoring a network of privately-owned irrigation wells in the Central Sands to measure groundwater fluctuations. The network currently consists of over 50 wells across multiple Central Wisconsin counties sampled one to three times/year. The database is maintained by GZA GeoEnvironmental, Inc., and information is available on the WPVGA website (www.wisconsinpotatoes.com).
- The WPVGA continues to collaborate with the University of Wisconsin and the DNR on a new initiative to recognize and reward water conservation. The Wisconsin Water Stewards Program establishes a baseline of water

stewardship practices and assists growers in making continuous improvements in the area of water conservation. Growers have access to a broad range of expertise to help determine the best way to manage and conserve water resources on their individual farms. This has also become a component of the WPVGA's high-bar sustainability program known as Healthy Grown.

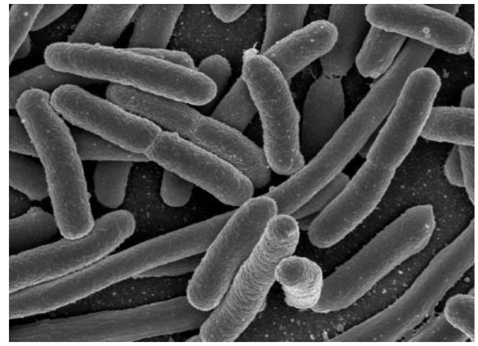
- The WPVGA is partnering with Discovery Farms Wisconsin on a producer-led project in the Antigo Flats, an area of 70,000 acres in north central Wisconsin. The project is interested in documenting Phosphorus (P) loss from runoff events, learning about stream flow, reducing P loads to the Spring Brook and Eau Claire River watersheds and evaluating the impact of in-field actions on water quality. Two edge-of-field surface monitoring sites are located in Langlade County on seed potato operations. The Nature Conservancy is also contributing grant funds toward this project (seven years at $15,000/year).
- In cooperation with the DNR, the WPVGA continues to collect and post data from over 25 monitoring wells to continuously track fluctuations in groundwater at regular intervals across three areas designated as high risk for surface water impacts (Little Plover River/Plover area, Long Lake/Plainfield area, and Pleasant Lake/Coloma area). Groundwater elevations are posted at https://wisa.cals.wisc.edu/ every three weeks. The DNR received permission from the WPVGA to conduct the data collection and posting from the monitoring wells in the Plainfield and Coloma areas as part of the Central Sands Lakes Study component of 2017 Wisconsin Act 10, related to the potential impacts of groundwater withdrawals on three lakes in the Central Sands.
- WPVGA Executive Director Tamas Houlihan participated in the search and screen committee to select a UW-Extension Commercial Vegetable Ag Water Quality Outreach Specialist to be based at UW-Stevens Point and work on potato and vegetable crops in the Central Sands. Guolong Liang was hired and officially began work on July 18. Plans are in place to have Dr. Liang work closely with the WPVGA Water Task Force as well as the WPVGA Research Committee on water quality research projects.

All of these WPVGA initiatives are working toward sustainable groundwater quantity and quality through evaluating and implementing strategies to increase the efficiency of irrigation and crop production while conserving the amount of water used and maintaining or improving water quality.

MICROBIAL PATHOGENS

What are they?

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, *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.



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

Microorganisms are prevalent and abundant in the subsurface and in groundwater (Griebler and Lueders 2009). The United States Geological Survey (USGS Michigan Water Science Center) 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 (Pan et al. 2017). 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 standards have been established in ch. NR 140 for total coliform bacteria, an indicator of possible microbial pathogen contamination. Both 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 total coliform 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. *E. coli* bacteria are a sub-group of coliform bacteria considered to be a more specific indicator of fecal contamination and the potential for pathogens to be present in drinking water. 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.

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 (Borchardt et al. 2011).

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 (Gilchrist et al. 2007). Groundwater monitoring around swine manure lagoons in Illinois found that antibiotic resistant genes, associated with leakage from the manure lagoons, were present in groundwater (Krapac et al. 2004). In a study of manure at a Wisconsin dairy farm, *E. coli* bacteria resistant to four different antibiotics were detected (Walczak et al. 2011).

Occurrence 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 (Bradford et al. 2013). 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 (per administrative codes: SPS 383, NR 206, NR 110, NR 204, NR 113, NR 214, NR 243). 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.

The Wisconsin State Laboratory of Hygiene conducted a laboratory column study in 2001, investigating the transport of microorganisms through unsaturated soil (Standridge et al. 2001). The soil used for the study was ASTM C-33 standard sand soil, used in Wisconsin for mound septic systems. This soil is a "general" textured filter media soil, that contains a minimum of both fine and coarse grained material. Both bacterial and viral pathogen indicator organisms were used in the study. Results showed that, under "normal" loading rates, all 5 of the pathogen indicators used for the study were removed or attenuated with infiltration through 2 feet of unsaturated soil.

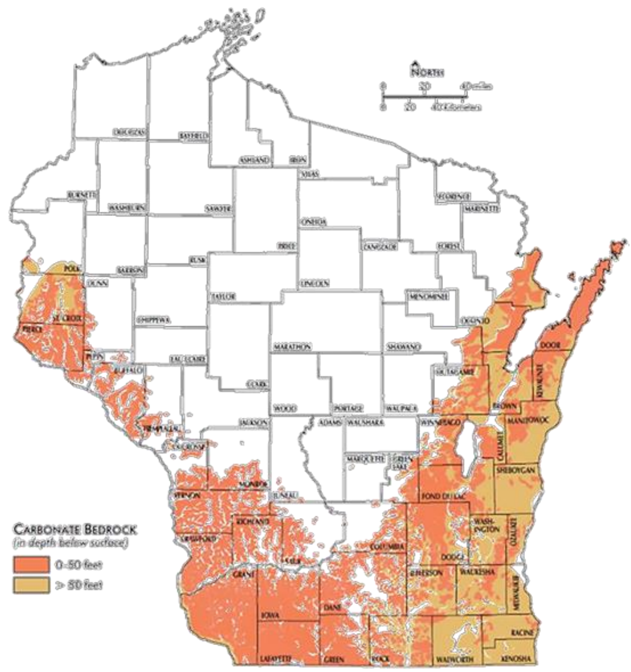
Most bacteria entering the ground surface along with rainwater or snowmelt are filtered out or attenuated as water seeps downward through the unsaturated soil zone to groundwater, however, some strains of bacteria can survive a long time and may find their way into the groundwater by moving through coarse 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.

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 (Knobeloch et al. 2013; US GAO 1997).

A study that sampled private water supply wells in Kewaunee County (Kewaunee Co. 2014) 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. Waste source and pathogen genetic markers were detected, using polymerase chain reaction (PCR) molecular methods, in some of the study wells that were tested for those markers.

A recent study in Wisconsin, designated the Southwest Wisconsin Groundwater and Geology (SWIGG) study, looked at the presence of total coliform bacteria and waste source and pathogen genetic markers in private water supply wells in Grant, Iowa and Lafayette Counties (Stokdyk et al. 2022). 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.



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

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 (Uejio et al. 2014). 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. More than 60 private wells in Wisconsin have had to be replaced, since 2006, due to manure contamination, at a cost to the state of over $500,000 (Source: DNR Well Compensation Fund records).

A recent, 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 (Borchardt et al. 2003b).

Viruses may be detected in water samples using cell culture methods that measure the cytopathic effect of viruses grown on various cell culture media. Not all types of viruses are culturable, but molecular nucleic acid based methods, such as PCR, can be used to detect viral genetic material, even from nonculturable viruses. Molecular nucleic acid based methods such as PCR, however, cannot distinguish between genetic material from viable, infectious viruses and genetic material from dead, inactivated or nonviable viruses (Donia et al. 2009).

Research studies, utilizing PCR methods, have detected human enteric virus genomic material in both public and private wells in Wisconsin (Borchardt et al., 2003a, 2004, and 2007). There is limited statewide groundwater virus occurrence data since testing for viral genomic material 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, it has been suggested that transport of viruses from municipal sewer systems to groundwater supplies may be occurring and that this transport might be very rapid (Hunt et al. 2010; Bradbury et al. 2013). These studies suggest that viral contamination of groundwater could potentially occur at other municipal water systems as municipal wells are generally completed in areas with sanitary sewer systems.

There is evidence that disinfection with chlorine or ultraviolet light may 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. Disinfection, however, 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 supply systems.

GCC Agency Actions

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). Analysis can successfully detect bovine adenoviruses an indicator of 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. 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. The DNR, in conjunction with DATCP, are working on revised performance standards and prohibitions related to manure land application in areas of the state with carbonate bedrock and shallow soils.

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.

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 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.

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*

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.

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. A study funded by the Wisconsin Groundwater Research and Monitoring Program investigated 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 needed on the transport and survival times of various viruses in groundwater aquifers.

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*

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

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

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NITRATE

What is it?

Nitrate (NO_3) is a water-soluble molecule that forms when ammonia or other nitrogen rich sources combine with oxygen. The concentration of nitrate in water is often reported as "nitrate-N" which reflects only the mass of nitrogen in the nitrate (ignores the mass of oxygen). Nitrate levels in groundwater are generally below 2 parts per million (as nitrate-N) where pollution sources are absent. Higher levels indicate an anthropogenic source of contamination such as agricultural or turf fertilizers, animal waste, septic systems or wastewater.


Flooded field after manure spreading. Nutrient application on agricultural fields accounts for 90% of nitrate in groundwater. Photo: Marty Nessman, DNR.

What are the human health concerns?

The health-based groundwater quality enforcement standard (ES) for nitrate-N in groundwater and the maximum contaminant level (MCL) for nitrate-N in public drinking water are both 10 ppm (WI NR 140.10, WI NR 809.11). Everyone should avoid long-term consumption of water containing nitrate above this level.

Infants below the age of 6 months who drink water containing nitrate in excess of the MCL are especially at risk, and could become seriously ill with a condition called methemoglobenemia or "blue-baby syndrome". This condition deprives the infant of oxygen and in extreme cases can cause death. The DHS has associated at least three cases of suspected blue-baby syndrome in Wisconsin with nitrate contaminated drinking water (Knobeloch et al., 2000). In children, there is also growing evidence of a correlation between nitrate and diabetes (Moltchanova et al., 2004; Parslow et al., 2007).

Birth defects have also been linked to nitrate exposure. Several epidemiological studies over the past decade have examined statistical links between nitrate exposure and neural tube birth defects (e.g., Brender et al., 2013). Some, but not all, of these studies have concluded there is a statistical correlation between maternal ingestion of nitrates in drinking water and birth defects. Further work, including a clear animal model, would be needed to conclusively demonstrate causation. Nonetheless, these studies collectively indicate an ongoing need for caution in addressing consumption of nitrate by pregnant women and support the continuation of private well testing programs for these women.

In the human body, nitrate can convert to nitrite (NO_2) and then to N-nitroso compounds (NOC's), which are some of the strongest known carcinogens. As a result, additional human health concerns related to nitrate contaminated drinking water include increased risk of non-Hodgkin's lymphoma (Ward et al., 1996), gastric cancer (Xu et al., 1992; Yang et al., 1998), and bladder and ovarian cancer in older women (Weyer et al., 2001).

The Wisconsin Department of Health Services (DHS) also highlights thyroid disease and colon cancer as additional health concerns and states, "When nitrate levels are high, everyone should avoid long-term use of the water for drinking and preparing foods that use a lot of water."

Biotic effects

Adverse environmental effects are also well documented. Loss of biodiversity in terrestrial and aquatic systems has been documented with increasing nitrate. (Vitousek, P. M., et al. 1997) A number of studies have shown that nitrate can cause serious health issues and can lead to death in fishes, amphibians and aquatic invertebrates (Camargo et al., 1995; Marco et al., 1999; Crunkilton et al., 2000; Camargo et al., 2005; Smith et al., 2005; McGurk et al., 2006; Stelzer et al., 2010). This is significant because many baseflow-dominated streams (springs, groundwater-fed low-order streams) in agricultural watersheds in Wisconsin can exhibit elevated nitrate concentrations, at times exceeding 30 ppm. Groundwater and drain tile transported nitrate, along with urea and ammonium play a role in driving harmful algal bloom biomass trends and potential toxicity (Davis et al. 2015; Harke et al. 2016).

How widespread is elevated nitrate in groundwater?

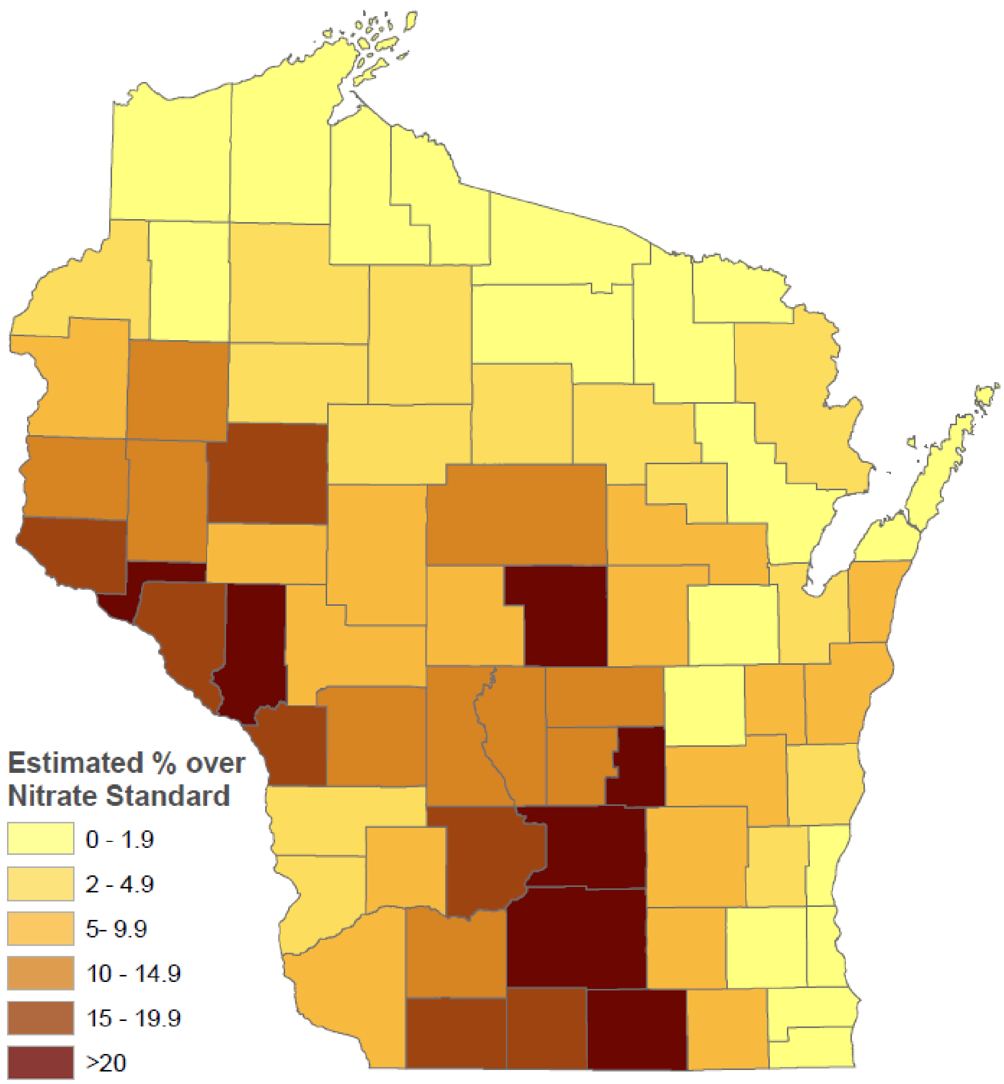
Nitrate is Wisconsin's most widespread groundwater contaminant. Nitrate contamination of groundwater is increasing in extent and severity in the state (Kraft, 2003; Kraft, 2004; Kraft et al., 2008; Saad, 2008). A 2012 survey of Wisconsin municipal water-supply systems found that 47 systems have had raw water samples that exceeded the nitrate-N MCL, up from just 14 systems in 1999.

Nitrate is Wisconsin's most widespread contaminant, yet 33% of private well owners have never had their water tested for it. Photo: DNR

Increasing nitrate levels have been observed in an additional 74 municipal systems. Private water wells, which serve about one third of Wisconsin families, are at risk as well. Statewide, about 10% of private well samples exceed the MCL for nitrate-N, although one third of private well owners have never had their water tested for nitrate (Knobeloch et al., 2013; Schultz and Malecki, 2015). In agricultural areas, such as the highly cultivated regions in south-central Wisconsin, around 20%-30% of private well samples exceed the MCL (Mechenich, 2015). Nitrate concentrations are poised to further increase as nitrate pollution penetrates into deep aquifers and migrates farther from original source areas (Kraft et al., 2008).

In 2014 NR 812 code (Well Construction and Pump Installation) was changed to require sampling of both newly constructed wells and existing wells that had pump work done, for nitrate. This was in response to the DHS revised health recommendation that long-term use of water over the standard by anyone poses a significant health risk.

In 2021 for new well and pump work there were 17,963 samples taken. 1,634 were greater than 10 ppm (9.1%) up from 6.3% last year. The pump work and new well data set has 195,344 samples. This is probably the least biased large data set available in Wisconsin. Overall 9.6% of sample results were greater than 10 ppm for nitrate. 30.4% are above the PAL of 2 ppm. However, some counties have a much greater percentage of well testing above the 10 ppm standard. See map below for individual county results.



Map of Estimated Percentage of Private Wells over Nitrate Standard by County (October 2014 through April 2022).

To obtain a safe water supply, private well owners may opt to replace an existing well with a deeper, better cased well or, if available, connect to a nearby public water supply. Owners of nitrate-contaminated private wells can qualify for the state well compensation grant program only if the nitrate-N level in their well exceeds 40 ppm and the water is also used to water livestock.

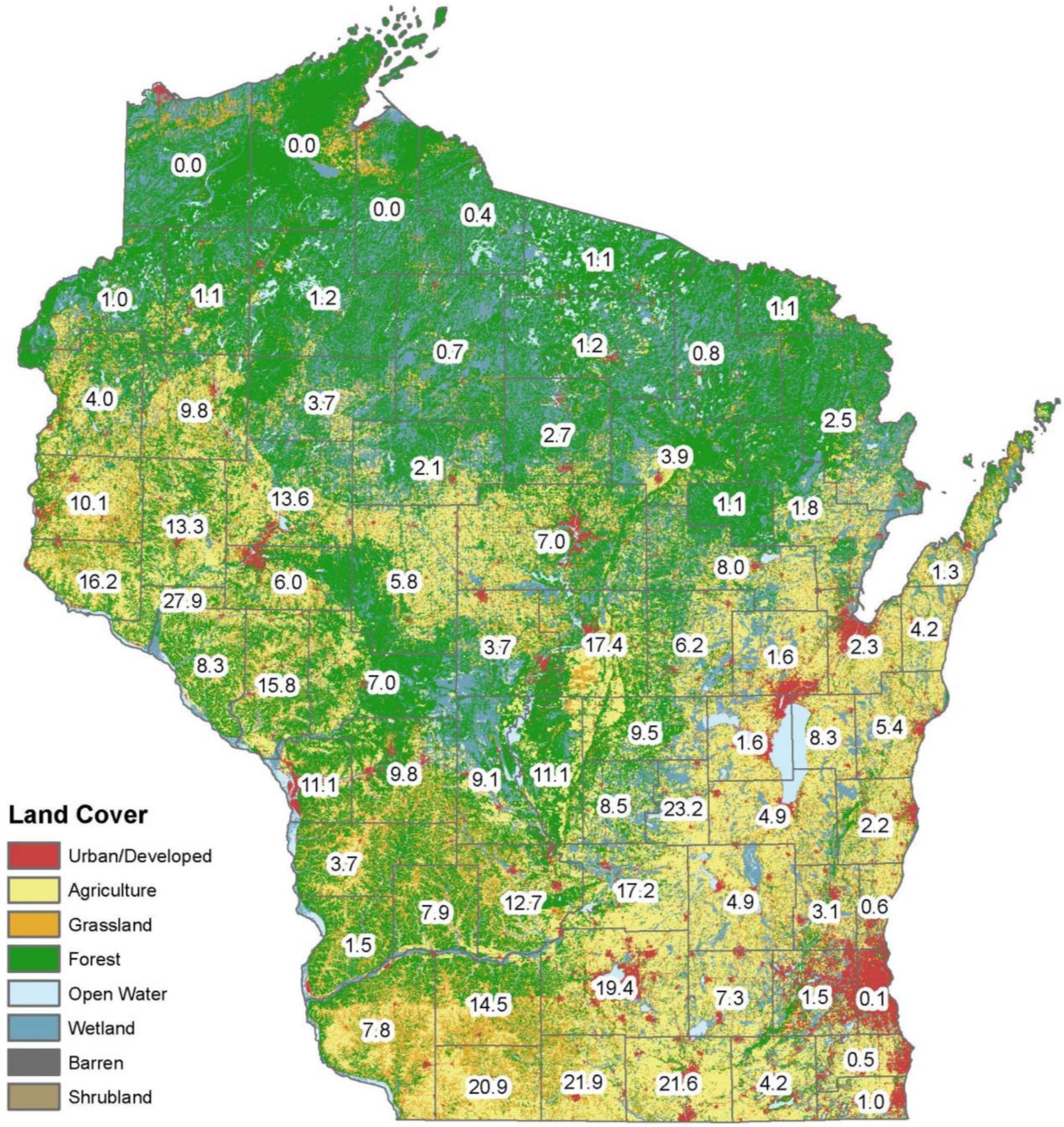
Alternatively, well owners may choose to install a water treatment system or use bottled water. In a survey of 1,500 families in 1999, the DHS found that few took any action to reduce nitrate exposure (Schubert et al., 1999). Of the families who took actions, most purchased bottled water for use by an infant or pregnant woman.

More recently, it appears that some private well owners in rural Wisconsin are installing reverse osmosis filter systems at considerable cost to obtain safe drinking water (Schultz and Malecki, 2015).

What makes an area vulnerable to nitrate contamination?

