Wisconsin Groundwater Coordinating Council

Report to the Legislature

Fiscal Year 2019

2019 GROUNDWATER COORDINATING COUNCIL MEMBERS

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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 – **Patricia Trainer**
Geological and Natural History Survey (State Geologist) – **Ken Bradbury**
Governor's Representative – **Steve Diercks**
University of Wisconsin System – **James Hurley**

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Center for Watershed Science and Education - **George Kraft* and Dave Mechenich**
Natural Resources Conservation Service - **Tim Weissbrod***

** Member of Standing Joint Solicitation Work Group*

Outreach & Partnership

Center for Watershed Science and Education - **Kevin Masarik** (Co-Chair)
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State of Wisconsin \ GROUNDWATER COORDINATING COUNCIL

GROUNDWATER
Wisconsin's
buried treasure

Tony Evers, Governor

101 South Webster Street
Box 7921
Madison, Wisconsin 53707

August 31, 2019

To: The Citizens of Wisconsin
The Honorable Governor Tony Evers
Senate Chief Clerk
Assembly Chief Clerk
Secretary-designee Craig Thompson - Department of Transportation
Secretary Dawn B. Crim - Department of Safety and Professional Services
Secretary-designee Brad Pfaff - Department of Agriculture, Trade & Consumer Protection
Secretary-designee Andrea Palm - Department of Health Services
Secretary Preston D. Cole - Department of Natural Resources President Ray Cross - University of Wisconsin System
State Geologist Kenneth Bradbury - Geological and Natural History Survey

The Groundwater Coordinating Council (GCC) is pleased to provide its 2019 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 *on-line report* summarizes and links to information on the GCC and agency activities related to groundwater protection and management in FY19 (July 1, 2018 to June 30, 2019). Search "GCC" on dnr.wi.gov to find the full report. Click on the rotating cover graphics to see indicators of the condition of Wisconsin groundwater, our current uses and the state of our groundwater information. 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,

Jim Zellmer, Chair
Groundwater Coordinating Council

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EXECUTIVE SUMMARY

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 2018 (FY18). The report is an interactive web-page 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

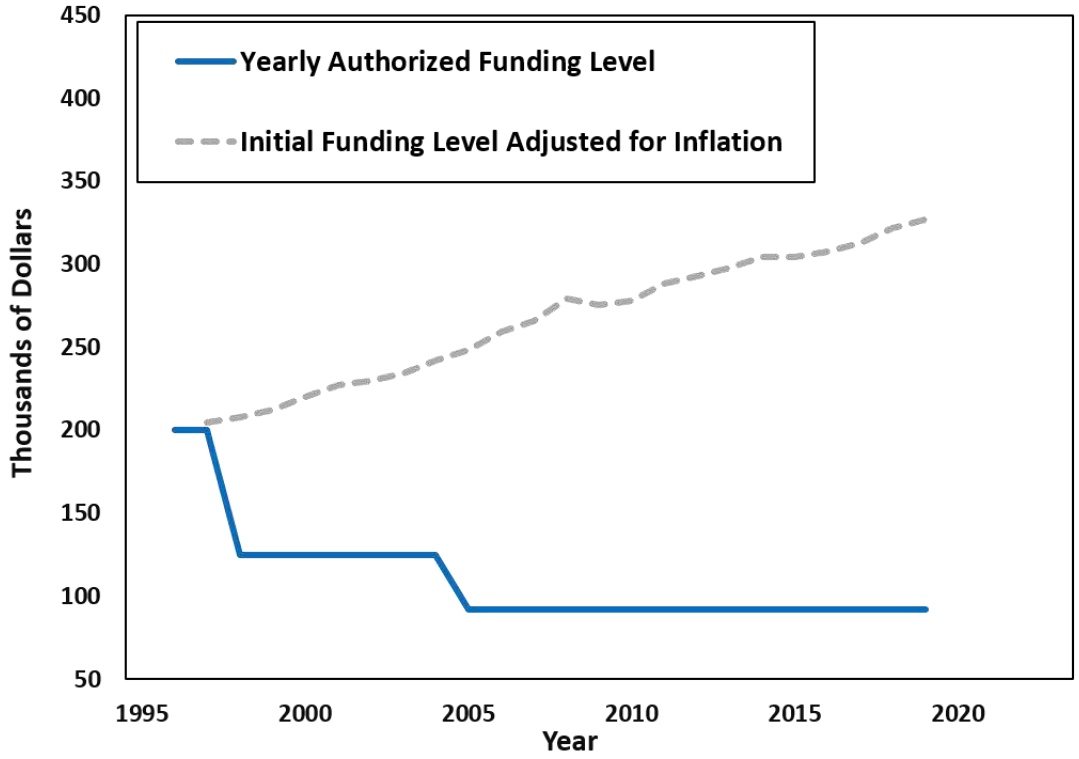
In addition to the council of agency leaders, the GCC is authorized to create subcommittees on "the subjects within the scope of its general duties…and other subjects deemed appropriate by the Council." See a list of GCC members and subcommittees on the inside cover of this executive summary.