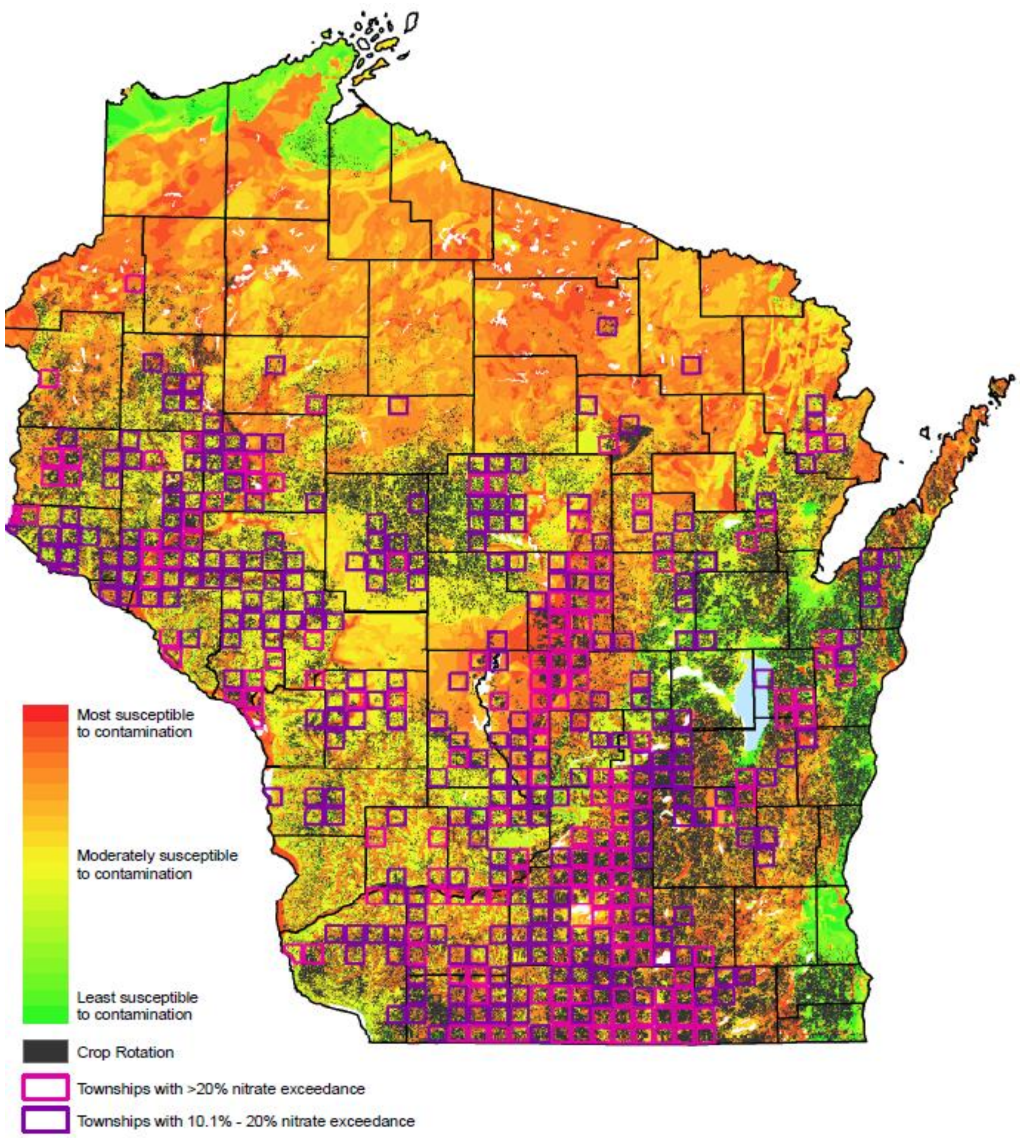
The sensitivity of an aquifer to contamination, sometimes called "intrinsic susceptibility", is a measure of the ease with which water enters and moves through an aquifer; it is a characteristic of the aquifer and overlying material and hydrologic conditions. The vulnerability of a groundwater resource to contamination depends on aquifer sensitivity in combination with a source of naturally occurring or anthropogenic contamination. Since the early 1990s, it has been well-accepted that around 90% of nitrogen inputs to groundwater in Wisconsin can be traced to agricultural sources including manure spreading and fertilizer application (Shaw, 1990). In a recently updated report, "Agricultural Chemicals in Wisconsin Groundwater, April 2017", the Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) and the Wisconsin Field Office of the National Agricultural Statistics Service (NASS) surveyed private wells and placed them into categories based on how intensively the surrounding land was cultivated for agricultural production. The survey found that overall, 8.2% of private wells in Wisconsin exceeded 10 mg/L for nitrate. However, marked differences in the percentage of wells over 10 mg/L were noted when grouping the data by surrounding agricultural intensity; the percentage increased from 1.7% when surrounding land was lightly cultivated to 20% of wells exceeding the health based standard when the surrounding land was greater than 75% cultivated (DATCP,2017).

Looking at a statewide scale, a simple plot of broad land use categories with the estimated percentage of private wells exceeding the health-based standard by individual counties also illustrates that more wells are impacted in agriculturally intensive areas of the state.



Map of Estimated Percentage of Private Wells over Nitrate Standard by County with Land Cover (October 2014 through April 2021).

The dominant effect of land use in comparison to aquifer sensitivity is also illustrated when overlaying township level private well nitrate data and agricultural land use with the Groundwater Contamination Susceptibility Model (GCSM). The GCSM for Wisconsin was developed by WGNHS, the DNR, and the USGS and is intended to be used at broad scales. Five physical resource characteristics for which information was available were identified as important in determining how easily a contaminant can be carried through overlying materials to the groundwater. These factors are type of bedrock, depth to bedrock, depth to water table, soil characteristics, and characteristics of surficial deposits (geologic materials lying between the soil and the top of the bedrock). Areas with sand and gravel are considered more sensitive to groundwater contamination; areas with silt and clay are considered less susceptible. When viewed at a statewide scale, many parts of the state with only moderate aquifer sensitivity have townships where greater than 10% and frequently greater than 20% of private wells exceed the health-based standard for nitrate in drinking water.



Sensitivity of Wisconsin's groundwater versus agricultural land use and nitrate impacts to private wells.

How is groundwater nitrate trending over time?

By analyzing a variety of data sources, evidence indicates that nitrate contamination of our groundwater resources has increased in more locations over time rather than decreased.

An assessment of overall statewide nitrate trends using existing private and public well data is challenging for several reasons. Fundamentally, public water data sampling is focused on the goal of providing water at the tap meeting required maximum contaminant levels (MCLs) and not to track changes in the groundwater resource over time. Private well sampling is conducted by a very low percentage of well owners in any given year and for those who do, their goal is getting information about the current condition of their water supply, not determining long-term changes in water quality of the resource itself. This leads to a large confidence interval in estimates of private wells above the nitrate standard and makes trends difficult to discern. What is needed is systematic repeated sampling of the same set of wells through time and this is rarely conducted in private wells. While public wells are required to regularly test and report results from a relatively stable set of wells, once they exceed the nitrate MCL the system is required by law to take action to come back into compliance with the MCL. The preferred action is to replace the well, thereby removing wells with increasing trends and biasing the public water data set towards wells without increasing nitrate concentrations. In addition, both new private and public wells tend to be sited, drilled and cased to avoid known water quality issues such as nitrate contaminated groundwater. The result of these factors is that both private and public wells are not consistently sampling the “same” water or depths over time and are biased toward utilizing groundwater without contamination, making an analysis of the groundwater resource, comparisons over time and trend analysis difficult using these existing data sets.

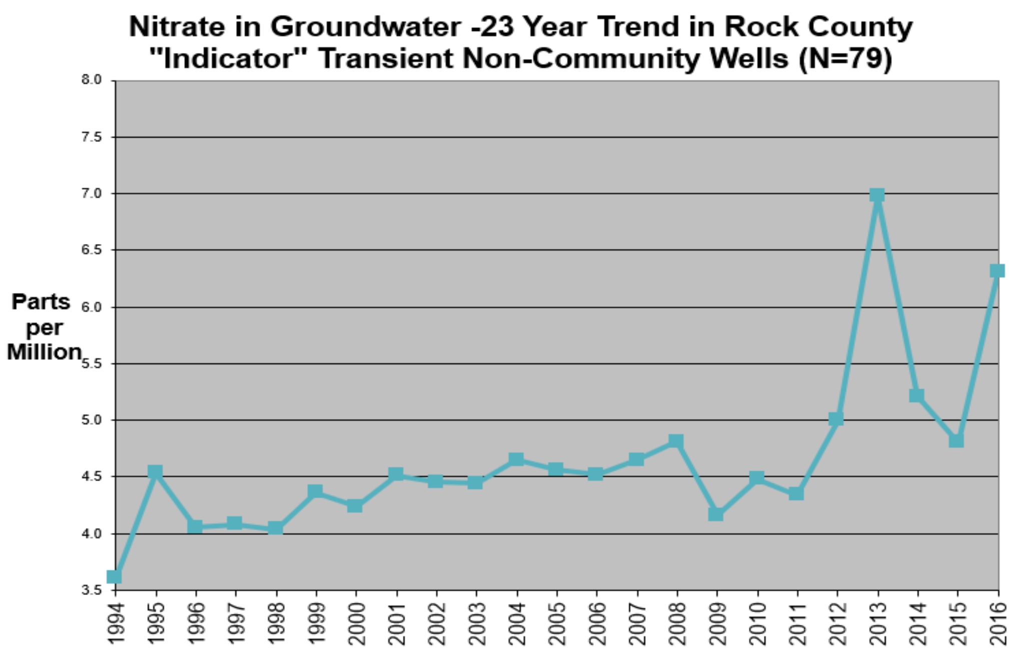
One available data set with a large number of wells distributed across the state is the Safe Drinking Water Act compliance data set for non-community public wells (e.g. small businesses, schools, and churches). There are approximately 11,0000 wells of this type active at any given time, and they are required to submit nitrate sample results to the DNR at least annually. In review of the historical record of public supply well data since 1975, we find a relatively consistent number of wells exceed the 5 mg/L and 10 mg/L nitrate thresholds in any decade (i.e. about 18.3% of non-community water systems exceed 5 mg/L and about 6.5% exceed 10 mg/L).

However, when looking at these public wells for the full period of record, there is a much larger set of wells represented (>20,000 wells) and the total number of wells exceeding these thresholds at any point in time is greater than in any discrete decade. Over the full record of the DNR Public Water System database, approximately 21% of these wells exceeded 5 mg/L and approximately 8.3% exceeded 10 mg/L. Many of the nitrate impacted wells have dropped out of the data set over time. This is to be expected, as these are wells providing drinking water and subject to regulation to meet drinking water standards. The table below lists MCL violations for nitrate in recent years by public well type – Municipal Community (MC), Other than Municipal Community (OC), Non-Transient, Non-community (NN) and Transient, Non-community (TN).

Year	MC	OC	NN	TN
2015	3	6	12	18
2016	0	2	3	8
2017	3	4	15	27
2018	2	4	12	17
2019	3	2	8	22
2020	3	5	6	19

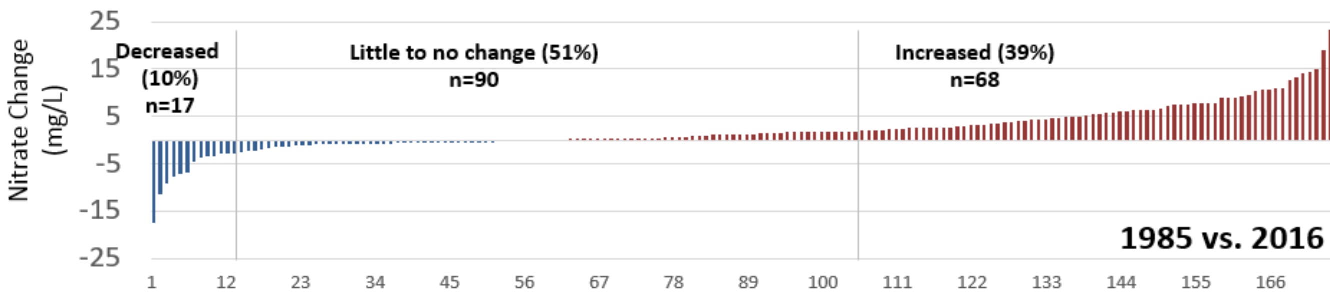
The numbers for TN systems do not include the wells on continuing operation between 10 ppm and 20 ppm.

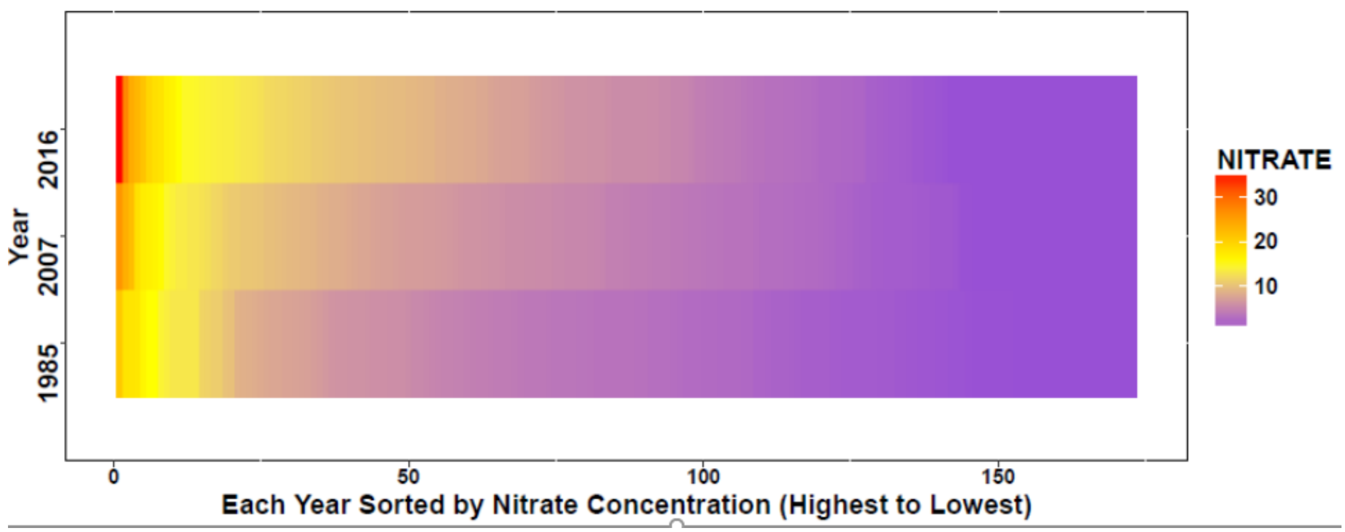
Upward nitrate trends over time are frequently observed when reviewing regional or local trends in well water quality, particularly where wells are vulnerable to nitrate contamination. For example, the Rock County Health department has been sampling and maintaining a data set based on a consistent set of transient non-community public wells over approximately 25 years. In aggregate, this consistent group of 79 wells has shown an increasing nitrate average concentration trend since 1994, with a marked increase in the last decade (see figure below).



Source: Rock County Department of Public Health

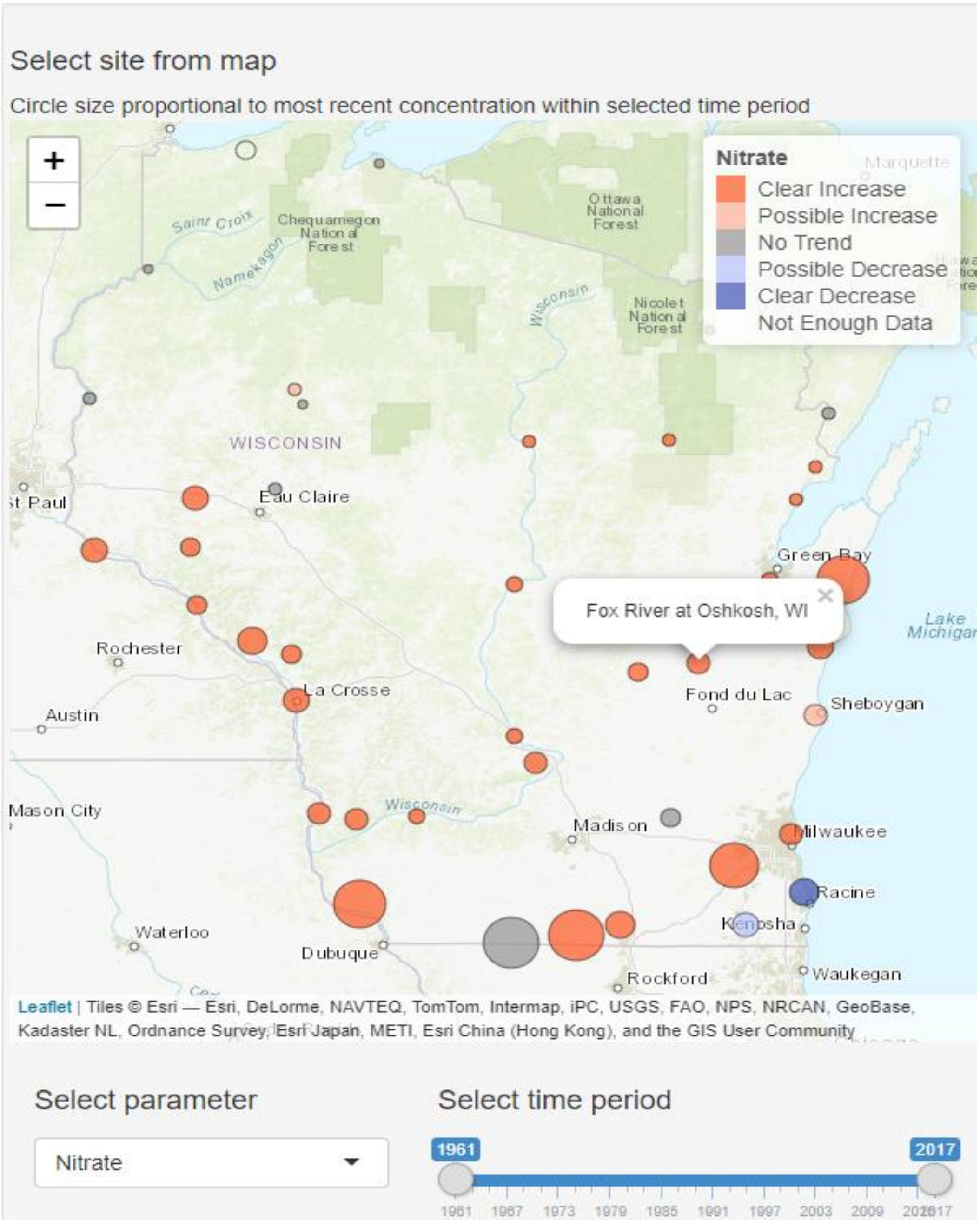
Chippewa County provides another example where a consistent set of private wells (175) were sampled multiple times over thirty years. This data set shows the importance of location: most wells saw little or no change over the 30 years (51%) and some wells showed a decrease (10%), while 39% showed an increase in nitrate concentrations (see figure below).



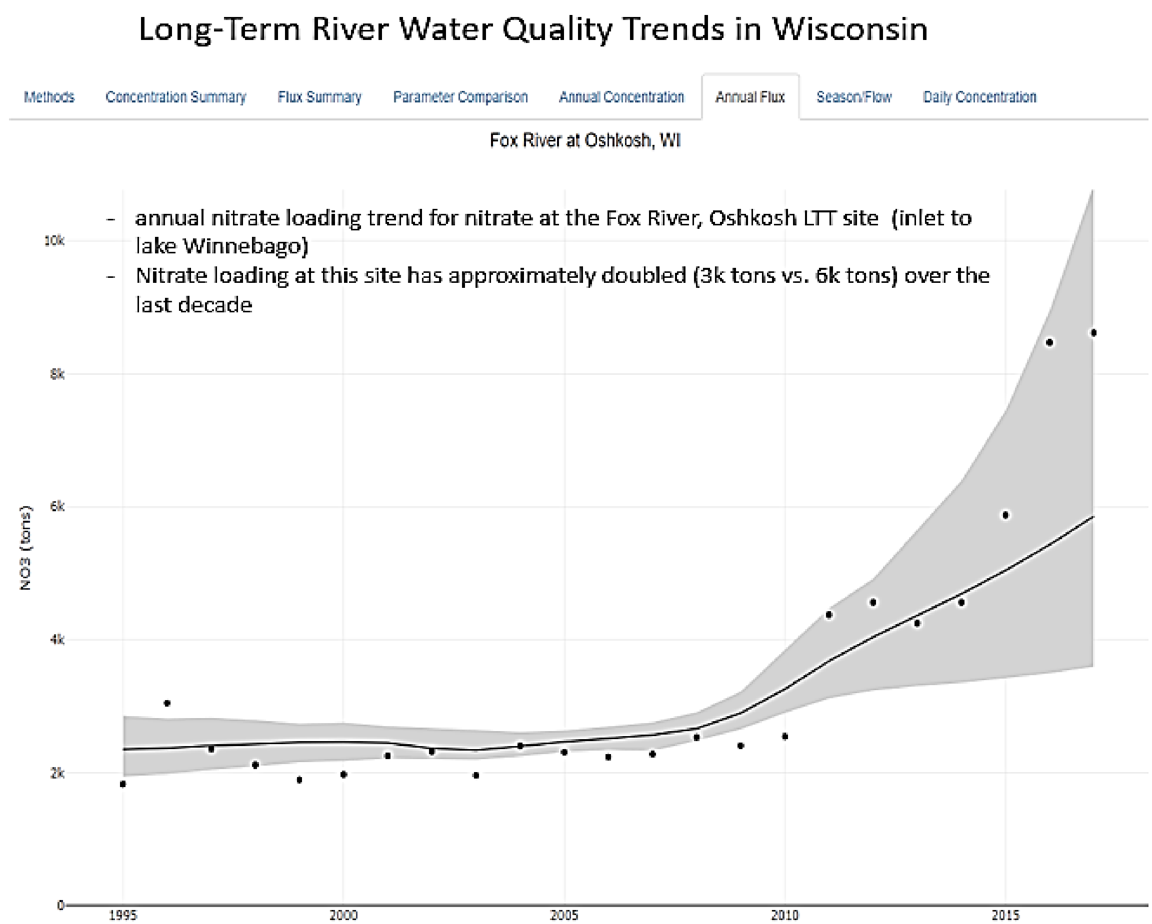


Source: Masarik et al., 2016 In preparation.

Another useful method to assess long term groundwater nitrate trends throughout the state is to evaluate data from groundwater baseflow dominated streams. A large portion of the state is covered by “groundwater dominated” watersheds (i.e. the ratio of groundwater baseflow to total streamflow is greater than 50%). Long term trend monitoring sites maintained by DNR and USGS in these watersheds can provide information about the aggregate water quality yielded by these watersheds over time for groundwater transported contaminants such as nitrate. Wisconsin has some large basins where the baseflow contribution at the monitoring station is estimated as high as 90% (USGS - Gerbert et al., 2011). Data from DNR’s Long Term Trend Network shows increases in nitrate concentration for most locations monitored throughout the state.



DNR Long Term Trend (LTT) Data Viewer: https://wisconsindnr.shinyapps.io/riverwq/



Estimated costs in Wisconsin to mitigate Nitrate

In 2019, the data from new wells and pump work from 2014 through 2018 was used in an analysis to develop a cost estimate for private wells to address nitrate over the health 10 ppm standard. The estimate is based on private well owners currently over the nitrate standard choosing the preferred safe at the source method of drilling to a depth where water below the standard can be obtained.

The process involved estimating the number of private wells in each county and multiplying that by the percentage of wells over 10 ppm for each county. A cost for individual well replacement was developed using the Groundwater Retrieval Network (GRN) nitrate data to determine the depth of penetration of nitrate into the aquifer. This depth was used as the estimated depth to construct a well reaching water safe at the source.

The estimated number of private wells exceeding the health standard for nitrate in Wisconsin is over 42,000, with a total cost estimate of abandoning the contaminated well and replacing with a new safe water supply exceeding 440 million dollars. Results by county are shown in the table below.

An estimate of the cost to well owners who have already replaced their well due to elevated nitrate was calculated by reviewing well construction reports submitted to the department where nitrate was listed as the reason for the new well. This likely underestimates the number of wells replaced for nitrate, because no reason was listed on the report. Using the same methodology, it is estimated that private well owners have spent more than 9 million dollars to replace wells with elevated nitrate levels to date.

County	Estimated # of private wells	Estimated % of wells over 10 ppm Nitrate Standard	Estimated # of private wells over Nitrate Standard	Estimated Replacement Cost (millions)
Adams	9959	12.4%	1232	$10.82
Ashland	2290	0.0%	0	$0.00
Barron	9336	9.3%	872	$8.69
Bayfield	5679	0.0%	0	$0.00
Brown	14077	2.9%	414	$4.93
Buffalo	3158	7.1%	224	$1.67
Burnett	6689	1.2%	82	$0.41
Calumet	3932	10.5%	413	$5.25
Chippewa	13242	13.5%	1788	$15.99
Clark	6581	5.4%	357	$1.80
Columbia	8762	17.9%	1564	$19.22
Crawford	2485	0.9%	24	$0.28
Dane	23506	18.3%	4313	$65.61
Dodge	11112	5.0%	553	$7.44
Door	11797	1.3%	153	$2.04
Douglas	5165	0.0%	0	$0.00
Dunn	7501	12.1%	906	$6.65
Eau Claire	9153	5.3%	483	$3.89
Florence	2423	1.6%	39	$0.18
Fond du Lac	12190	5.3%	649	$8.41
Forest	4073	1.3%	54	$0.19
Grant	5895	6.6%	389	$6.05
Green	5474	20.2%	1106	$15.22
Green Lake	4957	19.5%	968	$14.60
Iowa	3511	12.5%	438	$7.13
Iron	749	0.7%	6	$0.02
Jackson	4688	6.7%	312	$1.63
Jefferson	9491	8.3%	792	$8.16
Juneau	5166	11.6%	600	$3.85
Kenosha	15570	0.8%	132	$1.21
Kewaunee	3741	3.3%	122	$0.90
La Crosse	7216	13.4%	965	$8.99
Lafayette	2628	15.3%	402	$5.74
Langlade	6387	4.7%	298	$2.41
Lincoln	7396	3.7%	277	$1.55

County	Estimated # of private wells	Estimated % of wells over 10 ppm Nitrate Standard	Estimated # of private wells over Nitrate Standard	Estimated Replacement Cost (millions)
Manitowoc	8693	6.2%	539	$6.87
Marathon	22195	7.1%	1578	$11.36
Marinette	10295	2.3%	239	$1.41
Marquette	5951	9.4%	559	$5.90
Menominee	1287	0.0%	0	$0.00
Milwaukee	23534	0.3%	80	$0.48
Monroe	6561	10.1%	662	$4.63
Oconto	13336	2.4%	321	$2.54
Oneida	15788	1.7%	274	$1.31
Outagamie	13997	0.8%	117	$1.91
Ozaukee	11940	0.7%	80	$0.69
Pepin	1593	20.1%	320	$2.48
Pierce	4678	14.7%	689	$9.98
Polk	8907	4.7%	422	$3.75
Portage	8658	17.7%	1536	$13.13
Price	4868	1.9%	94	$0.38
Racine	16892	0.6%	99	$0.84
Richland	3262	8.8%	286	$2.47
Rock	12275	24.4%	2999	$32.45
Rusk	4857	3.6%	175	$1.00
Saint Croix	13362	12.2%	1624	$15.97
Sauk	7775	13.4%	1042	$9.33
Sawyer	9796	1.0%	99	$0.48
Shawano	7604	8.0%	606	$5.14
Sheboygan	11561	3.0%	344	$3.03
Taylor	5255	2.7%	144	$0.91
Trempealeau	5044	18.2%	917	$10.05
Vernon	4350	3.3%	142	$2.11
Vilas	12718	1.6%	201	$0.95
Walworth	17916	4.0%	715	$6.31
Washburn	6395	0.8%	53	$0.34
Washington	19541	3.8%	735	$10.52
Waukesha	57361	1.8%	1041	$14.38
Waupaca	10389	7.1%	736	$6.15
Waushara	9254	10.4%	964	$9.08
Winnebago	14271	1.9%	266	$4.27
Wood	8099	4.9%	394	$2.75
Totals	**676,237**		**42,019**	**$446M**

Because nitrate is both an acute and chronic health issue, community Public Water Systems cannot serve water over the Enforcement Standard (ES), and therefore must either replace the well or install approved treatment if they exceed the ES. In 2019, the city of Colby in Marathon County spent $769,000 to install a nitrate mitigation system. In 2018, the village of Junction City in Portage County replaced a public water supply well due to high nitrate concentrations at a cost of $1,128,000. That same year, the village of Fall Creek spent $1,074,000 to replace a well due to high nitrate. While complete information on the costs have not been confirmed, the current estimate is over 40 million dollars have been spent by municipal public systems to deal with nitrate. Theses cost estimates do not include increased sampling or investigative cost, nor operational costs to maintain treatment systems.

The Safe Drinking Water Act allows transient non-community (TN) systems to continue to operate with nitrate above the health standard of 10 mg/L but below 20 mg/L if nitrate level is posted. TN systems include motels, restaurants, taverns, campgrounds, parks and gas stations. Currently in Wisconsin there are nearly 300 TN systems in operation in this situation. Using the same process for developing costs as for the private well replacement, the total cost for TN well mitigation of the currently existing system over 10 ppm is 3.2 million dollars. Each year about 20 new TN systems go over the nitrate standard.

Over the past 10 years 61 Non-transient Non-community systems (such as wells serving schools, day care centers and factories) have gone over the standard. Using a similar cost estimate method as above, the cost to those systems is estimated at 747,000 dollars.

What is being done by GCC Agencies to address nitrate?

Nitrate has always been a core concern for GCC agencies. Over 40 projects or 10% of the total portfolio funded by the Wisconsin Groundwater Research and Monitoring Program (WGRMP), have investigated the occurrence, transport, removal or management of nitrogen in Wisconsin. In addition, multiple sampling programs have been carried out by the DNR, DATCP and the WGNHS to characterize the extent of contamination.

Exploring best nitrogen management practices on agricultural fields is a key research priority for the GCC. Photo: DNR

In addition to regular well sampling surveys performed by DATCP, DATCP supports the development of nutrient management plans (NMPs). These plans specify the amount and timing of nutrient sources applied to a field to optimize economic input. Approximately 31% of the agricultural land in Wisconsin is covered by an approved management plan (DATCP, 2015). All farms that apply nutrients to fields, including pastures, are required to have a nutrient management plan. DATCP provides financial assistance, free resources and training for farmers to encourage total coverage across the state.

DATCP estimated that in 2007, over 200 million pounds of nitrogen were applied to agricultural lands in excess of UW recommendations, a number that could be substantially reduced with broader adoption of NMPs. However, NMPs do not presently contain mechanisms specifically designed to assess potential nitrate loading to groundwater.

Numerous studies indicate that NMPs are not always effective at reducing nitrate levels to below the MCL. Even in the best managed agricultural systems, over the long-term (7 years) nearly 20% of nitrogen fertilizer bypasses plants and is leached to groundwater, which makes it likely that groundwater concentrations of nitrate-N at or above the MCL will continue to be a concern for Wisconsin residents (Brye et al., 2001; Masarik, 2003; Norman, 2003). That said, there is still significant potential for improvement through increased adoption of NMPs.

The Nitrate Initiative was started by the DNR Drinking Water and Groundwater Program in 2012 to develop partnerships and collaborate with the full spectrum of drinking water stakeholders, including the agricultural community, to evaluate strategies to reduce nitrate loading to groundwater from agricultural activities and enable protection of drinking water sources while maintaining farm profitability. Pilot projects were initiated in communities where municipal water systems were approaching unsafe levels of nitrate contamination. Common themes and challenges (both technical and social) emerged when looking at potential for land use changes in the vicinity of wells. Because nitrate is an acute contaminant, regulators, water suppliers and consumers need assurances that any mitigation efforts will be robust and reliable enough to assure a safe concentration of nitrate at the tap. When water resource managers engage with landowners and agricultural producers regarding practices in a source water protection area, these stakeholders need to know which conservation practices could achieve the desired water quality results, how intensively those practices need to be applied in a given setting and time period, and how much those practices will cost. Developing answers to these questions in the context of nutrient management leads to the realization that data on the efficacy of practices for protecting groundwater is either lacking or involves significant degrees of variability in the expected results. Tools do not presently exist at the Nutrient Management Planning level to allow for the effective formulation of NMPs and conservation practice regimes that will be protective of drinking water wells located downgradient of agricultural fields. Stakeholders also need to know the time period or "lag" between implementing practices in the field and the onset of water quality improvements at the tap. Traditional nutrient management planning and traditional wellhead protection planning are not designed or equipped to answer these questions.

This has led to the recommendation for the State, on a collaborative basis with all drinking water stakeholders, to engage in a process to develop new technical tools to facilitate the goal of protecting our sources of drinking water while maintaining profitable agricultural production, allowing local resource managers to create producer partnerships to implement new "groundwater protective" nutrient management plans in areas contributing recharge to potable wells.

Groundwater and nitrogen fertilizer decision support

The department has begun implementing workplans with technical partners to develop a series of Groundwater and Nitrogen Fertilizer Decision Support tools (GW & Nitrogen DSTs) for ultimate use by community water supplies, conservation departments, the agricultural community, and other drinking water stakeholders to help achieve groundwater protection in the context of nutrient management planning. Nitrogen fertilizer decision support tools will be developed and improved over time based on contributions from the full range of stakeholders. Guiding principles include creating tools that are complementary and supplementary to the existing Nutrient Management Planning programming in the state. Starting with basic tools and progressing to more advanced applications over time, stakeholders will be engaged to develop collaborative solutions to existing data and research gaps, as well as barriers to adoption. Early products will focus on "the basics" such as nitrogen budgets and "mass balance" type analysis. More advanced products will utilize outputs from models in order to incorporate nitrogen cycle drivers and simulation of the effects of weather variability. In source water protection areas where nitrate mitigation is needed, the goal is to pair estimates of nitrate leaching potential with existing nutrient management planning tools already in use in Wisconsin. For example, a user might export a data file from SnapPlus and process separately with a Nitrogen DST to generate estimates of nitrate leaching potential and explore scenarios and options to reduce nutrient losses. Because the nitrogen cycle is inherently "leaky", we expect some nitrate leaching to occur even under optimal management. The goal is to provide reasonable expected ranges of the nitrate leaching below the root zone that would be expected to occur based on the details of a nutrient management plan. Coupled with groundwater transport DSTs to evaluate wellhead vulnerability, the goal is to devise groundwater management plans that assure that potable wells located hydraulically downgradient will remain below the health-based standard for nitrate. To achieve the dual goal of source water protection while maintaining farm profitability, we must also elucidate any tradeoffs in productivity. Where economic offsets are expected to occur, quantification of these costs could serve as the basis for utilizing existing state and federal conservation practice funding sources in new ways that protect drinking water sources and the public health while maintaining strong local economies.

This long-term project provides a framework for continued development and improvement of nitrogen fertilizer decision support as additional research and data are incorporated over time. To be successful, drinking water stakeholders in the state, including the agricultural community, will need to share ownership and responsibility for continuous development and improvement of these tools, just as we continually develop and improve the science supporting crop production.

When fully realized, these tools would test alternative land management and nutrient management scenarios, predict the nitrate load reductions that can be expected from chosen conservation practices, inform economic tradeoffs, and address common questions, such as the estimated time delay between practice implementation and expected water quality improvements at a receptor of concern. Additionally, GW & Nitrogen DSTs will help better utilize existing state and federal non-point pollution control programs that fund land conservation practices. The DSTs could be used, for example, to meet requirements of traditional watershed-based plans (such as "9 Key Element" Plans) by providing information on estimated nitrate pollutant load reductions based on proposed management practices and helping to describe achievable milestones (e.g. magnitude and timing of water quality improvements). Approved watershed-based plans, now expanded to include groundwater protection, would then meet the pre-requisites for agricultural practice cost share funding from existing non-point source pollution mitigation programs.

The Groundwater DSTs (and the underlying spatial data sets) will have many uses and applications beyond understanding nitrate transport from below the root zone and through aquifers to a well or stream. To address potable well impacts from a variety of pollutants, including non-point pollution sources, we must facilitate identification of critical land areas where management actions will be most effective. Groundwater DSTs will leverage existing hydrogeologic research and modeling products and utilize advanced techniques to make essential hydrogeologic information more available to decision makers. Both the Groundwater and Nitrogen DTSs will be designed to communicate the sources of uncertainty associated with model predictions. Full realization of the DST products will quantitatively bracket model output ranges such that local planners can effectively incorporate these factors into the resource protection planning process.

In order to move forward with such a complex technical and social challenge, the Groundwater and Nitrogen Decision Support Tool development partnership is intended to expand over time, incorporating in parallel multi-disciplinary contributions from researchers at the University of Wisconsin, from other state agencies and organizations such as the Wisconsin Geologic and Natural History Survey (UW-Extension), the Wisconsin Department of Agriculture Trade and Consumer Protection, the Department of Health Services, the Wisconsin Rural Water Association and others. Key federal partners include USGS, EPA, and USDA-NRCS. The Wisconsin Land and Water Conservation Association is providing essential connections to county conservation and county health departments. Through these local connections, the range of participating agricultural stakeholders will expand, providing essential feedback and data for developing robust decision support and enable protection of drinking water supplies while sustaining profitable agricultural production.

Future Work

Given the pervasiveness of nitrate contamination in groundwater and the seriousness of suspected human health impacts, there is a need for a better understanding of the health effects of high nitrate in drinking water. DHS will continue to monitor and review the literature on this topic, particularly with regards to links with birth defects. Throughout all of this, continued groundwater monitoring is also needed to assess existing problem areas and identify emerging areas of concern. Development and communication of improved groundwater protection strategies, expanding source water protection resources, providing new technical tools and directing conservation incentives that promote efficient use of nitrogen and reduce losses to groundwater remain top priorities.

Further Reading

DNR overview of nitrate in drinking water

DNR overview of nutrient management planning

DATCP overview of nutrient management

DHS overview of nitrate health effects

DNR, DATCP, and DHS water quality recommendations

NR 151 rule changes for nitrate

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ARSENIC AND OTHER NATURALLY-OCCURRING ELEMENTS

ARSENIC - WHAT IS IT?

Arsenic is an odorless and tasteless, naturally occurring element present in soil and rock. Under certain environmental conditions, arsenic can dissolve and be transported in groundwater. It can also be released as a by-product from agricultural and industrial activities. Everyone is exposed to small amounts of arsenic since it is a natural part of the environment, but under some geologic conditions elevated amounts of arsenic can be released to groundwater.

The Wisconsin State health-based groundwater quality enforcement standard (ES) for arsenic in groundwater, and the maximum contaminant level (MCL) for arsenic in public drinking water, are both 10 parts per billion (ppb), or 10 micrograms per liter (ug/L) (WI NR 140.10, WI NR 809.11). People who drink water containing arsenic in excess of the 10 ppb MCL over many years could experience skin damage or problems with their circulatory system, nervous system, and have an increased risk of getting cancer.

Occurrence in Wisconsin

In Wisconsin, most arsenic found in groundwater is naturally occurring, released from minerals in bedrock and glacial deposits. Arsenic has been detected above the ES in the groundwater in every county in Wisconsin. Arsenic contamination of groundwater is common in northeastern Wisconsin in areas around Winnebago and Outagamie County and moderately high levels of arsenic (10 ppb – 30 ppb) are also common in some parts of southeastern Wisconsin.

Arsenic is common in northeastern Wisconsin (regions 1 and 3) and southeastern Wisconsin. *Figure*: *Luczaj and Masarik, 2015*.

In *northeastern Wisconsin*, a geologic formation called the St. Peter Sandstone contains arsenic-rich minerals. When sulfide minerals common in this rock are exposed to oxygen in the air – either at the water table elevation or from drilling activity – chemical reactions solubilize these minerals and lead to very high levels of arsenic in water (exceeding 100 ppb, or 10 times the ES). In low-oxygen groundwater environments, arsenic can be released from the St. Peter Sandstone at lower concentrations which may still exceed the ES. This more moderate contamination may result from the same sulfide minerals or from arsenic that is bound to iron oxide minerals.

In *southeastern Wisconsin*, most wells draw from glacial sand and gravel deposits or from Silurian dolomite bedrock formations. While oxidizing conditions tend to release arsenic from sulfide minerals in northeastern Wisconsin, reducing conditions (where dissolved oxygen is low) tend to release arsenic from iron compounds in the glacial deposits and dolomite of southeastern Wisconsin.

In *northern* Wisconsin sulfides and arsenopyrite can be found in the Precambrian granitic bedrock, and arsenic bearing iron oxides can be in the end moraine deposits of various glacial advances.

In *southwestern* Wisconsin sulfides associated with the lead-zinc district have contaminated a number of wells. Further north, sulfides in the Tunnel City formation have forced the replacement of at least a dozen wells from La Crosse to Barron counties. A report by Zambito, et. al. (2019) explains the occurrence of arsenic and metal bearing sulfides. Other metals commonly associated with arsenic are nickel, cobalt, copper, aluminum and vanadium.

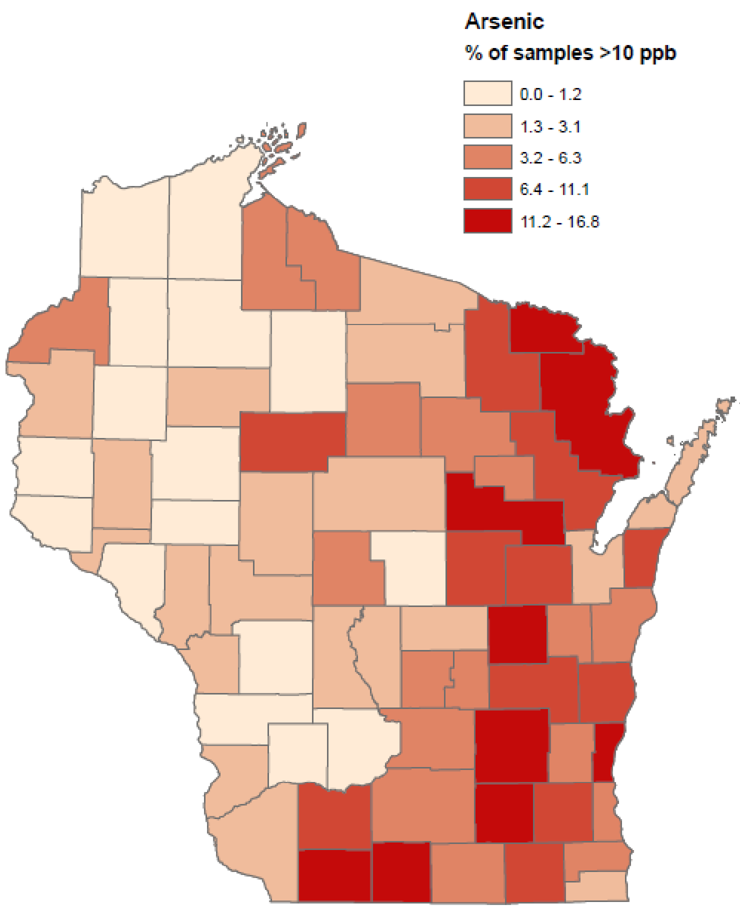
GCC Agency Actions

Naturally-occurring arsenic was unexpectedly discovered in Wisconsin in 1987 during a feasibility study for a proposed landfill in Winnebago County. Follow up sampling by DNR and reports from nearby homeowners revealed a pressing need to determine the distribution and frequency of the problem. As a result, over the next several years DNR, the Department of Health Services (DHS) and local health officials teamed with researchers funded by the Wisconsin Groundwater Research and Monitoring Program (WGRMP) to sample thousands of private wells in the Winnebago and Outagamie County area and analyze where and why arsenic levels were elevated (Burkel, 1993; Burkel and Stoll, 1995). As researchers identified first the geologic formation, then the chemical reactions responsible for the situation (Pelczar, 1996; Simo, 1995 and 1997; Gotkowitz et al., 2003), the DNR outlined a Special Well Casing Depth Area and developed well construction guidelines to protect drinking water wells in this area from contamination. Simultaneously, DHS worked with local health officials to inform residents of health risks, provided low-cost testing of private wells, and gathered information about people with long-term exposure to arsenic in one of the largest epidemiological studies ever conducted in Wisconsin (Knobeloch et al, 2002; Zierold et al., 2004).

In the early 2000s, the US EPA lowered the MCL for arsenic from 50 ppb to 10 ppb (the current standard), which raised concerns for schools and residents in southeastern Wisconsin that had been observing arsenic levels in the 10-50 ppb range. Initial testing by the DNR and the Wisconsin Geological and Natural History Survey (WGNHS) revealed that the geochemical explanations for arsenic contamination in northeastern Wisconsin could not explain the problem in southeastern Wisconsin (Gotkowitz, 2002), so the WGRMP funded further research to analyze the new situation and develop more appropriate guidelines (Sonzogni et al., 2003; Bahr et al., 2004; Root 2005; West et al., 2012). One of the important outcomes of these studies was improved understanding of how chlorine disinfection, which is often used to treat microbial biofilms (slime) in wells, can affect the release of arsenic (Gotkowitz et al, 2008). Shock chlorination of private wells should be limited in much of northeastern Wisconsin because it has a strongly oxidizing effect that encourages release of arsenic from sulfide minerals. Well chlorination does not similarly affect arsenic bound to iron compounds in groundwater environments such as southeastern Wisconsin. In these settings, well disinfection may in fact reduce arsenic levels by controlling microbes that contribute to iron dissolution.

The extensive research completed in Wisconsin over the past 20 years illustrates the highly variable nature of Wisconsin's geologic sources of arsenic to groundwater. A well with no detectable arsenic can be right across the street from a well that tests well above the 10 ppb MCL. Arsenic concentrations can vary over time, too. This makes regular testing – with efficient, accurate and affordable methods - critical. WGRMP-funded researchers have been important partners in this effort and have designed portable field sampling kits, improved upon existing laboratory methods and are currently working on sensors that can immediately detect arsenic levels in groundwater. Most recently a project has begun looking at the association of bedrock fold and faults with arsenic contamination.

In 2014, the DNR began requiring testing for arsenic when pump work was being done on existing wells. The data is being analyzed to determine if additional Special Well Casing Depth Areas should be developed.



Map 1. Beginning in 2014 the department has required arsenic sampling when pump work is done on existing wells. The map above is from the 35,000+ samples collected over the first 7 and a half years. The map depicts the percent of wells over 10 ppb arsenic in each county (see tabular data below). This analysis shows that arsenic is more widespread than previously thought.

County	% >10		County	% >10
Adams	1.3		Marathon	2.1
Ashland	3.4		Marinette	16.8
Barron	1.0		Marquette	4.2
Bayfield	0.6		Menominee	4.9
Brown	2.0		Milwaukee	4.3
Buffalo	0.6		Monroe	0.6
Burnett	3.5		Oconto	10.5
Calumet	3.5		Oneida	1.5
Chippewa	0.6		Outagamie	10.6
Clark	2.4		Ozaukee	16.6
Columbia	5.8		Pepin	2.8
Crawford	1.6		Pierce	0.2
Dane	4.7		Polk	2.2
Dodge	13.4		Portage	0.9
Door	1.8		Price	1.0
Douglas	0.5		Racine	5.7
Dunn	1.9		Richland	0.2
Eau Claire	1.0		Rock	3.2
Florence	14.7		Rusk	1.5
Fond du Lac	9.4		Saint Croix	0.8
Forest	6.6		Sauk	0.9
Grant	1.9		Sawyer	0.9
Green	11.1		Shawano	15.8
Green Lake	5.7		Sheboygan	10.0
Iowa	7.6		Taylor	10.2
Iron	3.7		Trempealeau	2.5
Jackson	2.0		Vernon	0.0
Jefferson	12.0		Vilas	1.7
Juneau	1.7		Walworth	6.7
Kenosha	3.1		Washburn	0.9
Kewaunee	7.0		Washington	5.9
La Crosse	2.8		Waukesha	7.5
Lafayette	15.5		Waupaca	6.5
Langlade	5.3		Waushara	2.1
Lincoln	3.3		Winnebago	15.9
Manitowoc	3.6		Wood	3.9

Table 1. Percent of wells over 10 ppb arsenic by county.

Arsenic continues to be an issue for Wisconsin well owners. In 2021 the pump work samples for 374 wells were over the Enforcement Standard (ES) at 5%, and 2,042 were over the Preventive Action Limit (PAL) at 28%, with a maximum level of 1,290 ppb. In addition department staff reviewed and responded to over 70 sample results from the Wisconsin State Lab of Hygiene that were over 10 ppb.

Future Work

Sampling and testing private wells remain important priorities for understanding and managing arsenic contamination in Wisconsin. To encourage private well sampling, local health departments continue to offer fee-exempt testing to low income families. The DNR and some county governments are also working to both promote well sampling programs and explore impediments to private well sampling.

Arsenic-rich minerals, such as arsenic-rich pyrite (pictured), are natural sources of arsenic in groundwater in Wisconsin. *Photo: JJ Harrison.*

In areas of the state known to be vulnerable to arsenic contamination, there is a focus on reducing exposure. Several communities have expanded the service area for public water systems and moved homes from private wells to public supplies. This expansion has been effective in reducing exposure in towns like Algoma in Winnebago County.

Areas outside the original region of concern in northeast Wisconsin and the more recent area of concern in southeast Wisconsin have not been as well described. Revisions to NR 812 now require wells to be tested for arsenic, in addition to bacteria and nitrate, during pump installation or when testing is requested during property transfers involving existing private wells. This may help to fill the data gap. In addition, researchers from the WGNHS funded by the WGRMP are currently working to understand the mineralogy of the Tunnel City rock formation in western Wisconsin, which may help define the risk of arsenic contamination in that region.

Discovery triggers geochemical questions, science improves understanding and helps GCC agencies better protect human health – this pattern is repeated by GCC agencies and researchers whenever natural contaminants are identified in groundwater in unexpected amounts in a new location. This continues today with ongoing investigations that are exploring the occurrence of strontium near Green Bay and the presence of heavy metals in geologic formations near La Crosse, among others.

OTHER NATURAL CONTAMINANTS IN WI GROUNDWATER

NATURALLY-OCCURRING RADIONUCLIDES

Radionuclides are radioactive atoms. It is possible for radionuclides to be manmade, as is the case with some materials from nuclear power reactors, but they also occur naturally in rock formations and are released to groundwater over millions of years by geochemical reactions. Common naturally-occurring radionuclides in groundwater include uranium and thorium, which both decay to different forms of radium, which in turn decays to radon. General indicators of high-energy radiation are monitored in water as alpha, beta, and gamma (now included in a broader group called photon emitters) activity.

There are no ch. NR 140 groundwater quality standards for radionuclides in Wisconsin but MCLs for public drinking water systems have been established for the radionuclides uranium and (total) radium, and for alpha and beta (plus photon) particle activity. No public water supply MCL has been established for radon but the United States Environmental Protection Agency (US EPA) has proposed that radon levels in water be no higher than 4,000 picocuries per liter (pCi/L), where indoor air radon abatement programs exist, and no higher than 300 pCi/L where indoor air radon abatement programs do not exist.

RADIUM IN SOUTHEASTERN WISCONSIN

A well-known example of natural contamination in Wisconsin is radium in southeastern Wisconsin. By the late 1990s, drawdown in this region due to decades of large-scale pumping was causing concerning increases in radium levels in drinking water. Initial links between radium and geologic formations in eastern Wisconsin had been drawn by GCC researchers in 1990 (Taylor and Mursky, 1990), but the source of radium was poorly understood, making it difficult to know how to manage drinking water sources. Research funded by the WGRMP in the late 1990s more clearly demonstrated that high radium is most common near the edge of the Maquoketa shale, which runs from Brown County in the north to Racine County in the south (Grundl, 2000).

A remaining puzzle was why radium levels were elevated to the east of the Maquoketa shale boundary but not to the west – conventional understanding of the sources of radium did not seem sufficient to explain observations. In the early 2000s, researchers at the University of Wisconsin and the Wisconsin Geological and Natural History Survey (WGNHS) leveraged new models and knowledge about groundwater flow patterns in the Waukesha area to elucidate the relationship between radium and sulfate minerals in the area, collecting much needed information on the geochemical backdrop of the region in the process (Grundl et al., 2003). Today, there are still unanswered questions about the precise geochemical processes that control radium activity, but our improved understanding of radium sources helps water managers in eastern Wisconsin define their options: treat water from deep aquifers, blend with water from shallow aquifers, or find alternate surface sources for drinking water.

NATURALLY-OCCURRING CHROMIUM IN GROUNDWATER

As water flows underground, metals such as chromium, may be dissolved from rock or soil and be mobilized, and therefore present in groundwater. Natural sources of chromium in groundwater include some types of igneous bedrock and soils derived from those bedrock sources. In groundwater, chromium can generally be found in one of two forms, as trivalent chromium (Cr lll), or chromium-3, or as hexavalent chromium (Cr VI), or chromium-6. While trivalent chromium is an essential nutrient, hexavalent chromium is acutely toxic and has been classified as "likely to be carcinogenic to humans". Water quality analysis for chromium is generally done for "total chromium" (trivalent chromium + hexavalent chromium). The US EPA has established a public water supply MCL for total chromium at 100 micrograms per liter (µg/L) and, in Wisconsin, the ch. NR 140 groundwater quality enforcement standard (ES) for total chromium is 100 µg/L. The DHS has recently recommended a ch. NR 140 ES for hexavalent chromium of 70 nanograms per liter (ng/L).

CHROMIUM IN DANE COUNTY

In Dane County, residents were surprised to learn in 2011 that hexavalent chromium (Cr [VI]) is present in Madison drinking water in very low concentrations. While trivalent chromium (Cr [III]) is an essential trace nutrient in low concentrations, Cr (VI) is a suspected carcinogen. As DHS responded to questions about the health effects of Cr (VI), WGNHS quickly embarked on a sampling study to determine whether there was a naturally occurring source of chromium in the local bedrock formations (Gotkowitz et al., 2012). Findings indicate that chromium naturally occurs in all formations, but only the upper aquifers seem to have the geochemical conditions to promote mobility of aqueous Cr (VI).

Sampling irrigation wells for Cr (VI). *Photo: Patrick Gorski*

WGRMP-funded researchers at UW-Madison and the Wisconsin State Laboratory of Hygiene followed up with a project to explore what geochemical environments create ideal conditions for Cr (VI) mobility in key geologic formations across the state (Gorski et al., 2015). Work like this helps Wisconsin communities prepare for a federal drinking water standard for Cr (VI), which does not currently exist but is expected to in the future.

NATURALLY-OCCURRING STRONTIUM IN GROUNDWATER

Naturally occurring, non-radioactive strontium is present in Wisconsin groundwater and has been found at very high concentrations in some parts of the State. Non-radioactive, or "stable strontium", naturally occurs in rock and soil and, under certain geochemical conditions, is dissolved from rock and soil sources and mobilized in groundwater. Very high levels of naturally occurring strontium have been documented in municipal water supply wells in eastern Wisconsin (USGS 1963). Strontium's chemical behavior is similar to calcium and strontium minerals have been found in carbonate bedrock deposits in Wisconsin. The weathering and dissolution of carbonate bedrock containing strontium minerals may be a source of elevated strontium in groundwater. Highly mineralized brines have also been shown to contain very high levels of dissolved strontium. No public water supply MCL has been established for strontium, but the US EPA has established a lifetime health advisory level for strontium in drinking water at 4,000 µg/L. The DHS has recently recommended a ch. NR 140 ES for strontium of 1,500 µg/L.

A research project, funded through WGRMP, was conducted to study the occurrence and sources of strontium in groundwater in northeastern Wisconsin (Luczaj 2013). Very high levels of strontium in wells drawing water from the Cambrian Ordovician bedrock aquifer in the northeast part of the state were documented in the study. The research found that groundwater chemistry in the Cambrian Ordovician aquifer was influenced by deep regional bedrock faults, that created aquifer groundwater "zones" with differing major ion chemistry. Strontium minerals, precipitated from Michigan geologic basin hydrothermal brines, in carbonate bedrock and interstitial cement in sandstone formations were determined to be the likely source of elevated strontium in groundwater. The heterogenous nature of bedrock strontium mineral deposition, and the influence of major faults on groundwater chemistry, were suggested as reasons for the observed variability in strontium concentrations in well water across the study area.

UPDATE ON GROUNDWATER STANDARDS RELATED TO NATURALLY-OCCURRING ELEMENTS IN WI GROUNDWATER

Strontium, hexavalent chromium, aluminum, cobalt and molybdenum are all metallic elements that may be naturally occurring in rock and soil. Under certain geochemical conditions, such as reducing redox conditions, these metals may be dissolved from rock or soil and mobilized in groundwater. Anthropogenic contamination may also be the source of these metals in groundwater.

As part of a continuing commitment to protect public health, public welfare, and the environment, the DNR periodically updates groundwater quality standards in ch. NR 140, Wis. Adm. Code. In 2018 the DNR requested that DHS review toxicological information and, if warranted, provide new or updated groundwater quality standards for substances found in Wisconsin groundwater. In 2019, as part of ch. NR 140 "Cycle 10", DHS provided recommendations for new and revised groundwater quality standards for strontium, hexavalent chromium, aluminum, cobalt and molybdenum (see https://www.dhs.wisconsin.gov/water/gws-cycle10.htm). On February 23, 2022, the DNR Natural Resources Board (NRB) considered approval of proposed revisions to ch. NR 140 to incorporate the DHS NR 140 Cycle 10 groundwater standard recommendations, including the recommended new and updated standards for strontium, hexavalent chromium, aluminum, cobalt and molybdenum. The NRB did not approve the proposed NR 140 Cycle 10 groundwater quality standards.

Further Reading

DNR overview of arsenic in drinking water wells

DNR special well casing depth areas for arsenic

DHS overview of arsenic health effects

WGNHS report on arsenic release due to well disinfection

WGNHS report on preliminary investigation near Lake Geneva, Wisconsin

DHS report on arsenic in Wind Lake Private Wells, Town of Norway, Racine County

Wisconsin Natural Resource magazine article on arsenic in private wells (December 2000)

Origin and Distribution of Dissolved Strontium in the Cambrian-Ordovician Aquifer of Northeastern Wisconsin

Grundl, T.J. 2000. Maquoketa shale as radium source for the Cambro-Ordovician aquifer in eastern Wisconsin. Wisconsin groundwater management practice monitoring project, DNR-141. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.GrundlMakoqueta

Hexavalent Chromium (Cr(VI)) in WI Groundwater: Identifying Factors Controlling the Natural Concentration and Geochemical Cycling in a Diverse Set of Aquifers

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PESTICIDES

What are they?

Pesticides are a broad class of substances designed to kill, repel or otherwise disrupt living things that are considered pests. They include insecticides, herbicides, fungicides and anti-microbials, among other types of biocides. Normal field applications, spills, misuse or improper storage and disposal can all lead to pesticide contamination in groundwater. As pesticides breakdown in soil and groundwater or are absorbed and metabolized by the target pest, some are converted into related compounds called metabolites, which may also be harmful to the pest or other living things.

Pesticide application sign. Photo: DATCP.

The health effects of exposure to pesticides or pesticide metabolites vary by substance. About 30 pesticides (and some pesticide metabolites) currently have ~~a~~ ch. NR 140 groundwater quality standards ([WI NR 140.10)](), and a smaller number have an established maximum contaminant level (MCL), applicable at public drinking water systems ([WI NR 809.20)](). However, at least 90 different pesticides are used on major crops in Wisconsin (WASS, 2006). Occasionally, pesticides and pesticide metabolites that do not have a NR 140 groundwater quality enforcement standard (ES) or public drinking water MCL are detected in drinking water supplies, and information on the health effects of these pesticide compounds is often very limited or difficult to evaluate. It is also difficult to predict the health effects of multiple pesticides in drinking water; several studies have indicated that pesticide mixtures can have different health effects than exposure to individual pesticides at the same concentrations (Porter, 1999; Hayes et al., 2006).

Periodically the Department of Agriculture, Trade and Consumer Protection (DATCP) identifies pesticides that are newly approved, have a high rate of use, or have been detected ("parent" compound or metabolites) in groundwater. These pesticides may be candidates for state groundwater standards development. Identified candidate pesticides and metabolites may be included on a list of substances that the DNR transmits to the WI Department of Health Services (DHS) requesting that DHS review available toxicologic information and, if appropriate, provide recommendations for ch. NR 140 groundwater quality standards.

In March 2018 and April 2019, lists of substances designated "Cycle 10" and "Cycle 11", that included pesticides and pesticide metabolites, were sent to DHS for review. The pesticides and metabolites on the Cycle 10 list included eight herbicides and herbicide metabolites: Isoxaflutole, Isoxaflutole DKN, Isoxaflutole BA, Glyphosate,

Glyphosate AMPA, Thiencarbazone-methyl, Sulfentrazone and Dacthal TPA & MTP degradates, and three neonicotinoid insecticides: Thiamethoxam, Imidacloprid and Clothianidin. The Cycle 11 list included five herbicides: Metalaxyl, Flumetsulam, Fomesafen, Hexazinone, Saflufenacil, and one insecticide, Chlorantraniliprole. DNR received recommendations from DHS on all 16 pesticide/pesticide metabolite standards (see https://www.dhs.wisconsin.gov/water/gws.htm).

Commonly detected pesticides and their metabolites which have established groundwater quality or drinking water standards in Wisconsin include atrazine, alachlor, metolachlor, and acetochlor.

Atrazine is an herbicide commonly used on corn. The groundwater quality ES for atrazine and its three chlorinated metabolites is 3 parts per billion (ppb). The drinking water MCL for atrazine (does not include metabolites) is 3 ppb. A number of epidemiological and animal studies have been conducted evaluating the potential health and environmental impacts from atrazine exposure (Hayes et al., 2002; ATSDR, 2003; Hayes et al., 2003; Hayes et al., 2006; Hayes et al., 2011; Craigin et al., 2011; Agopian et al., 2012; Agopian et al., 2013). People who drink water containing atrazine in excess of health-based standards over many years could experience problems with their cardiovascular system or reproductive difficulties.

Alachlor is an herbicide used on corn and soybeans. Use of alachlor in Wisconsin has been replaced by other herbicides in the same family (e.g., metolachlor, acetochlor) (NASS, 2015 and 2016), however, its metabolites still linger in groundwater. Both the groundwater quality enforcement standard (ES) and public drinking water MCL for alachlor are 2 parts per billion (ppb), and the groundwater quality ES for one of its metabolites, *alachlor ESA*, is 20 ppb. People who drink water containing alachlor in excess of health-based standards over many years could have problems with their eyes, liver, kidneys or spleen, or experience anemia, and may have an increased risk of getting cancer.

Metolachlor is an herbicide used widely on corn and soybeans, and on vegetable crops including peas, snap beans and potatoes. Both the parent and metabolite forms (metolachlor, metolachlor-ESA and metolachlor-OXA) are routinely detected in groundwater and health-based groundwater quality standards have been established for these compounds. The groundwater quality ES for metolachlor is 100 ppb, and the groundwater quality ES for metolachlor-ESA and OXA combined is 1,300 ppb. Although metolachlor and its metabolites are commonly detected in groundwater, the concentrations detected are typically well below their respective ESs.

Acetochlor is an herbicide used for pre-emergent control of weeds in corn. The state groundwater quality ES for acetochlor is 7 ppb. A groundwater quality ES of 230 ppb has also been established for the combined acetochlor metabolites, acetochlor ESA and acetochlor OXA. No public water supply MCL has been established for acetochlor or its metabolites. Animal studies have shown that oral exposure to acetochlor can produce significant neurological effects (EPA, 2006). Acetochlor has been classified by the EPA as a “suggestive human carcinogen”.

Occurrence in Wisconsin

In Wisconsin, the main source of pesticides in groundwater is agricultural herbicide and insecticide applications. For this reason, detection is more common in highly cultivated areas where agriculture is well established, notably in the south central, central and west-central parts of the state.

In 2016, DATCP conducted a statewide statistical survey of agricultural chemicals in groundwater that found an estimated 41.7% of private wells in Wisconsin contained a pesticide or pesticide metabolite (DATCP, 2017), up from 33% of private wells in a similar survey conducted in 2007 (DATCP, 2008). The primary metabolites of metolachlor and alachlor, metolachlor ESA and alachlor ESA, were the two most commonly detected pesticide products in those surveys. Atrazine and its metabolites, known collectively as the total chlorinated residues of atrazine (atrazine TCR), were also prevalent and occurred in about 23% of wells. Less than 1% of well samples with atrazine TCR detections had atrazine TCR levels that exceeded the groundwater quality ES of 3 ppb.

GCC Agency Actions

Serious concerns about pesticide contamination in Wisconsin were first raised in 1980 when aldicarb, a pesticide used on potatoes, was detected in groundwater near Stevens Point. The DNR, DATCP and other agencies responded to concerns by implementing monitoring programs and conducting groundwater surveys, initially testing exclusively for aldicarb, (Rothschild et al., 1982; Kraft 1990), but soon expanding to other pesticides and pesticide metabolites (Postle and Brey, 1988). DATCP also developed rules to restrict aldicarb use in areas vulnerable to groundwater contamination.

A plane sprays pesticides on a field. Photo: DATCP.

When findings from these sampling surveys in the late 1980s and early 1990s showed that atrazine, a popular corn herbicide, was particularly prevalent in groundwater across the state (LeMasters and Doyle, 1989; Cowell and LeMasters, 1992), special projects were conducted to investigate how and why it reaches groundwater. Notably, researchers funded by the Wisconsin Groundwater Research and Monitoring Program (WGRMP) discovered that normal field application of atrazine – not just point spills and misuse – was an important source of atrazine in groundwater (Chesters et al., 1990; Chesters et al. 1991). This knowledge, combined with other findings regarding the roles of soil, geology and agricultural management (Daniel and Wietersen, 1989; Lowery and McSweeney, 1992; Levy and Chesters 1995; Levy et al. 1998), allowed DNR and DATCP to effectively and fairly design both groundwater standards and the atrazine rule, as detailed in this profile on the experience.

Where atrazine use has been prohibited by the atrazine rule, follow-up studies demonstrate there is a clear reduction in atrazine levels, which generally drop below the groundwater standard in 2 to 7 years (DATCP, 2010). Many farmers would like the option to use atrazine in these areas, but they have adapted well to growing corn without it. A 2010 DATCP survey found that the vast majority of farmers in atrazine prohibition areas have not observed a decrease in yield, and that most believe it is not more difficult to control weeds with other alternatives. The survey found that there is an even split in those who think weed control is more vs. less costly without atrazine (DATCP, 2011a). By far, the most popular alternatives to atrazine are glyphosate-containing products such as Roundup. From a groundwater perspective, this is fortunate since glyphosate binds very tightly to soil and thus is generally not considered a groundwater threat. There are concerns, however, that overuse of glyphosate may lead to glyphosate-resistant weeds.

Many sampling programs initiated by DATCP, the DNR and other agencies in the mid-1980s to early 1990s are still ongoing today. The longest running sampling program for pesticides began in 1985 and is designed to evaluate the potential impact of agriculture on groundwater quality by sampling monitoring wells near selected agricultural fields in areas with high groundwater contamination potential. Testing in this program confirms that the metabolites of metolachlor and alachlor are the two most common pesticides products detected in groundwater near the monitoring well sites.

A DATCP review of data from samples it collected statewide from 2008 through 2016 revealed an increased occurrence of detections of neonicotinoid insecticides in samples collected from monitoring wells, irrigation wells, private wells, and surface water samples. DATCP reported detections of the neonicotinoid insecticides clothianidin, imidacloprid and thiamethoxam in samples from monitoring wells, irrigation wells, and private wells tested, with most detections occurring in sandy irrigated vegetable growing areas in the Central Sands region and on terraces of the Wisconsin River Valley (DATCP, 2019). The review also reported that out of 34 streams sampled statewide, multiple

Preparing to sample monitoring wells near an agricultural field. Photo: DATCP.

detections of imidacloprid and thiamethoxam were reported year-round in two streams also located within the Central Sands region. Concentrations of total neonicotinoids detected in these streams pose significant concerns for aquatic invertebrates and other non-target aquatic species present in the streams. The report detailing the findings of DATCP's review was shared with U.S. EPA as they continue to evaluate the role that these compounds may have in declining pollinator populations nationwide.

Another study that has been repeated annually since 1995 focuses on re-sampling wells that once previously exceeded a pesticide standard. Over 160 wells have been sampled multiple times in this program, and over time, atrazine levels have been shown to decline in about 80% of the wells (DATCP, 2010). Many of these wells are located in what are now atrazine prohibition areas and the declines are likely the direct result of restrictions placed on the use of this pesticide in these areas.

DATCP has also conducted a statewide, statistically designed survey of agricultural chemicals in Wisconsin groundwater five times since the early 1990s (1994, 1996, 2001, 2007 and 2016). In 2016, nearly four hundred samples from private drinking water wells were analyzed for 101 pesticide compounds, including 70 herbicides, 26 insecticides, 4 fungicides and 1 pesticide safener. Health standards have been established for 27 of the compounds analyzed. In addition to capturing the current picture of agricultural chemicals in groundwater, this series of studies relates these findings to land use and compares results of the 2016 survey to those of previous surveys. The final report of the results of the 2016 survey was published in early 2017 (DATCP 2017). DATCP is planning the next survey for 2023. Publications of DATCP surveys are available on the web at:
https://datcp.wi.gov/Pages/Programs_Services/GroundwaterReports.aspx

Future Work

DATCP began oversight of a Stipulated Agreement and Special Order between DATCP and Bayer CropScience (BCS) related to the limited use of the BCS pesticide isoxaflutole in Wisconsin. Isoxaflutole is a relatively new corn herbicide that has a high likelihood of leaching to groundwater. The agreement allows for use on corn grown in just 12 counties (Columbia, Dane, Dodge, Fond du Lac, Grant, Green, Jefferson, Lafayette, Rock, Sauk, Walworth and Waukesha) while BCS performs specific studies over five years that are intended to clarify the potential for surface or groundwater impacts. Throughout the study, BCS will monitor surface water and tile drainage sites that receive isoxaflutole applications. They will also monitor groundwater at eight groundwater monitoring sites that receive three applications of the pesticide over the multi-year study period.

Further development of health standards and laboratory methods is of paramount importance for keeping pace with the evolving use of agricultural chemicals to ensure that the agricultural success that is so crucial for our state is fairly balanced with the protection of groundwater and human health.

Update on Groundwater Standards for Pesticides

As part of a continuing commitment to protect public health, public welfare, and the environment, the DNR periodically updates groundwater quality standards in ch. NR 140, Wis. Adm. Code. In March 2018 and April 2019, lists of substances designated "Cycle 10" and "Cycle 11", that included pesticides and pesticide metabolites, were sent to DHS for review. The pesticides and metabolites on the Cycle 10 list included eight herbicides and herbicide metabolites: Isoxaflutole, Isoxaflutole DKN, Isoxaflutole BA, Glyphosate, Glyphosate AMPA, Thiencarbazone-methyl, Sulfentrazone and Dacthal TPA & MTP degradates, and three neonicotinoid insecticides: Thiamethoxam, Imidacloprid and Clothianidin. The Cycle 11 list included five herbicides: Metalaxyl, Flumetsulam, Fomesafen, Hexazinone, Saflufenacil, and one insecticide, Chlorantraniliprole.

DNR received recommendations from DHS on all 16 pesticide/pesticide metabolite groundwater quality standards (see https://www.dhs.wisconsin.gov/water/gws.htm) and began rulemaking to incorporate the DHS recommendations into ch. NR 140. On February 23, 2022, the DNR Natural Resources Board (NRB) considered approval of proposed revisions to ch. NR 140 to incorporate the DHS Cycle 10 groundwater standard recommendations, including recommended standards for pesticides and pesticide metabolites, into ch. NR 140. The NRB did not approve the proposed NR 140 Cycle 10 groundwater quality standards at their Feb. 23, 2022 meeting. The DNR has currently placed rulemaking, to incorporate the DHS Cycle 11 groundwater standard recommendations into ch. NR 140, on hold.

Further Reading

DHS resources for contaminants in drinking water
DNR overview of pesticides in drinking water wells
DATCP water quality reports
DATCP Home Groundwater Standards for Pesticides (wi.gov)

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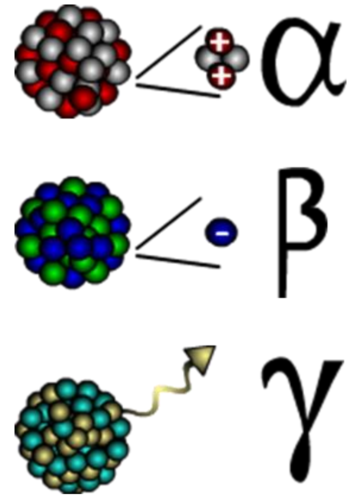
NATURALLY-OCCURRING RADIONUCLIDES

What are they?

Radionuclides are radioactive atoms. It is possible for radionuclides to be manmade, as is the case with some materials from nuclear power reactors, but they also occur naturally in rock formations and are released to groundwater over millions of years by geochemical reactions. Common naturally-occurring radionuclides in groundwater include uranium and thorium, which both decay to different forms of radium, which in turn decays to radon.



Alpha, beta, and gamma types of radiation. *Figure: US EPA*.

There are no NR 140 groundwater quality standards for radionuclides in Wisconsin but drinking water at public water systems is monitored for general indicators of radioactivity (alpha, beta, gamma activity) and for specific radionuclides (uranium, radium).

Maximum contaminant levels (MCLs) in public drinking water systems have been established for radionuclides at 15 picocuries per liter (pCi/L) for alpha activity, 4 millirems per year (mrem/yr) for beta or gamma activity, 5 pCi/L for total radium (radium−226 and radium−228), and 30 micrograms per liter (ug/L) for uranium (WI NR 809.50-809.51). People who drink water containing alpha, beta or gamma radiation, or radium or uranium in excess of established MCLs, over many years, may have an increased risk of getting cancer. In the case of uranium, an increased risk of kidney toxicity is possible as well. There is no public drinking water standard for radon, although the United States Environmental Protection Agency has proposed that radon levels be no higher than 4,000 pCi/L where indoor air abatement programs for radon exist, or 300 pCi/L where indoor air radon abatement programs do not exist.

Occurrence in Wisconsin

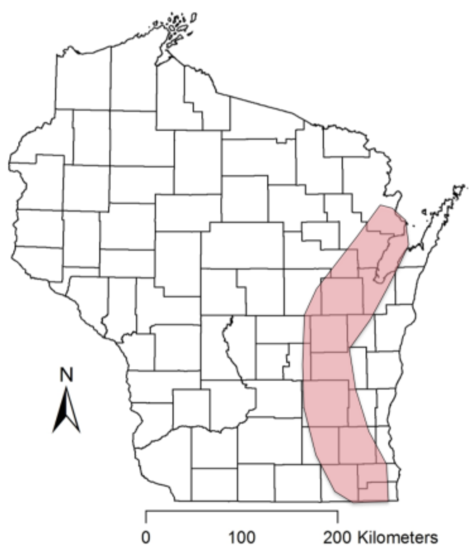
Radionuclides occur naturally in rock formations, and every well in Wisconsin contains some level of dissolved radionuclides. In most places these levels are not concerning, but some areas of the state tend to have notably high concentrations of radium, radon, and/or gross alpha activity.

In *northern Wisconsin*, there are notably high levels of both radon and gross alpha activity. Here, the geologic source is usually granite bedrock or, in some cases, granitic sand and gravel deposits.

In *eastern Wisconsin*, wells that draw from a very deep sandstone aquifer, the Cambrian-Ordovician, to the east of where it underlies another geological formation, the Maquoketa shale, often have levels of radium above the MCL. This band of high radium activity stretches from Brown County in the north to Racine County in the south and primarily affects public wells, since drilling deep enough to reach this aquifer is usually prohibitively expensive for smaller private systems. The geochemical explanation for the high radium levels is that the solubility of radium is related to the solubility of sulfate minerals in this aquifer, and the sulfate minerals that are common to the east of the Maquoketa shale are more soluble than those to the west of the Maquoketa due to confined conditions and geochemical differences.

About 80 public water systems have exceeded a radionuclide drinking water MCL standard at some point in time. The DNR has been working with these systems since 2003 to ensure that they develop a compliance strategy and take corrective action, so currently less than 10 remain that are providing water in excess of established radionuclide MCLs.

GCC Agency Actions



Area of Wisconsin where most of the wells that exceed the drinking water MCL for radium are located. This band coincides with where the Cambrian-Ordovician sandstone aquifer underlies the Maquoketa shale. *Figure*: *Luczaj and Masarik, 2015*.

By the mid-1980s, regular monitoring of public water supplies in north central Wisconsin seemed to indicate that there was an increased risk of radionuclide contamination in wells drawing from the granite bedrock aquifer. This raised concern since, at the time, drilling to this deeper granite aquifer was viewed as the best alternative if wells in the shallow sand and gravel aquifer became contaminated by manmade sources. After collecting and analyzing nearly 500 samples from this area in the late 1980s, the DNR showed that the granite bedrock aquifer is indeed a significant source of radionuclides, especially *radon*, and the DNR began taking steps to educate well owners and expand the investigation. Follow up work in other regions of the state by the DNR, WGNHS, and DHS also showed that while nearly all aquifers in the state contain some amount of radon (at or above 300 pCi/L), exceedingly high levels (over 4,000 pCi/L) are only found in granite or in sand and gravel deposits derived from granite (Mudrey and Bradbury, 1993). A few studies by University of Wisconsin researchers at this time also noted that unusually high levels of *radium* in eastern Wisconsin seemed to be related to the Maquoketa shale formation (Taylor and Mursky, 1990; Weaver and Bahr, 1991).

In the early 2000s, the flow patterns and geochemistry of groundwater in southeastern Wisconsin became of great interest as large-scale pumping driven by growing communities outside Milwaukee began to dramatically change groundwater conditions. One puzzle to scientists was why *radium* levels were elevated to the east of the Maquoketa shale in this region but not to the west – conventional understanding of the sources of radium did not seem sufficient to explain observations. Leveraging new models and knowledge about groundwater flow patterns in the Waukesha area, researchers at the University of Wisconsin and WGNHS, funded by the Wisconsin Groundwater Research and Monitoring Program (WGRMP), elucidated the relationship between radium and sulfate minerals in the area, collecting much needed information on the geochemical backdrop of the region in the process (Grundl and Cape, 2006; Grundl et al. 2006).

A study of radium in groundwater, in the Cambrian-Ordovician aquifer system, was conducted in the vicinity of Madison in 2016 - 2017 (Mathews et al. 2019). This study evaluated radium occurrence in groundwater relative to several geochemical parameters, as well as the presence of naturally occurring radium "parent elements", uranium and thorium, in aquifer bedrock units. The Cambrian-Ordovician aquifer in central Wisconsin is composed of an unconfined bedrock aquifer unit and a confined bedrock aquifer unit, separated by the Eau Claire shale aquitard.

Radium parent radionuclides (^{238}U and ^{232}Th) were found associated with both the Eau Claire shale aquitard and bedrock layers in both unconfined and confined Cambrian-Ordovician aquifer units. The study found an association in the upper, unconfined aquifer unit, between elevated levels of radium in groundwater and relatively high levels of total dissolved solids (TDS). High TDS in groundwater, creating competition between radium and other dissolved ions for sorption sites, is proposed as the explanation for the elevated groundwater radium found in the unconfined aquifer unit. Elevated groundwater radium in the lower, confined aquifer unit was found to be associated with very low groundwater dissolved oxygen (DO) levels. Dissolution of iron and manganese hydroxide radium adsorption sites occurs under low DO conditions and adsorbed radium can be mobilized into groundwater under those geochemical conditions.

The Wisconsin State Laboratory of Hygiene and other WGRMP-funded researchers have also made advances in sampling techniques and laboratory testing for radionuclide parameters, which tend to be very sensitive to collection and analysis methods. These studies have demonstrated how simple differences in approaches can cause one analysis to conclude a water sample is below the MCL while another can conclude the opposite about the same sample (Sonzogni et al., 1995; Arndt and West, 2004). Following these findings, researchers have developed corrections and guidelines to ensure reported test results are as accurate as possible.

Future Work

The DNR continues to work with public water systems that exceed drinking water standards for radionuclides to bring them into compliance. Options include blending water high in radionuclides with water from sources containing lower levels of radionuclides, finding an alternative water supply or constructing a new well in a low radionuclide aquifer, and softening or applying another effective radionuclide removal treatment technique to the water supply. The need for compliance with radium drinking water standards is the main reason the city of Waukesha sought, and received approval under the Great Lakes Compact, for diversion of Lake Michigan water.

Further Reading

[DHS resources for contaminants in drinking water]

[DNR overview of radium in drinking water wells]

[DNR overview of radon in drinking water wells]

[WGNHS report on distribution of radionuclides in groundwater]

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VOLATILE ORGANIC COMPOUNDS

What are they?

Volatile Organic Compounds (VOCs) are a group of common industrial and household chemicals that evaporate, or volatilize, when exposed to air. Examples of products containing VOCs include gasoline and industrial solvents, paints, paint thinners, air fresheners and household products such as spot and stain removers. Chemical names for the VOCs in these products include benzene, Trichloroethylene (TCE), toluene and vinyl chloride, among others. Improper handling or disposal of VOCs is often the reason why they occur in groundwater.

Collection of household products containing VOCs including paints, stains, and paint thinners. *Photo: Tom Murphy VII*

Health risks vary depending on the VOC. Short-term exposure to high concentrations of many VOCs can cause nausea, dizziness, anemia, fatigue or other health problems. Long-term exposure to some VOCs may cause cancer, liver damage, spasms, and impaired speech, hearing and vision. For more on the health effects of specific VOCs, see the resources listed by the Wisconsin Department of Health Services (DHS) at https://www.dhs.wisconsin.gov/water/index.htm.

Occurrence in Wisconsin

At least 59 different VOCs have been found in groundwater in Wisconsin, although only 34 of those have health based standards (groundwater WI NR 140.10, drinking water WI NR 809.24). The main sources of VOCs in Wisconsin groundwater are landfills, leaking underground storage tanks (LUSTs), and a variety of facilities that use VOCs in their regular operations, including gas stations, bulk petroleum and pipeline facilities, plating facilities, dry cleaners and other industrial facilities. The Department of Natural Resources (DNR) currently tracks about 700 current or former landfills, 21,000 LUSTs and 8,000 other facilities which are required to monitor groundwater. The DNR also tracks approximately 39,000 spills, some of which are also sources of VOCs. Given how common potential sources of VOCs are, these substances are more frequently found in groundwater near urban industrial and commercial areas. However, exceedances of groundwater standards for VOCs have been reported in every county in the state.

Installation of a compacted clay and geotextile liner at a landfill site in Wisconsin. *Photo*: *DNR*

GCC Agency Actions

Drilling to monitor for VOCs near a Wisconsin landfill. *Photo*: DNR

Early studies by the DNR and DHS in the late 1980s and early 1990s focused on VOC contamination from landfills, specifically from those without linings to protect groundwater from leachate. DNR scientists found that VOCs contaminated groundwater at 60% of unlined industrial landfills and 80% of unlined municipal solid waste landfills (Friedman, 1988; Batista and Connelly, 1989). Further review of monitoring data showed that while VOC levels typically decrease following the closure of unlined landfills, concentrations remain high and do not always show continued improvement within a reasonable period of time (Battista and Connelly, 1994). In the late 1990s, this knowledge raised concerns since increasing numbers of residential developments were located close to old, closed landfills. In 1999, the DNR and DHS designed targeted sampling of private wells near old, closed landfills to investigate and address the problem. For wells where VOCs were detected above drinking water standards, residents were given health advisories not to drink water and the DNR took follow-up measures at the nearby landfills. Much more stringent engineering standards have guided the design of modern landfills (those built after the 1980s), so these have a much better record in terms of VOC contamination, but older landfills continue to remain a concern (US DHHS, 2006).

A critical role of GCC agencies is identifying and monitoring all known sources of VOCs, not only landfills. The Department of Agriculture and Consumer Protection (DATCP) keeps track of all underground storage tanks (USTs) with a capacity of 60 gallons or greater; this registry has identified over 180,000 USTs since 1991. Hazardous waste treatment, storage and disposal facilities must be licensed by the DNR and are subject to corrective action authorities in the event of spills or releases. The DNR's Bureau for Remediation and Redevelopment oversees investigation or remediation at 128 RCRA 2020 corrective action sites. More broadly, the Hazardous Substance Spill Law requires immediate notification to the DNR when any hazardous spills or discharges occur and requires that all necessary actions be pursued to restore the environment to the extent practicable. The spills program also develops outreach materials to help reduce the number and magnitude of spills and provide guidance for responding to spills. Topics addressed include spills from home fuel oil tanks, responses to illegal methamphetamine labs and mercury spills, all of which can lead to significant environmental impacts, if not properly addressed.

Future Work

Continuing to identify and monitor known sources of VOCs is key to continued protection of drinking water. Each year, several hundred contaminated sites, some of which involve VOCs, are reported to the DNR and each year, cleanup begins at another several hundred sites. Continuing to track and respond to this ongoing issue remains an important objective for GCC agencies.

As part of a continuing commitment to protect public health, public welfare, and the environment, the DNR periodically updates groundwater quality standards in ch. NR 140, Wis. Adm. Code. In 2018 the DNR requested that DHS review new toxicological information available for five VOCs: Trichloroethylene (TCE), Tetrachloroethylene (PCE), 1,2,3-Trichloropropane (1,2,3-TCP), 1,1-Dichloroethane (1,1-DCA) and 1,4-Dioxane, to see if updated groundwater standards for these substances was warranted. Based on its review, DHS recommended updated standards for four of the reviewed VOCs: TCE, PCE, 1,2,3-TCP and 1,4-Dioxane (see https://www.dhs.wisconsin.gov/water/gws.htm).

On February 23, 2022, the DNR Natural Resources Board (NRB) considered approval of proposed revisions to ch. NR 140 to incorporate the DHS NR 140 Cycle 10 groundwater standard recommendations, including the recommended updated standards for: TCE, PCE, 1,2,3-TCP and 1,4-Dioxane. The NRB did not approve the proposed NR 140 Cycle 10 groundwater quality standards.

Further Reading

DHS resources for contaminants in drinking water

DNR overview of VOCs in private drinking water wells

DNR map of open and closed contaminated sites

DNR database of contaminated soil and groundwater

DHS overview of vapor intrusion

USGS report on VOCs in the nation's groundwater and drinking water wells

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EMERGING CONTAMINANTS

What are they?

Pharmaceuticals, including antibiotics and birth control pills, and personal care products are one group of emerging contaminants. *Photo: US Department of Defense*

An emerging contaminant is a substance for which there is increasing evidence of environmental occurrence and that the substance may cause adverse human and/or environmental health effects. The term is shorthand for "contaminants of emerging concern". There are two general reasons why concern about a substance can be emerging. The first is technological improvements: some emerging contaminants may have been present in the environment for a long time but new measurement methods improve our ability to detect them. The second reason is emergence of a compound not previously common in the environment due to a new substance being manufactured, or recent changes in use or disposal practices of existing substances. Research on the occurrence and health effects of these contaminants is important to characterize the nature of the risk and decide what actions may be required to protect human and environmental health.

Emerging contaminants consist of a range of substances, many of which are produced synthetically, and may enter the environment in wastewater from municipal or industrial sources. Treatment of municipal wastewater typically lowers the concentrations of emerging contaminants, but considerable levels may remain after treatment. Groundwater is impacted if contaminants in treated wastewater infiltrate to groundwater. Emerging contaminants may also enter the environment from agricultural wastes, which may be solid or liquid. Agricultural wastes are often land-spread to make nutrients from the wastes available to crops, but if the wastes contain contaminants, they may migrate toward groundwater as irrigation water, rainwater or snowmelt infiltrate.

Degradation processes, if they occur, can reduce the amount of contaminant that makes it to groundwater. Degradation can be abiotic--for example, through reaction with water, known as hydrolysis—or biotic, meaning that a microbial organism starts a chemical reaction, in which the organism uses some of the original molecule but the rest—a *metabolite*—is left over. Degradation is normally only considered to be complete if all of the parent compound is converted to other naturally occurring chemicals, such as carbon dioxide (CO_2), water (H_2O), and dinitrogen gas (N_2). Incomplete degradation, also known as transformation, is when the parent compound transforms into one or more metabolites but not all the way to naturally occurring chemicals.

Another process that can reduce the amount of a contaminant that arrives in groundwater is *sorption*. Sorption is a physical/chemical reaction in which substances, dissolved or suspended in water, form a bond with minerals or soil organic matter, attaching them to the solid material. Sorption can be reversible, meaning that *desorption* can also occur later. Desorption can occur when the concentration of the same substance in infiltrating water decreases. This can happen, for example, during a large rain event. If a contaminant desorbs under commonly occurring conditions, sorption only increases the amount of time before contaminants make it to groundwater.

Emerging contaminants for which a laboratory analytical standard (i.e., the pure substance dissolved in water or another liquid at a known concentration) exists are often measured with *liquid chromatography with mass spectrometry detection* (LCMS). With this technique, a liquid sample is injected into the laboratory instrument, with or without procedures to "clean up" the sample by removing other compounds that may interfere with measurement. Substances within the sample are then ionized with an electrical charge, and ionized portions of the substances are detected with *mass spectrometry*. The results of mass spectrometry can then be used to determine the molecular weight of the substances in the sample under investigation and identification of specific compounds in the sample can be made.

Technologically advanced variations of this technique include the use of *tandem mass spectrometry detection* (MS/MS), in which two different methods of ionizing the chemicals dissolved in water are used, creating more fragments of the original substance. MS/MS is used for the measurement of Per- and Polyfluorinated Alkyl Substances (PFAS), an important group of emerging contaminants.

Availability of a laboratory analytical standard of a substance is necessary for definitive detection and quantitation. However, emerging research laboratory techniques use high resolution mass spectrometry (HRMS) to obtain a more holistic picture of the variety of chemical compounds present in a sample, including ones for which an analytical standard does not exist. When emerging contaminants are known or suspected to transform, HRMS is particularly useful for finding the metabolites. HRMS is also useful for detecting compounds in the second category of emerging contaminants—newly manufactured substances—for which a laboratory analytical standard may not yet exist. The information on the combinations of split fragments can be compared to a library of possible molecules. From this comparison, inferences about possible chemicals (including metabolites) present can be made, even without a laboratory analytical standard for the substance. HRMS laboratory devices are more expensive and currently less commonly available than LCMS (including ones with MS/MS capability).

The following sections give information on categories of emerging contaminants that may be found in Wisconsin groundwater.

Pharmaceuticals and Personal Care Products

Pharmaceuticals enter the environment through disposal of unused pills as well as excretion of the compounds or their metabolites from the human body. A metabolite is a compound produced by the body's metabolism from the "parent" compound, i.e. the original pharmaceutical. Metabolites often, but not always, have similar chemical properties as the parent compound. Pharmaceuticals detected in groundwater worldwide include antibiotics, non-steroidal anti-inflammatory drugs, birth control medications, and many other prescription medicines. Many pharmaceuticals begin to degrade in soil passage or groundwater, but the presence and types of metabolites are, to a large extent, still being discovered. Stimulants such as caffeine and nicotine, as well as recreational drugs, may also be found in groundwater.

Together, pharmaceuticals and personal care products (PPCPs) - including shampoos, detergents and "over-the-counter" non-prescription medicines - make up a category of emerging contaminants that largely enter the environment from domestic wastewater and municipal sources. Point sources of PPCP discharge into the environment include wastewater treatment plants, which may remove some but not all of these compounds from wastewater, discharge from septic systems, land application of wastewater septage and leakage from older landfills.

Per- and Polyfluorinated Alkyl Substances (PFAS)

A group of emerging contaminants of much current concern are perfluoroalkyl and polyfluoroalkyl substances (PFAS). These molecules are comprised of organic carbon chains in which some (poly-) or all (per-) hydrogen atoms have been replaced with fluorine atoms. PFAS have been used in a variety of industry and consumer products since the 1940s and are now being detected in groundwater and drinking water supplies worldwide. PFAS gained widespread use in part due to their ability to repel water and oil and withstand high temperatures. They are found in numerous consumer products, such as non-stick cookware, stain- and water-repellent clothing and carpeting, grease-resistant liners to food packaging including microwave popcorn, some spray paints, and Class B fire-fighting foams (fires involving flammable liquids).

Many polyfluorinated substances that are part of the PFAS chemicals family transform in the environment to other PFAS, especially to perfluoroalkyl acids such as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS). However, PFAS are not known to degrade in groundwater or elsewhere in the environment into any non-toxic end products. Therefore, they may accumulate in environmental settings. Ways PFAS can enter the environment include placement of PFAS-containing products in landfills, use of the products in combination with water resulting in their presence in wastewater, spreading of biosolids (a product of wastewater treatment) on cropland to replenish soil organic matter, and direct use and lack of containment of the chemicals at manufacturing and firefighting sites.

The two most widely studied PFAS are PFOA and PFOS, both of which present health risks and are commonly found in groundwater. While these two substances may have been manufactured directly during the mid-20th century, manufacturing shifted during the late 20th century to polyfluorinated substances (precursors) that may transform to end products, including but not limited to PFOA and PFOS. These compounds may transform slowly in soil and groundwater, representing ongoing sources of PFOA and PFOS to the environment. Since the turn of the century, manufacturing has shifted to shorter chained compounds such as perfluorobutane sulfonate (PFBS) and its precursors, in applications where previously PFOS or its precursors was used. Additionally, manufacture of PFAS containing additional chemical structures (e.g. ethers) has emerged, with this category of PFAS being known as "replacements". Examples of replacement PFAS are hexafluoropropylene oxide dimer acid (HFPO-DA, sometimes referred to by the trade name "GenX", (a replacement of PFOA) and PFBS (a replacement of PFOS). PFBS and HFPO-DA are among the compounds that were evaluated by the Wisconsin Department of Health Services and that agency has provided recommendations for groundwater quality standards for the two substances to the DNR.

For more information on PFAS, please see the PFAS section of the report.

Pesticides and other Agricultural Contaminants

In many agricultural practices, pesticides are applied to crops to kill or hinder the effects of "pests", which can be insects, competing plants (weeds), fungi, and bacteria. On large areas of crops, application is done from small airplanes to distribute the chemicals over a large area. Due to crop irrigation and precipitation events, pesticides may leach into groundwater. Although about 30 pesticides are currently regulated in Wisconsin, over 90 are known to be used.

Most pesticides can sorb to soil and aquifer material, meaning they often travel to and through groundwater more slowly than the water itself. Some are also transformed into metabolites by bacteria. Active methods of destroying pesticides include photocatalytic techniques, which combine use of light and chemicals to "catalyze" pesticide-destruction reactions.

Although pesticides have been in use since the middle of the 20th century, new pesticides continue to come into use. One such pesticide is the herbicide isoxaflutole, which currently has approval for limited use for weed control on corn crops. Field testing, to evaluate potential groundwater impacts from Isoxaflutole use, are currently underway. For more information on pesticides, please see the pesticides section of the report.

Though functionally part of the PPCPs category of emerging contaminants, antibiotics and anti-parasitical drugs are also used in agriculture, to prevent infection outbreaks in mass raising of livestock. The overall amount of antibiotics used in such applications may be similar to or even greater than usage of antibiotics in human medicine, but generally fewer antibiotic substances are used in livestock applications. An example of a livestock antibiotic is sulfamethazine. Sulfamethazine has a tendency to sorb to soil and can be transformed under toxic conditions, but it may not be fully degraded to naturally occurring chemicals. Another type of contaminant from agriculture is hormones. Steroid hormones have been found in a study of dairy wastewater (Zheng et al., 2008).

Microbial Contaminants

Microbial contaminants such as viruses and pathogenic bacteria can be contaminants in groundwater. In fact, most bacteria that exist in the natural environment are thought to present little if any human health risk. Some bacteria can also improve water quality by degrading other emerging contaminants (e.g. PPCPs). However, a few bacteria are pathogenic (disease causing) and can cause human health impacts. Areas where soil is thin and groundwater supplies are drawn from a carbonate (limestone/dolomite) bedrock aquifer may be especially susceptible to microbial contamination.

Two sources of microbial contaminants are manure from livestock and human sanitary sewage. Pathogenic microbes from these sources may cause gastrointestinal illnesses, sometimes severe. A common type of enteric bacteria (bacteria that reside in the gut of humans and other animals) is *Escherichia coli* (commonly referred to as *E. coli*). Most *E. coli* strains are harmless, but pathogenic strains exist, for example the Shiga toxin-producing strain *E. coli* O157:H7. Water tests for *E. coli* detect a strain of *E. coli* that itself is harmless, but which is a good indicator that pathogenic microbes may be present.

Viruses in groundwater include norovirus, adenovirus and enterovirus. Viruses generally cannot reproduce without a host, but they can infect bacteria. A virus that infects, or replicates within bacteria is referred to as a “bacteriophage” (or simply “phage”). This usage of bacteria as hosts may enable viruses to survive longer in groundwater.

Antibiotic resistance is considered by the World Health Organization to be a major threat to health, food security, and development. After usage of an antibiotic, there is a tendency for bacteria that survived previous applications of the substance to become a larger part of the overall bacterial population—this phenomenon is antibiotic resistance. While antibiotics are used in both human and veterinary medicine, a greater number of antibiotic compounds are thought to be used in humans. As a consequence of antibiotic use in human medicine, multi-resistant bacteria (i.e., bacteria resistant to more than one antibiotic) have been found in clinical settings. Antibiotic resistance has been found in municipal wastewater discharge in studies in Europe, with patterns indicating that the resistance developed in clinical settings is spreading into the environment (Pärnänen et al. 2019). In another study, a strain of *E. coli* resistant to multiple antibiotics was found in hospital wastewater, although community wastewater appeared to be a greater overall contributor of antibiotic resistance (Paulshus et al. 2019). In a study of groundwater impacted by dairies in California (Li et al. 2014), antibiotic resistant *E. coli* bacteria were found in one sample, indicating potential for antibiotic resistant bacteria to be present in groundwater.

For more information on microbial pathogen, see the Pathogens section of the report.

Microplastics

Microplastics are small pieces of plastic, often less than 1 millimeter in size. The name "micro" broadly refers to the size range of micrometers—a micrometer is one one-thousandth of a millimeter. Some microplastics are produced at this size for specific (industrial) purposes, while others are breakdown products of larger plastics (SAPEA, 2019). Microplastics have been found in marine environments for decades (Rochman, 2018), but more recently are being discovered in terrestrial environments, including Lake Michigan (Mason et al., 2016). A recent study published in the journal *Science* found atmospheric deposition of on average 132 plastics per square meter every day on western U.S. protected lands (Brahney et al., 2020). Microplastics appear to accumulate in soils, including ones used for agriculture (Rochman, 2018). A recent study found microplastics—possibly leaked from septic systems—in karst groundwater in Illinois (Panno et al., 2019). While infiltration of water through soils might slow, minimize, or prevent the spread of microplastics into groundwater due to the filtering effect of soils, karst groundwater is particularly susceptible to contamination because water often is present in open fractures. While Wisconsin also has near-surface karst groundwater in some parts of the state, no studies of microplastics in the State's groundwaters are known.

Other Emerging Contaminants

Emerging contaminants not discussed above but which have been studied worldwide include flame retardants, phthalates and other plasticizers, and nanomaterials. Flame retardants are substances that are added to household, commercial building or other products to reduce flammability. A subset of flame retardants of particular concern are brominated compounds, such as polybrominated diphenyl ethers (often abbreviated "PBDEs") and polybrominated biphenyls (often abbreviated "PBBs").

Phthalates are used in bendable plastics as softening agents but are not chemically bound to the plastic and can leach out into water. Research indicates that they might not bioaccumulate (unlike many other synthetic organic compounds), but they have been found to be endocrine disrupting compounds, or substances that disrupt endocrine systems of humans and animals.

Nanomaterials are industrially produced physical particles that are between approximately 1 and 100 nanometers in size (there are one million nanometers in one millimeter). They have diverse uses in industry and commercial products, such as electronic components, paints and coatings, ultraviolet blockers in sunscreens, telecommunication, packaging materials and auto parts.

Occurrence in Wisconsin

The occurrence of emerging contaminants in Wisconsin is not easily generalized, but several studies supported by the GCC have investigated the potential for certain emerging contaminants to enter groundwater from specific sources.

PFAS.

For information on the occurrence of PFAS in Wisconsin's groundwater, please see the PFAS section.

Pharmaceuticals and Personal Care Products.

Antibiotics have been detected in treated wastewater effluent from facilities across the state, with very low concentrations of tetracycline and sulfamethoxazole detected in groundwater directly adjacent to a wastewater treatment facility groundwater discharge site (Karthikeyan and Bleam, 2003). Acetaminophen (Tylenol), paraxanthine (a caffeine metabolite) and the hormones estrone and β-estradiol have been detected in private on-site wastewater treatment system (POWTS) effluent in a Dane County study (Bradbury and Bahr, 2005), and estrogenic endocrine disrupting compounds (EDCs) were detected in POWTS effluent in a southeast Wisconsin study (Sonzogni et al., 2006). Neither study detected these compounds in groundwater. A follow up study at the Dane County site, ten years after subdivision development, however, found a number of contaminants that may have moved from POWTS discharge into groundwater. Artificial sweeteners—often used as an indicator of municipal wastewater effluent—were found in seven of ten monitoring wells and two water supply wells.

Pete Chase and Jacob Krause, WGNHS, install well casing during a WGRMP-funded experiment designed to improve understanding of virus transport from wastewater to drinking water wells. *Photo: Blake Russo-Nixon*.

Microbial pathogens.

Human enteric virus indicators and pathogenic bacteria indicators have been found in groundwater supply wells in the Madison area (Bradbury et al., 2015). Studies also suggest human enteric viruses from wastewater sources may be present in private and public drinking water wells across the state (Borchardt et al., 2003a, 2003b, 2004, 2007; Bradbury et al. 2013).

Nested piezometers installed for monitoring groundwater levels and sampling for groundwater contaminants near Spring Green. Photo: Blake Russo-Nixon.

Pesticides.

For information on the occurrence of pesticides in Wisconsin's groundwater, see the pesticides section.

GCC Agency Actions

By definition, much is unknown about emerging contaminants, so an important role of the GCC is supporting research studies that further scientific understanding of these substances. In addition to the many studies mentioned above that tested for occurrence of emerging contaminants, other WGRMP-funded projects have explored pathways of contaminant transport. One group of these studies investigated factors that affect the mobility and fate of antibiotics in the subsurface (Gao and Pedersen, 2005 and 2010; Gu and Karthikian, 2005a, 2005b, 2008; Gu et al., 2007; Sibley and Pedersen, 2008; Pedersen et al., 2009). This body of work has helped describe under what conditions specific antibiotic compounds bind to soil, which is important for assessing the risk to groundwater from antibiotics in wastewater sources.

Health effects of emerging contaminants vary and are not always well understood. Some emerging contaminants, including some pesticides and PPCPs, act as endocrine disrupting compounds (EDCs), which adversely affect the behavior of natural hormones in animals and humans. EDCs include both anthropogenic chemicals, such as pesticides and plasticizers, and naturally occurring compounds like steroids and plant-produced estrogens. Scientific studies suggest toxic endpoints varying by compound, with possible health effects including developmental, reproductive, neurologic and immune problems, as well as cancer (NIH, 2010). In many cases, more research is needed.

Periodic groundwater monitoring in areas known to be vulnerable to emerging contaminants is another way in which GCC agencies coordinate efforts to understand emerging contaminants. DATCP's regular statistical survey of agricultural chemicals and targeted monitoring programs in agricultural areas are examples of this. The DNR also regularly reviews groundwater data from near active and closed landfills, mining operations and hazardous waste remediation sites to gather information on potential sources of emerging contaminants.

Future Work

In Wisconsin law, there is an established process for regulated facilitates to review groundwater monitoring data and identify contaminants of emerging concern (WI 160.27). A fundamental component of this process is the long-term groundwater monitoring data itself, so maintenance and expansion of current networks is an ongoing priority for the GCC.

The US Environmental Protection Agency (EPA) also has a process for regularly gathering data on emerging contaminants and assessing potential risks nationwide. The Unregulated Contaminant Monitoring Rule (UCMR) provides for monitoring of unregulated contaminants every five years, in all large (serving > 10,000 people) and a sample of small (serving < 10,000 people) public water systems. The Third

UCMR (UCMR3) monitoring period was completed in 2015. Monitoring for the Fourth UCMR (UCMR4) began during 2018 and focused on select pesticides and several naturally occurring compounds. The Fifth UCMR (UCMR5) will begin in 2023 and will focus on PFAS, with an expanded analyte list and lower detection limits compared to UCMR3. Data collected at Wisconsin public water supply systems during UCMR monitoring along with GCC-supported monitoring and occurrence study results provide valuable information on the occurrence of emerging contaminants in Wisconsin's groundwater resources.

The US EPA also maintains a Contaminant Candidate List (CCL) of physical, chemical, biological and radiological substances that might potentially be found in drinking water. Potential contaminants listed on the CCL are substances not currently subject to federal Safe Drinking Water Act (SDWA) regulation but are known, or anticipated to be present in public water supply systems. The US EPA evaluates occurrence data on these unregulated contaminants and this information assists with identification of potential emerging contaminants in Wisconsin groundwater.

Currently, there are no federal regulatory standards for PFAS associated with any environmental media. As part of a continuing commitment to protect public health, public welfare, and the environment, the DNR periodically updates groundwater quality standards in ch. NR 140, Wis. Adm. Code. In 2018 the DNR requested that DHS review toxicological information available for a number of substances found in Wisconsin groundwater, including two PFAS compounds, PFOA and PFOS. This group of substances DNR asked DHS to review were designated the "Cycle 10" substances. In 2019 the DNR requested that DHS review toxicological information available for another group of substances found in Wisconsin groundwater. This group was designated the "Cycle 11" list of substances and included a number of PFAS compounds.

Based on its review, DHS recommended state groundwater quality standards for many of the substances on the Cycle 10 and 11 lists (see https://www.dhs.wisconsin.gov/water/gws.htm). On February 23, 2022, the DNR Natural Resources Board (NRB) considered approval of proposed revisions to ch. NR 140 to incorporate the DHS Cycle 10 groundwater standard recommendations, including the recommended standards for PFOA and PFOS. The NRB did not approve the proposed NR 140 Cycle 10 groundwater quality standards. The DNR is now evaluating work on substances contained in Cycle 10 and has paused work on rulemaking to incorporate the DHS Cycle 11 groundwater standards recommendations into NR 140.

Further Reading

DNR overview of pharmaceuticals and PCPs in the environment

DNR overview of per- and polyfluoroalkyl substance (PFAS) contamination

Wisconsin Remediation and Redevelopment Database (WRRD)

DATCP Groundwater Quality Reports

NIH factsheet on endocrine disruptors

US EPA Third Unregulated Contaminant Monitoring Rule (2012-2016) fact sheets

US EPA Third Unregulated Contaminant Monitoring Rule (2012-2016) data summary

US EPA Fourth Unregulated Contaminant Monitoring Rule (2017-2021) information

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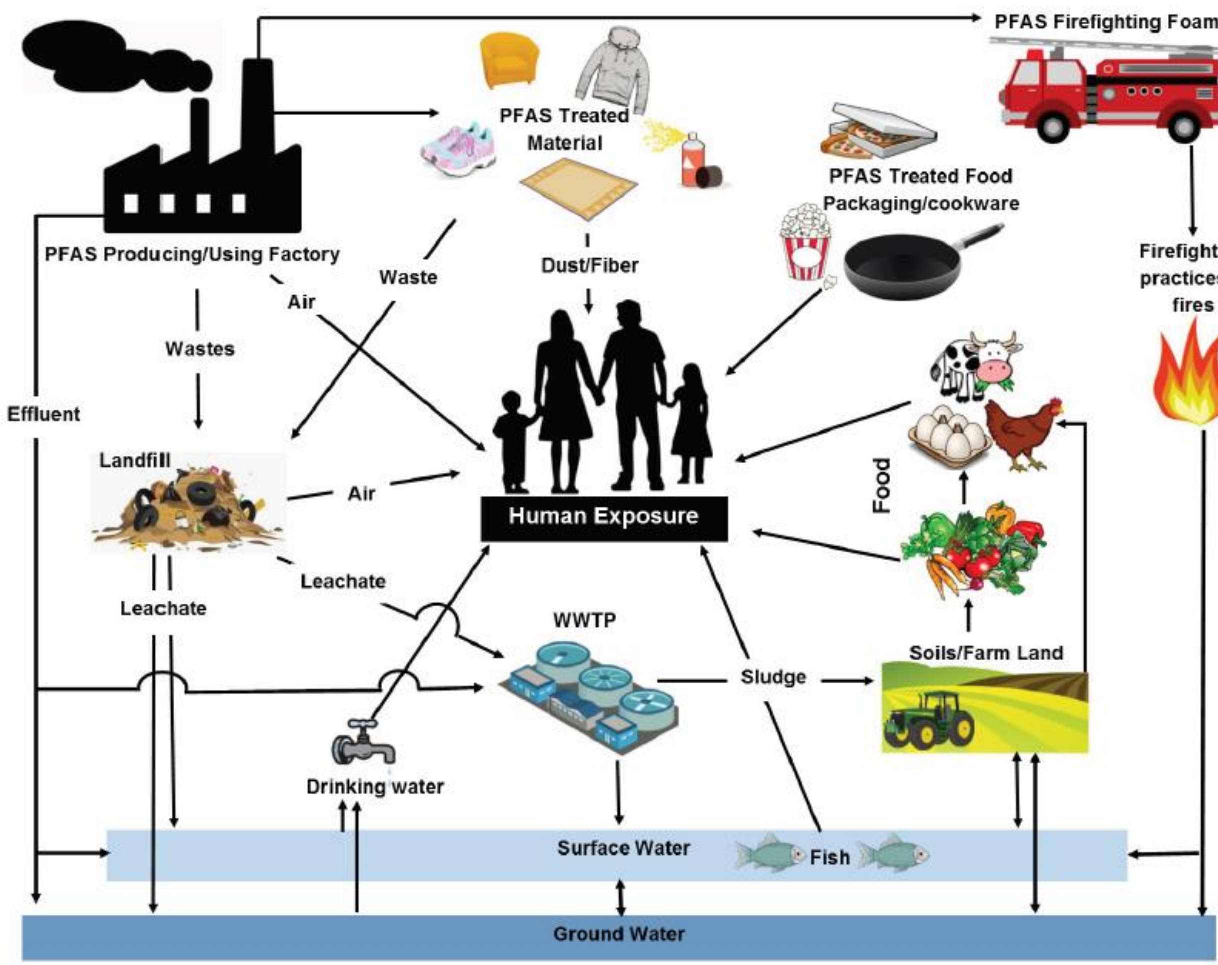
PER- AND POLYFLUORINATED ALKYL SUBSTANCES

What are they?

Perfluoroalkyl and polyfluoroalkyl substances (PFAS) are a large group of human-made chemicals that have been used in industry and consumer products worldwide since the 1940s. Their ability to repel water and oil and withstand high temperatures has made PFAS a particularly useful ingredient in industrial and commercial products, including non-stick products, stain- and water-repellent clothing, and aqueous film forming foams (AFFFs). These chemicals do not easily break down in the environment and have been known to accumulate in the environment and humans.



Sources of PFAS and modes of human exposure. *Image credit: Maine Drinking Water Program, Service Connection newsletter, Volume 25, Issue 4. Image adapted from Oliaei et al., 2013.*

Although PFAS have been used extensively since the mid-20th century, in recent years the scientific health research community has made progress to better understand their potential impacts to human health. This understanding continues to evolve based on ongoing research. Perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) are the two most-studied individual PFAS chemicals. Current studies of these

PFAS suggest exposure may affect childhood development, decrease female fertility, increase the risk of high blood pressure in pregnant women, increase cholesterol levels, increase the risk of thyroid disease, and decrease antibody response to vaccines. EPA research suggests that some PFAS may have the potential to cause cancer, but the topic requires further research.

Currently, there is limited regulatory authority regarding PFAS at the federal level. In 2016, the EPA issued a non-enforceable Lifetime Health Advisory level (HAL) for PFOA and PFOS of 70 parts per trillion (ppt) in drinking water. In June 2022, the EPA issued Interim updated lifetime HALs for PFOA and PFOS of 0.004 ppt and 0.02 ppt, respectively (four to five orders of magnitude lower than the previous HAL of 70 ppt). These health advisories are applicable to non-cancer health outcomes (the evaluation regarding cancer outcomes is still ongoing). Also in June 2022, EPA issued HALs for GenX chemicals, which refers to hexafluoropropylene oxide dimer acid (HFPO-DA) and its ammonium salt, and perfluorobutanesulfonic acid (PFBS) of 10 ppt and 2,000 ppt, respectively.

Firefighters training with firefighting foam. A specific type of firefighting foam, known as Aqueous Film Forming Foam, contains significant amounts of PFAS and is designed for use on fires involving flammable liquids (Class B).

The EPA Interim updated lifetime HALs for PFOA and PFOS are lower than currently available laboratory technology can measure. The PFOS HAL is about 10x lower than what instruments typically in use today can detect. The PFOA HAL is about 30x lower than what instruments typically in use today can detect. If future technology advances occur to detect at these lower levels, it remains to be seen if it will be possible to perform the analysis without contamination at sub-ppt levels. Although the new EPA HALs for PFOA and PFOS are below current detection limits, toxicity studies suggest that negative health effects may occur even at concentrations of PFOA or PFOS in water that are not currently detectable. EPA has stated in an FAQ on the HALs that it is known that the lower the levels of PFOA and PFOS, the lower the risk.

The WI Department of Health Services (DHS) has recommended state public health groundwater quality enforcement standards for 18 PFAS compounds. These recommended standards serve as state drinking water HALs. DHS has also recommended a cumulative risk assessment approach, called a hazard index (HI), for PFAS. The DHS PFAS HI takes into consideration all PFAS that have a recommended groundwater enforcement standard. The DHS PFAS HI is the summation of individual PFAS hazard quotients (HQs). The HQ is the ratio of the exposure dose (drinking water sample concentration) for: DONA, PFBS, PFHxS, PFNA, PFDA, PFTeA, PFUnA, PFDoA, PFODA, HFPO-DA , PFBA or PFHxA, or the combined concentration of NEtFOSE, NEtFOSAA, NEtFOSA, FOSA, PFOA, and PFOS, divided by their respective recommended public health enforcement standard. If the PFAS HI exceeds 1.0, DHS recommends that the water not be consumed.

The DNR, under Chapter 292, Wisconsin Statutes, has authority to require parties that discharge PFAS to the air, land, and waters of the State to take action to restore the environment to a practicable level. DNR's Water Quality Program has authority to regulate discharges to surface water in accordance with the federal Clean Water Act. New DNR administrative rules will go into effect in 2022 to gradually phase in PFAS monitoring requirements for wastewater discharges. In some cases, new regulations will require some industrial sources to take action to reduce their PFAS discharge to municipal wastewater treatment facilities.

Occurrence in Wisconsin

The DNR has begun sampling initiatives for PFAS in drinking water and ambient groundwater. These efforts include municipal drinking water sampling, open to all municipal systems, and a groundwater research study sampling private wells. Both projects are occurring on a basis of voluntary participation.

The municipal drinking water project is sampling post-treatment water from about 130 municipal systems statewide (as of July 14, 2022). Laboratory analysis is being done using EPA Method 537.1 for 18 PFAS, which includes 13 of the 18 PFAS that have established DHS drinking water HALs. Results from the West Central and South Central regions of the state, received as of June 21st, indicate that 38 systems have no detections above the method reporting limits and 12 systems have detections with PFAS HI values less than 0.5. One system (Prescott Waterworks) had one Entry Point sample with a PFAS HI value between 0.5 and 1.0, while samples from four municipal systems (Adams, Mosinee East, Marshfield and Weston) have HI values of 1.0 or higher. The project is expected to be completed in August 2022.

In June 2022, the DNR began a project to sample for PFAS and other water quality parameters in 450 private wells, spaced apart geographically across the entire state. The main objective of the research study is to determine concentrations of PFAS present in ambient groundwater, that is, groundwater in locations that are not near a known high concentration release of PFAS. Another objective is to evaluate the usefulness of several potential source indicator chemicals, chemicals that might be used to pinpoint what source(s) of PFAS to groundwater may be present in an area. Potential PFAS source indicators include some PFAS compounds that are environmental transformation products of fluorotelomer polymers, inorganic compounds such as nitrate and chloride, and some non-PFAS organic compounds. Those non-PFAS organics are the environmental transformation products of two commonly used herbicides and a suite of human waste indicators that includes artificial sweeteners and caffeine. The project is a partnership between the DNR, Wisconsin State Laboratory of Hygiene and the Center for Watershed Science and Education at the University of Wisconsin-Stevens Point.

Prior to these two projects, limited information about the occurrence of PFAS in Wisconsin's groundwater resource had come mostly from the EPA's third Unregulated Contaminants Monitoring Rule (UCMR-3), conducted between 2013 and 2015, and from voluntary sampling by a few municipalities. In the UCMR-3 sampling, PFAS were detected in municipal water systems in La Crosse, West Bend, and Rhinelander. At the time, laboratory analysis was only done for six PFAS analytes, whereas since the beginning of 2020, laboratory analysis for Wisconsin samples has often been done for at least 33 PFAS analytes. Also, laboratory reporting limits were considerably higher in the UCMR-3 project than they are today. The data from UCMR-3 served as an initial indicator of the fact that both groundwater and drinking water supplies in Wisconsin have been impacted by PFAS. Voluntary sampling by a few municipalities (from 2019 through the first quarter of 2022) has shown additional impacts above Wisconsin DHS HALs in Madison, Eau Claire, Wausau and Rib Mountain. PFAS impacts in La Crosse and the Town of Campbell on French Island have also been documented during ongoing site investigations in those locations.

In the past several years, much work on PFAS in Wisconsin has focused on contaminated site investigations. As of July 2022, there are over 70 open site investigations statewide (DNR Bureau for Remediation and Redevelopment BRRTS Tracking System at https://dnr.wisconsin.gov/topic/Brownfields/botw.html) where one or more PFAS have been identified as a contaminant. Such contaminated site investigations include former firefighting training areas (civilian, corporate and military), industrial facilities, landfills, and an area where biosolids were land applied.

The latter two types of sites are secondary sources, where PFAS were not produced or used directly but rather released to the environment due to their presence in consumer products or other waste streams. Among landfills, older unlined landfills may present a higher risk to groundwater. The environmental stability and lack of effective treatment of PFAS in municipal sewage plants may lead to their presence in biosolids, which might threaten the practice of biosolids land spreading as a beneficial reuse of municipal waste. In areas without municipal sewerage, PFAS may also be released to groundwater from septic systems due to their presence in numerous commercial products.

Where PFAS are discovered in groundwater and attributed to a responsible party, the site investigation and required remedial actions may result in a multi-year cleanup process, and for larger and more complex sites cleanup activities may take decades. This work includes all impacted media, not just groundwater. Despite the fact that

PFAS are exclusively created by industrial production and they do not occur naturally, PFAS have been found at relatively low levels in surface water (https://dnr.wisconsin.gov/topic/PFAS/SWFish.html), soil (in a study across North America - Rankin et al., 2016) and precipitation (in a study focused on Indiana and Ohio - Pike et al., 2020; publication of a Wisconsin-specific study of PFAS in precipitation is in process and expected later in 2022). These studies indicate the potential that lower PFAS concentrations may also be found in ambient groundwater. The groundwater private well PFAS sampling project that began in June 2022 is intended to 1) provide information about the chances of finding PFAS in private and small public (e.g., restaurants, schools, churches) drinking water systems. The project will also provide information to entities involved in PFAS site investigations that may help with determining if lower PFAS groundwater concentrations, more distal from the investigation site detections of PFAS, are from the site or may instead be coming from more disperse sources (e.g., consumer products).

GCC Agency Actions

Currently, there are no state or federal groundwater protection standards for PFAS. To address this regulatory gap, DNR requested DHS review of a total of 36 PFAS and, if warranted, provide recommendations for state NR 140 groundwater quality standards. The DHS PFAS review was part of their NR 140 Cycle 10 and 11 review efforts. For their review, DHS searched for toxicity information for 36 individual PFAS. In June 2019, DHS recommended a groundwater enforcement standard of 20 parts per trillion (ppt) as a combined standard for PFOA and PFOS (part of the Cycle 10 recommendations). In November of 2020, DHS recommended groundwater enforcement standards for 16 additional PFAS as part of their Cycle 11 groundwater standard recommendations. DHS recommended that four of the Cycle 11 PFAS be regulated as combined standards, along with PFOA and PFOS. For the remaining 12 PFAS, individual standards were recommended.

On February 23, 2022, the DNR Natural Resources Board (NRB) considered approval of the DHS NR 140 Cycle 10 groundwater standard recommendations, including the recommended standard of 20 ppt for PFOA and PFOS, as state NR 140 groundwater quality standards. They also considered a proposed NR 809 public drinking water Maximum Contaminant Level (MCL) for PFOA and PFOS. The proposed public drinking water MCL was based on the June 2019 DHS PFAS review and recommendations.

The NRB did not approve the proposed NR 140 Cycle 10 groundwater quality standards, with only three Board members voting in favor of the standards. The NRB did vote 4-3 to enact an NR 809 PFOA and PFOS combined MCL but revised the MCL from the 20 ppt DHS 2019 recommendation to the EPA 2016 HAL of 70 ppt. The EPA 70 ppt HAL was issued approximately three years before the DHS recommendation of 20 ppt. The difference between the two numbers shows that more was learned about the toxicity of PFOA and PFOS during the three years between issuance of the two numbers. In June 2022, the legislature approved the proposed NR 809 PFOA and

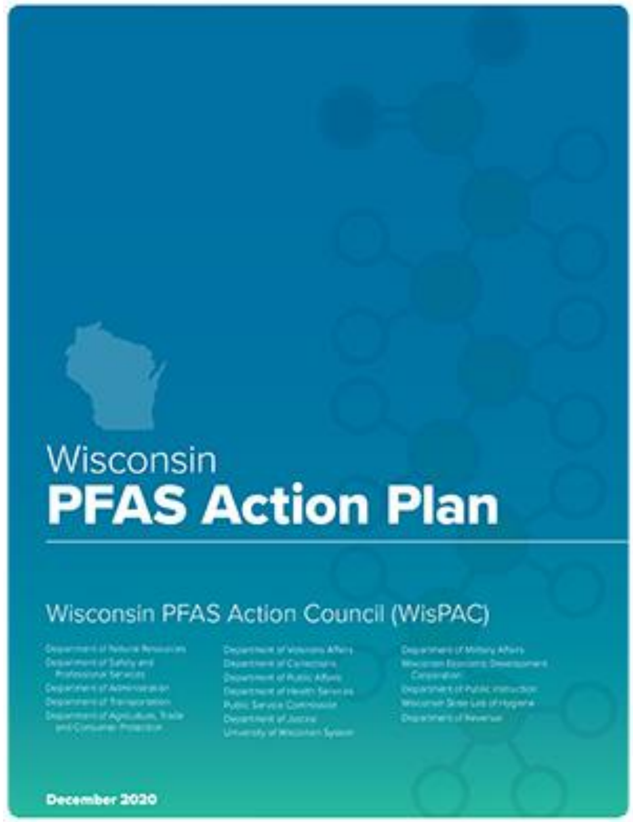
PFOS MCL as revised by the NRB. Consequently, an MCL of 70 ppt for PFOA and PFOS will go into effect in August 2022 with sampling requirements for municipal systems being phased in beginning in December 2022. Sampling requirements for Other-Than-Municipal Community water systems (e.g., apartment complexes outside of a municipal service area) and Nontransient Noncommunity systems (e.g., schools) will be phased in beginning in 2023.

At the Feb. 23, 2022 NRB meeting some NRB members, voting in opposition to the recommended DHS 20 ppt PFOA and PFOS groundwater enforcement standard, expressed the opinion that the Wisconsin standard should be based on a federal number, such as the 2016 EPA HAL of 70 ppt (for PFOA and PFOS combined). In June 2022, EPA issued Interim updated Health Advisories of 0.004 ppt for PFOA and 0.02 ppt for PFOS, which are 17,500 times lower and 3,500 times lower than the 2016 EPA HAL, respectively. DNR has not proposed any new groundwater quality standards for PFOA and PFOS at this time. However, DNR and DHS are closely monitoring EPA progress toward setting federal MCLs for PFOA and PFOS to determine if updated groundwater enforcement standard recommendations in ch. NR 140, in accordance with ch. 160 Wisconsin Statutes, are warranted.

A consequence of the February 23rd NRB vote not to approve the Cycle 10 update of NR 140 Groundwater Standards is that DNR has paused work on rulemaking on the Cycle 11 update of NR 140. The Cycle 11 NR 140 update potentially will included DHS scientific, health-based groundwater standard recommendations for four additional PFAS, to be grouped with PFOA and PFOS for a combined standard of 20 ppt. Those four additional PFAS compounds are: perfluorooctane sulfonamide (PFOSA; CAS number 754-91-6), n-ethyl perfluorooctane sulfonamide (NEtFOSA; CAS number 4151-50-2), n-ethyl perfluorooctane sulfonamidoacetic acid (NEtFOSAA; CAS number 2991-50-6) and n-ethyl perfluorooctane sulfonamidoethanol (NEtFOSE; CAS number 1691-99-2). All four of these are known precursors to PFOS, that is, they chemically transform in both the environment and the human body into PFOS. While it has been suggested that the DNR does not have authority to make combined groundwater quality standards, the four Cycle 11 compounds above, plus PFOS, are an example of a group of chemicals for which there is a clear scientific basis for combined standards, rather than for those compounds being regulated individually.

In the absence of NR 140 groundwater standards and MCLs at a level that the scientific community agrees accurately reflect current knowledge about the toxicity of PFOA and PFOS, DNR and DHS still recommend to the public that the DHS HALs from 2019 and 2020 be viewed as the best available guidance for human consumption of PFAS impacted drinking water. This guidance applies to water that is used for drinking as well as for cooking. As additional guidance regarding cumulative health effects of PFAS mixtures, DHS recommends that a PFAS HI be calculated for all PFAS drinking water samples. If the calculated PFAS HI for a drinking water sample exceeds 1.0, DHS recommends that the water not be consumed. Guidance for temporary water for private well owners affected by PFAS is available. DHS and the Wisconsin Department of Safety and Professional Services (DSPS) also have a brochure available on treatment options to lower PFAS levels in drinking water.

The Wisconsin PFAS Action Plan was released in December 2020. The plan was developed by the Wisconsin PFAS Action Council, or WISPAC, to serve as a roadmap for addressing PFAS contamination in diverse environmental media and settings in the state. The PFAS Action Plan presents several recommendations, including one specifically for drinking water (including groundwater sources). That recommendation is to conduct statewide drinking water testing, including all municipal systems as well as some other priority community and non-community public water systems. Work on sampling municipal systems, on a voluntary basis, is now underway.



The Wisconsin PFAS Action Plan was released in December 2020.

The PFAS Action Plan also presents several other recommendations that directly or indirectly relate to groundwater. The following table presents an overview of recommendations most directly related to groundwater (readers are referred to the PFAS Action Plan for more detail and other recommendations not listed here) and the status of implementation:

Recommendation number	**Summary of recommendation (see the PFAS Action Plan for full text)**	**Status of groundwater-related implementation**
1.1	Establish science-based environmental standards for PFAS	Three members of the Natural Resources Board (NRB) voted in favor of the NR 140 Cycle 10 recommendations (which included PFOA and PFOS), with three in opposition and one abstaining. As a result, the recommended, science-based groundwater quality

		enforcement standard of 20 ppt for PFOA and PFOS was not approved. DNR has paused work on Cycle 11 (16 additional PFAS) rulemaking.
1.2	Safely manage PFAS in landfill leachate	DNR is reviewing scientific studies on PFAS in landfill leachate.
2.4	Test public water systems for PFAS	A statewide voluntary sampling program has been underway since April 2022.
3.4	Identify PFAS sources and reduce discharges to wastewater facilities	New wastewater effluent discharge rules were passed by the NRB. These rules will be phased in beginning in fall 2022 and may help facilitate reduction of industrial discharges of PFOA and PFOS to publicly owned wastewater treatment facilities.
5.2	Monitor background[1] levels of PFAS in the environment (includes groundwater and a variety of other environmental media).	DNR began sampling of 450 private wells statewide to learn about the prevalence of PFAS in Wisconsin shallow groundwater. Well selection excluded areas within 3 miles of a known PFAS site in order to represent ambient conditions.

Table footnote:

[1] Multimedia research has shown that PFAS can be transport long distances from a source. The term 'background', as it appears in the PFAS Action Plan, is meant in the sense that some low concentrations of certain PFAS might be widespread and/or not readily attributable to a local source. However, PFAS do not occur naturally.

Further Reading

DNR PFAS page: https://dnr.wi.gov/topic/Contaminants/PFAS.html

DHS Groundwater Contaminant recommendation process: https://www.dhs.wisconsin.gov/publications/p02432.pdf

DHS Cycle 10 and Cycle 11 groundwater quality standard recommendations: https://www.dhs.wisconsin.gov/water/gws.htm

Interstate Technology and Regulatory Council fact sheets: https://pfas-1.itrcweb.org/

US Agency for Toxic Substances and Disease Registry PFAS page:

https://www.atsdr.cdc.gov/pfas/index.html

US Environmental Protection Agency PFAS page: https://www.epa.gov/pfas

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WATER USE

Chapter 281 of the Wisconsin Statutes requires annual reporting to the Wisconsin Department of Natural Resources of monthly withdrawals from all wells and surface water withdrawal systems capable of supplying water at a rate of 100,000 gallons per day or more. This includes water uses such as public supply systems, energy production, paper manufacturing and agricultural irrigation. The reported water use data is spatially located, which allows for DNR to provide customized water use information to specific locations, withdrawal types and water uses. These annual water use reports improve our understanding of spatial and temporal trends in water withdrawals.

The 2018 Water Use StoryMap showed that the largest category of groundwater withdrawals was municipal public water supplies (DNR 2019). The second largest category of groundwater withdrawal in the state was agricultural irrigation. Agricultural irrigation water use varies from year to year depending on the timing of rainfall during the growing season.

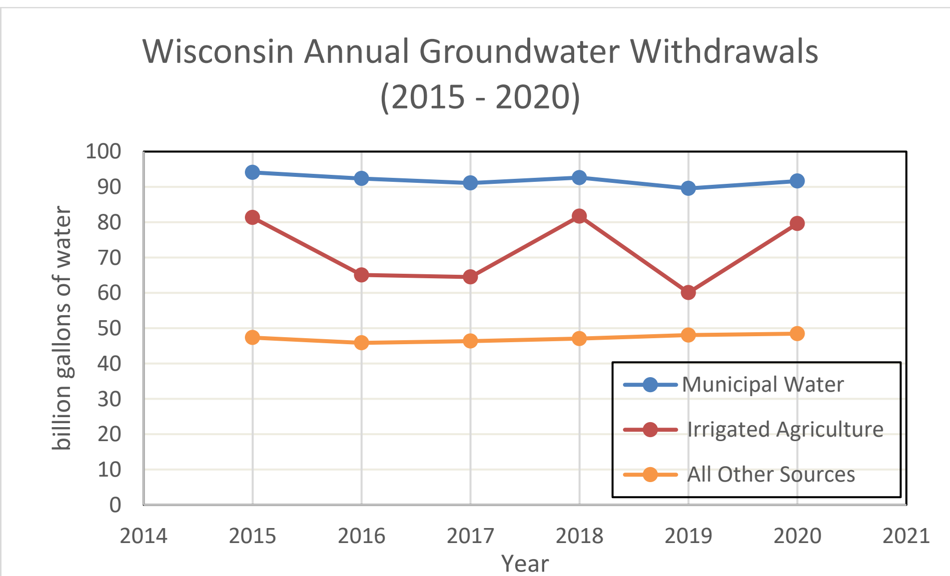

Figure 1. Wisconsin annual groundwater withdrawals, 2015 – 2020. (DNR)

New tools are available to view water use data spatially and to search and aggregate water use data at https://dnr.wi.gov/topic/WaterUse/data.html.

Reference:

Wisconsin Department of Natural Resources. 2019. Wisconsin Water Use – 2017 Reported Withdrawals. Technical Memo. 6p. Available at: https://dnr.wisconsin.gov/sites/default/files/topic/WaterUse/WithdrawalReport/2017.pdf.

GROUNDWATER/SURFACE WATER INTERACTIONS

Groundwater pumping is substantially impacting streamflows and water levels in lakes and wetlands in parts of Wisconsin. This issue differs from the large regional drawdown issues in the northeast and southeast, where water level declines are mainly in the confined or semi-confined systems not well connected to surface waters.

Central Sands

The Central Sands region lies east of the Wisconsin River and encompasses 1.75 million acres in parts of Adams, Marathon, Marquette, Portage, Shawano, Waupaca, Waushara and Wood counties. The 800 miles of trout stream and 300 lakes are generally well connected to the sand and gravel aquifer and provide recreation and tourism value including hunting, fishing, canoeing and kayaking. The productive sand and gravel aquifer also supports groundwater withdrawals from water use sectors including irrigated agriculture, municipalities and industry. Within this region 25% of the state's groundwater is pumped from several thousand high capacity wells, predominantly for irrigation. The number of high capacity wells and reduced water levels in some areas has caused concerns about the potential impacts of groundwater withdrawals on water resources. One example of the impact of groundwater withdrawals on water resources is the Little Plover River in Portage County. The Little Plover River, a Class I trout stream and Exceptional Resource Water in Portage County, has dried in parts during various years since 2005.

The Wisconsin Geological and Natural History Survey and United States Geological Survey constructed a groundwater flow model for the Little Plover River watershed in Portage County. This model is a scientific tool for understanding the complexities of geology, groundwater recharge and discharge, surface-water flow, well development and use and water balance. The model simulates the complex temporal and spatial interactions among streamflow, pumping and climate and provides users "what-if" evaluations of possible decisions involving management of water use or land-use changes. The Little Plover River Basin was chosen for this pilot study because the river has been the focus of recent management concern and because a great deal of hydrogeologic data already exists for this area (https://fyi.uwex.edu/littleplovermodel/files/2014/08/Little-Plover-River-handout.pdf).

Beginning in 2017 stakeholders including the Village of Plover and agricultural producers in conjunction with DNR, consultants and the Wisconsin Wetland Association, formed the Little Plover River Watershed Enhancement project with the goal of achieving sustained flow and aquatic health within the river. The stakeholders are utilizing the groundwater flow model as one tool to assist with establishing land and water best management practices.

In addition to examining the connection between groundwater withdrawals and streamflow in the Little Plover River area, 2017 Wisconsin Act 10, referred to by the DNR as the Central Sands Lakes Study, provides the basis for the DNR to define significant impacts on three Central Sands lakes (Plainfield, Long and Pleasant) in Waushara County and quantify the relationship between groundwater withdrawals, lake levels and significant impacts. The lakes have been of keen interest to stakeholders in Central Wisconsin, particularly in the last decade. The key findings from the three year study are that groundwater withdrawals cause reductions in Pleasant, Long, and Plainfield Lakes. The reductions are significant and impact the lakes' ecosystems in Long and Plainfield Lakes. The study findings show that the reduction caused by groundwater withdrawals to study lake levels are a result of the collective impact from many high-capacity wells rather than any specific high-capacity well. As a result, the DNR recommends a regional framework, such as a water use district, to implement measures to reduce significant impacts from groundwater withdrawals. Learn more at: https://dnr.wi.gov/topic/Wells/HighCap/CSLStudy.html.

Dane County

Although groundwater and surface water resources are plentiful in Dane County, there are several well documented cases of impacts to surface water due to groundwater withdrawals. Just as regional drawdowns have developed across Dane County in response to high-capacity pumping of groundwater for municipal and industrial supply (see Regional Drawdowns section of the report), several smaller streams and spring systems have also been impacted over the past several decades resulting in reduced flow rates.

Some of the most significant impacts have been to Starkweather Creek on the east side of Madison as well as springs along the south shore of Lake Mendota, north shore of Lake Wingra and around lake Monona. Baseflow in Starkweather Creek has decreased as stormwater is diverted from impervious areas to drainage ditches and high-capacity pumping lowers water levels. At Springhaven Pagoda, which was built in the late 1800's to house a spring near the shore of Lake Monona, the spring has stopped flowing entirely. At Merrill Springs, near Spring Harbor along the south shore of Lake Mendota, a spring pool that was built in the mid-1930s has decreased its flow by upwards of 90% (http://www.springharboronline.com/where-are-the-springs-in-spring-harbor.html). The reduction in these surface water flows is considered to be due to decreases in recharge from urbanization and, even more importantly, the result of regional drawdowns from pumping high-capacity wells.

The Dane County groundwater flow model, which is calibrated based on observed water levels in wells and lakes, as well as flow rates in streams and springs, has provided further evidence of impacts to surface water along the Yahara River corridor. Model simulations over the past decades have consistently shown a reversal in groundwater flow along the southern two-thirds of Lake Mendota and all of Lake Monona. The result is that lakes that historically gained groundwater now lose water to the groundwater system. This reversal, which is due primarily to the concentration of high-capacity wells in the greater Madison area, has effectively drawn groundwater levels down in wells and impacted flows in sensitive stream and spring systems which are replenished by shallow groundwater supplies.

Springs Inventory

Groundwater springs [video link] are special places where the water table reaches the land surface and overflows into streams and wetlands. Springs are critical natural resources since they supply cool, oxygen-rich water for trout and often harbor threatened and endangered species. Springs are also a window into the groundwater below the surface and they can provide a great deal of information about the chemical composition and flow of local groundwater. Springs are often well loved for their scenic beauty at public parks.

Because these special natural resources are vulnerable to groundwater pumping, the Department of Natural Resources (DNR) reviews high capacity well applications involving wells constructed near springs for adverse environmental impacts. Springs, for the purpose of a high capacity well review are defined in statute as "… an area of concentrated groundwater discharge occurring at the surface of the land that results in a flow of at least one cubic foot per second at least 80 percent of the time." There are over 10,000 known springs in Wisconsin and it is not a simple task to determine, given a proposed high capacity well, which nearby springs need to be assessed. Correct information about the location and flow rate of each spring is critically important to have, but existing data come from many sources – some as old as 1905 – with varying levels of quality and accuracy. Springs can also be used as easy sampling points for indicators of groundwater quality.

Pheasant Branch spring in Middleton, WI. *Photo: WGNHS*

In keeping with the stated mission of the GCC to assist in the efficient management and exchange of groundwater data, GCC agencies and researchers have worked together to gather data about Wisconsin's springs into a centralized inventory for Wisconsin. In 2007, the establishment of a statewide springs database (Macholl, 2007) was a major step forward in pulling together data from disparate sources. In 2017 researchers at Beloit College and WGNHS completed a three-year springs inventory for the State of Wisconsin. This inventory created a springs database by conducting field surveys of springs with historical flow rates of 0.25 cfs or more and established reference springs in representative hydrogeological and ecological settings for long-terming monitoring. Accessible to scientists, water resources managers and the general public the springs inventory is available on the DNR Wisconsin Water Quantity Data Viewer. DNR continues the springs inventory monitoring project by identifying new springs, continue monitoring of reference spring sites, and revisiting previously identified springs in the springs inventory.

Wisconsin Stream Model

DNR researchers have developed a detailed model that predicts streamflows in ungaged streams using identify factors (such as land use, groundwater recharge and climatic elements). The model also links these variables to the abundance of fish species in Wisconsin's streams. This project helps determine what hydrologic changes are likely to cause significant *environmental impacts* to Wisconsin streams.

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REGIONAL DRAWDOWNS

The effects of groundwater withdrawals on a regional scale are seen in the Lower Fox River Valley, southeastern Wisconsin, Dane County and the Central Sands. The Lower Fox River Valley and southeastern Wisconsin were designated Groundwater Management Areas based on water level drawdowns of more than 150 feet observed in those two regions. Drawdowns in parts of Dane County have been around 50 feet. Large groundwater drawdowns indicate changes in the flow systems. Around 1900, flowing wells were present in both the Lower Fox River Valley and southeastern Wisconsin. Pumping has caused drawdowns in those aquifers so that today the water levels are often hundreds of feet below the ground surface. Excessive drawdowns can cause reduced yields to wells, lower water quality and divert water from surface waters.

Lower Fox River Valley

Water levels in the Lower Fox River Valley have varied widely over time. Water levels in the deep aquifer of the Lower Fox River Valley were above the land surface before significant pumping from that aquifer in 1900. By 1957, increased pumping in the deep sandstone aquifer lowered water levels by hundreds of feet. In response, the City of Green Bay switched from groundwater supply to surface water supply and the water levels increased more than 200 feet in the aquifer.

By 2005, increased pumping from the communities surrounding Green Bay caused water levels to decrease to the low levels seen in 1957. In response to that drawdown, six suburban communities in the Lower Fox Valley reduced consumption of groundwater by about 8.2 million gallons per day by switching to surface water supplied by pipeline from Lake Michigan in 2007. As a result, water levels in the deep sandstone aquifer in and

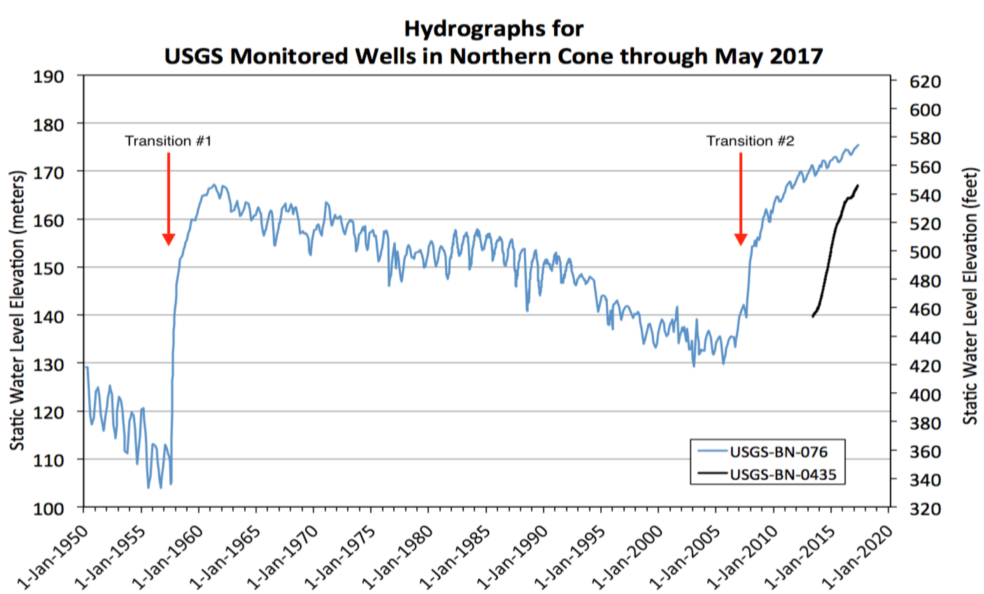

Figure 1: Changes in groundwater levels in a groundwater level monitoring well in Green Bay, Wisconsin. Transition 1 is City of Green Bay Switch to surface water. Transition 2 is Green Bay suburbs switch to surface water (Luczaj).

around Green Bay have risen. These changes at one well can be seen in Figure 1.
The water levels continue to rise, and some homeowners and the town of Howard have reported flowing wells. If water use continues to decrease, the number of flowing wells will increase over time as the water levels rise above the land surface. Contours of water levels before and after the reduction of pumping in 2007 are shown in Figure 2.

We know from previous drawdown and pumping records that when the pumping rate reaches around 6 million gallons per day that the deep aquifer has the potential to become dewatered, raising concerns about changes in the aquifer chemistry that might increase arsenic or radium concentrations. This provides good rationale for monitoring high-capacity pumping in this aquifer.

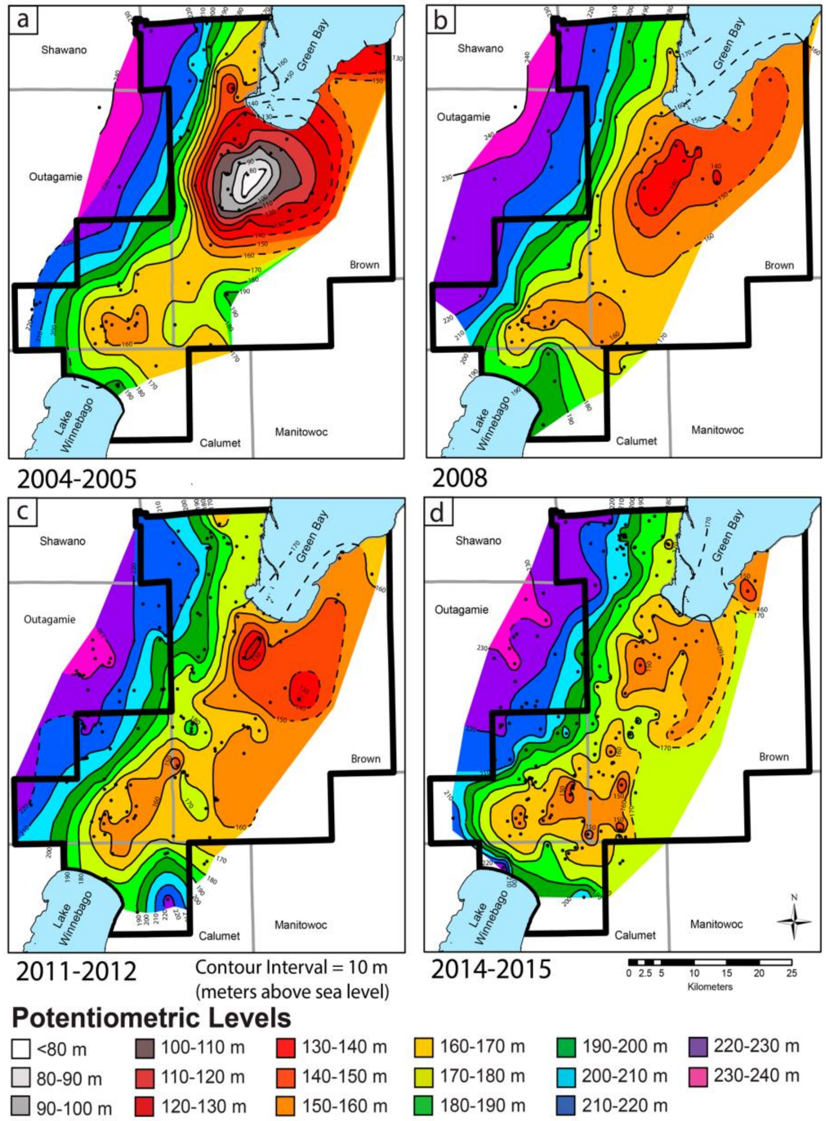

Figure 2: Water table elevations in Brown County

Southeastern Wisconsin

Water levels in southeastern Wisconsin have shown the largest decreases in Wisconsin. These decreases have raised concerns about increases of radium to wells above drinking water standards and increased pumping costs. As was the case for the Lower Fox River Valley, water levels in the deep sandstone aquifer were above the land surface before significant pumping in 1900. Pumping increased steadily from 1900 to 2000 and water levels in some wells steadily decreased by more than 500 feet. Figure 3 shows the water table decline until around 2000 to 2005. Research and monitoring from the late 1990's and early 2000's demonstrated an average of 7 feet per year decline in deep wells (Feinstein et al., 2004). However, an added well in Waukesha County to the groundwater observation network shows 2020 water levels to be approximately 150 feet higher than the levels observed in a nearby observation well in 1998 (Pfeiffer, 2013). The reduced drawdown is likely due to reduced pumping by communities from groundwater conservation efforts, reduced industrial water use and from seeking alternative sources of water to the deep sandstone. The deep sandstone aquifer sometimes has radium concentrations over the drinking water standard of 5 pC/l. Treatment of that water can be costly, leading some communities to look at other water sources.

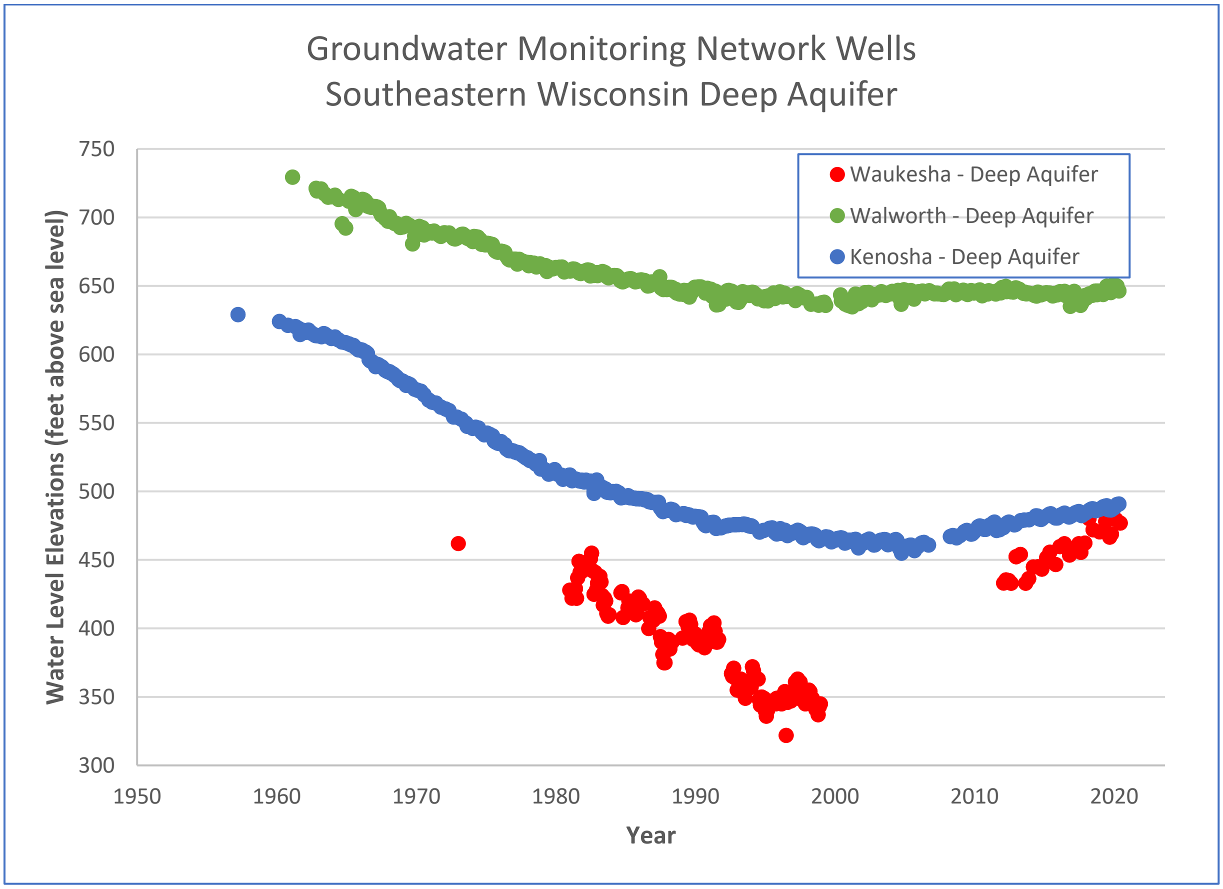

Figure 3: Water levels in a groundwater level monitoring wells in Waukesha, Kenosha and Walworth counties (DNR).

Dane County

Dane County presents another example of regional drawdowns which have been well documented through water level measurements and the development of multiple groundwater flow models, at a county-wide scale, over the past several decades. The 2016 Dane County model (Parsens, et al. 2016) has focused on increasing the spatial resolution of the model grid, better simulating surface water groundwater interactions, and introducing transient flow capabilities, all while upgrading the computer codes and calibration methods. Each of these model improvements provides new insights into the groundwater system within Dane County and a greater understanding of regional scale drawdowns.

The Dane County model was used to simulate drawdowns in both the Mount Simon Sandstone and at the water table. Figures 4 and 5 were generated by comparing predevelopment water levels to those measured in 2010 and document the presence of significant drawdowns in central Dane County, below the Yahara River corridor. In Dane County, municipal water supply is by far the primary groundwater user, representing roughly 80% of the total withdrawal rate of 50 million gallons per day. The next largest withdrawals are made by irrigation (under 10%) and aquaculture (under 5%).

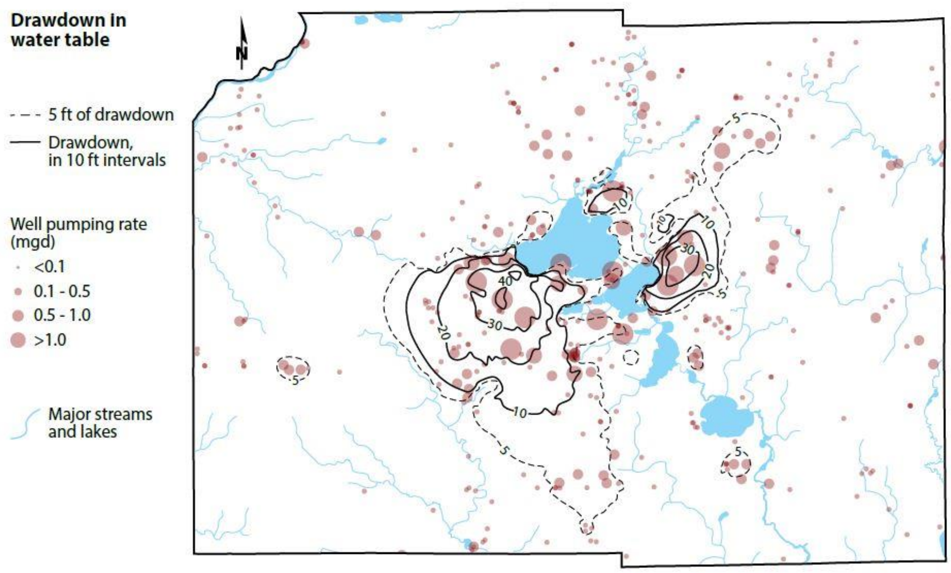

Figure 4: Simulated drawdown (feet) in the Mount Simon Sandstone; predevelopment to 2010. The Mount Simon Sandstone, located several hundred feet below land surface and up to 800 feet thick, is the lowermost aquifer unit within Dane County. This porous sandstone is a highly productive aquifer which provides the bulk of groundwater supplies to high-capacity municipal and industrial wells across Dane County (WGNHS).

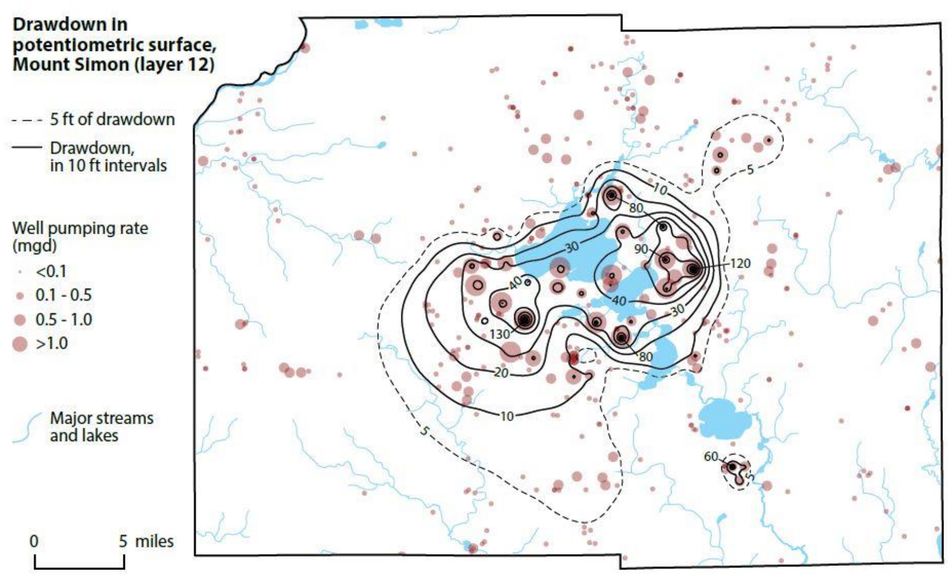

Figure 5: Simulated drawdown (feet) at the water table; predevelopment to 2010. Drawdowns from the lower Mount Simon aquifer system propagate upwards to the shallow sand and gravel and upper bedrock aquifer systems to create drawdowns at the water table (WGNHS).

Water use data collected for the updated 2016 model, indicate that groundwater withdrawals have declined by up to 15% over the past 10-15 years across Dane County. These reductions are believed to be primarily attributable to wet years, during which water demand drops; and local groundwater conservation efforts. The 2016 model improves our understanding of regional drawdowns across Dane County and provide insights into groundwater systems across South Central Wisconsin.

Central Sands

In the Central Sands, the study of groundwater flow and its complex interactions with stream flows and lake levels dates back to historical experiments by USGS, WGNHS and the Wisconsin Conservation Department (precursor to the DNR) in the 1960s. Decades of continued study by GCC agencies and GCC-supported researchers, have further described the hydrogeology, climatology and impacts of groundwater pumping on lakes, rivers and wetlands in this region (Kniffen et al., 2014). This research, specific to the Little Plover River watershed (Bradbury and others, 2017), confirms that the Little Plover River is closely connected to the groundwater system, making it vulnerable to impacts from nearby high capacity well groundwater withdrawals. Under 2017 Wisconsin Act 10, the department evaluated and modeled the potential impacts of groundwater withdrawals on three specific lakes in the Central Sands region through the Central Sands Lakes Study. The three lakes in the study are all in Waushara County – Long Lake and Plainfield Lake near Plainfield, and Pleasant Lake near Coloma.

The study included the use of a groundwater flow model to evaluate cumulative impacts from existing and potential groundwater withdrawals on the three lakes. The groundwater flow model involved data collection and compilation across the region.

The key findings are that groundwater withdrawals cause reductions in Pleasant, Long, and Plainfield Lakes. The reductions are significant and impact the lakes' ecosystems in Long and Plainfield Lakes. The study findings show that the reduction caused by groundwater withdrawals to study lake levels are a result of the collective impact from many high-capacity wells rather than any specific high-capacity well. The DNR recommends a regional framework, such as a water use district, for addressing impacts to water resources from high-capacity well pumping.

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GROUNDWATER-LEVEL MONITORING NETWORK

Wisconsin's groundwater-level monitoring network has been operated jointly by the Wisconsin Geological and Natural History Survey (WGNHS) and the U.S. Geological Survey (USGS) since 1946, working in close cooperation with the Department of Natural Resources (DNR). As of June 2021, this network consists of 97 long-term monitoring wells and project-specific, limited-term monitoring wells. The long-term 97 permanent wells, or "Core Network," are in 47 of Wisconsin's 72 counties. This Core Network provides a consistent, long-term record of fluctuations in water levels in shallow and deep aquifers. The project-specific wells are supported with funding from various groundwater studies across the state and are generally only operational over the lifetime of an active groundwater study. These project wells provide valuable data and are often considered for addition to the Core Network if selection criteria are met.

Water levels collected from the network help scientists and managers evaluate effects of well pumping, the response of groundwater levels to drought or increased precipitation and effects of land-use change on groundwater resources. These data are also routinely used in the development of regional groundwater flow models, as long-term water-level measurements serve as reliable calibration targets.

In FY 2018, due to increasing reliance on network data to meet its Water Use program needs, DNR greatly expanded its funding and management support of the Core Network. On a day-to-day basis USGS and WGNHS continue to support the evaluation and maintenance of the monitoring network, aid in data collection, interpretation, and provide information to public and private clients through dedicated webpages. WGNHS provides a general overview of the monitoring network at https://wgnhs.uwex.edu/water-environment/groundwater-monitoring-network, and USGS maintains an interactive portal for viewing and downloading data at https://waterdata.usgs.gov/wi/nwis/gw.

In FY 2022, DNR committed $100,000 to the Wisconsin Groundwater Monitoring Network and provided additional funding of $75,875 to USGS to conduct additional monitoring on 5 stream gages, 1 lake gage, and 20 short-term project wells in central and northern Wisconsin. WGNHS received grants the USGS National Ground-Water Monitoring Network (NGWMN) program in FY 2019 and FY 2021 for $198,089 and $271,848 respectively. Once the work on both grants is completed, these two recent grants, together with a 2016 NGWMN grant will result in repairs to forty-three wells, eight well replacements, and nine new wells, adding four new counties to the Network (Barron, Buffalo, Dunn, and St. Croix).

In 2022 the DNR released a StoryMap illustrating the collaboration between DNR, WGNHS, USGS, UW System and others to collect water quantity data to support our understanding on groundwater levels and interaction between surface water and groundwater. Visit https://storymaps.arcgis.com/stories/03c2609bb8bd470fafe2f4a83788f74d to learn more.

CENTRAL SANDS LAKES STUDY

The Central Sands Region spans portions of Adams, Marathon, Marquette, Portage, Shawano, Waupaca, Waushara and Wood Counties. The DNR defines the Central Sands as a contiguous area east of the Wisconsin River with sand and gravel deposits greater than 50 feet deep. These deposits create a productive aquifer that is used for irrigation, public and private water supplies, industry, and commercial uses. The Central Sands region also contains over 300 lakes and thousands of miles of streams.

Over the past 60 years, we have observed low water levels in lakes and streams in Wisconsin's Central Sands Region. Various researchers have studied the relationship between land use and impacts to water resources in the Central Sands Region. Their work has shown that the two main causes of water level changes are weather and the pumping of high capacity wells. Weather varies considerably from place to place and from year to year. The number of high capacity wells in the Central Sands Region have increased over the past few decades, which has raised concerns about pumping of groundwater and the impacts on water levels. In response to these concerns, the DNR evaluated and modeled Pleasant, Long, and Plainfield Lakes in Waushara County to determine whether groundwater withdrawals cause a significant reduction in lake levels below their average seasonal levels, as directed by the Wisconsin State Legislature, specifically Wis. Stat. § 281.34(7m)(2017 Wisconsin Act 10).

The DNR, in collaboration with the Wisconsin Geological and Natural History Survey (WGNHS), United States Geological Survey (USGS) and the University of Wisconsin System, completed the $887,000 Central Sands Lakes Study using an approach that involved data collection and groundwater flow modeling.

The key findings are that groundwater withdrawals cause reductions in Pleasant, Long, and Plainfield Lakes. The reductions are significant and impact the lakes' ecosystems in Long and Plainfield Lakes. The study findings show that the reduction caused by groundwater withdrawals to study lake levels are a result of the collective impact from many high-capacity wells rather than any specific high-capacity well. The DNR recommends a regional framework, such as a water use district, for addressing impacts to water resources from high-capacity well pumping.

Additional information on the study is available through the study reports, appendices and recorded presentations. The DNR held a public hearing and comment period in Spring 2021 and submitted their findings and recommendations to the Wisconsin Legislature on May 27, 2021.

LITTLE PLOVER RIVER MODEL AND WATERSHED ENHANCEMENT PROJECT

With financial support from DNR, the Wisconsin Geological and Natural History Survey and the United States Geological Survey constructed a groundwater flow model for the Little Plover River watershed in Portage County. This model is a scientific tool for understanding the complexities of geology, groundwater recharge and discharge, surface-water flow, well development and use and water balance. The model simulates the complex temporal and spatial interactions among streamflow, pumping, and climate and provides users "what-if" evaluations of possible decisions involving management of water use or land-use changes. The Little Plover River Basin was chosen for this pilot study because the river has been the focus of recent management concern and because a great deal of hydrogeologic data already exists for this area. Learn more at: https://fyi.uwex.edu/littleplovermodel/files/2014/08/Little-Plover-River-handout.pdf.

Beginning in 2017 stakeholders including the Village of Plover and agricultural producers in conjunction with DNR, consultants, and the Wisconsin Wetland Association, formed the Little Plover River Watershed Enhancement project with the goal of achieving sustained flow and aquatic health within the river. The stakeholders are utilizing the groundwater flow model as one tool to assist with establishing land and water best management practices. Learn more about the collaborative restoration effort at https://www.ploverwi.gov/328/Little-Plover-River-Watershed-Enhancemen.

GROUNDWATER LEVELS AND AQUIFER RESPONSE

Monitoring groundwater levels can be used for:

- understanding local water resources;
- assessing aquifers in drought or wet conditions;
- assessing groundwater divides and surface water impacts;
- calibrating groundwater flow models and other decision-support tools; and
- helping to determine the relationship between water resources and withdrawals.

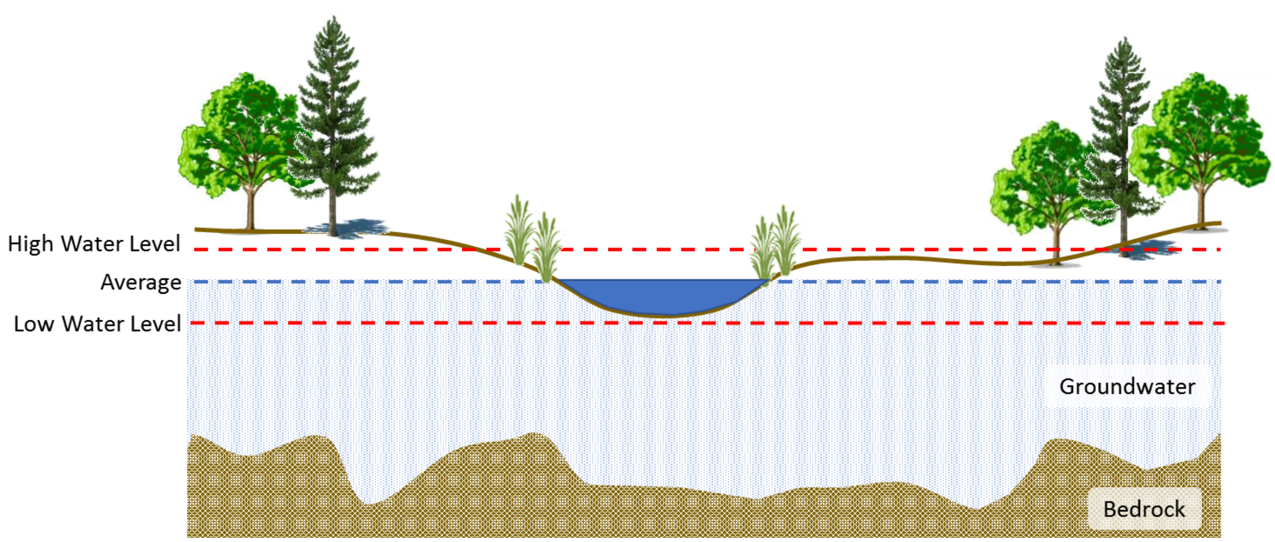
Groundwater level monitoring

The DNR and its partners at the United States Geological Survey (USGS) and the Wisconsin Geological and Natural History collectively operate and maintain a statewide network of monitoring wells that provide necessary long-term data for Wisconsin's statewide water resources inventory. The groundwater monitoring network, started in 1946, now consists of 92 long-term monitoring wells that measure groundwater levels in aquifers across the state.

The DNR's water quantity data viewer shows the location and water levels associated with the statewide groundwater monitoring network.

Groundwater level fluctuations

The upper surface of groundwater, referred to as the water table, can fluctuate in response to precipitation events and water withdrawals. During times of drought, local water tables can decline due to decreased recharge and increased water use (e.g. watering lawns, irrigating farm fields, municipal water supply). The result is that the water table can fall below surface water resources or from wells that withdraw water from the aquifer (see diagram below).

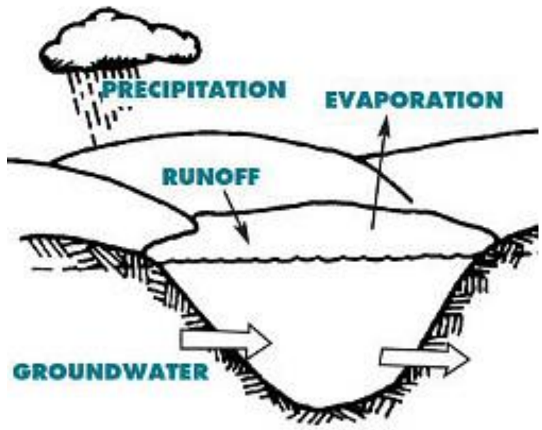


Water level variation diagram. Image credit: DNR.

The opposite can also occur, resulting in a high water table (too much groundwater). Groundwater flooding occurs when frequent, sustained rainfall leads to excessively fast recharge of local groundwater levels and the water table rises above the land surface. This type of flood may be pronounced near seepage lakes (see diagram above). This type of flood can be long-lasting because water table decline requires drainage from the entire aquifer above the flood level. For the time that it takes for this drainage to occur, flood waters can cause significant property loss, human displacement and disruption of transportation.

Seepage lakes may also experience flooding of shoreline beaches and buildings due to a rise in the water table elevation and the related long-term increase in lake levels. Floods and droughts are part of life in Wisconsin and elsewhere, but they come with significant economic, public health and environmental costs.

It may be difficult to determine if nearby flooding is due to surface water or groundwater flooding. For example, increased groundwater flow to nearby streams and rivers may cause the waterbodies to flood; or storm sewers that typically would drain to rivers don't work properly if too much inflow into the pipes from groundwater is occurring.



Seepage lake: a natural lake fed by precipitation, limited runoff and groundwater. It does not have a stream outlet. Image credit: UW Stevens Point.

Over the past several years, Wisconsin has received a record-breaking amount of precipitation. The accumulation of above-average precipitation has resulted in many areas of Wisconsin experiencing high water and flooding issues. Information is available from the DNR to help residents cope with flooding.

Status of groundwater levels

Department staff track recent and historical precipitation and compare that data to long-term averages to characterize and identify trends. These precipitation patterns are compared to water level readings in monitoring wells statewide. After several years of above average rainfall, groundwater levels were at or near all-time highs in 2020 and 2021. Since then, groundwater levels have started to decline following a period of more typical rainfall amounts. While groundwater levels have started to decline, there are portions of the state where groundwater levels are still above average.

Flooding resources

Recommendations for private wells inundated by flooding

Coping with flooding

Flood insurance