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.

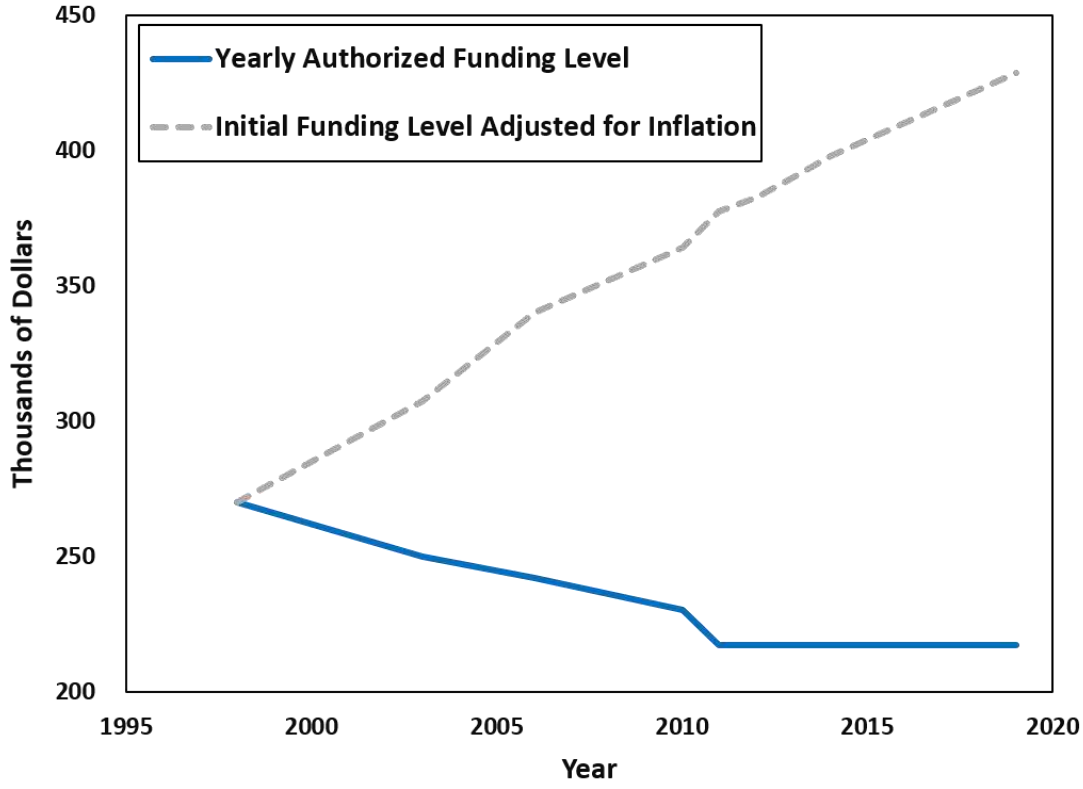
Coordination of Groundwater Research and Monitoring Program

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.

DNR Funding for
Wisconsin Groundwater Research and Monitoring Program



UW System Funding for
Wisconsin Groundwater Research and Monitoring Program



EXECUTIVE SUMMARY

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, 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 Monitoring & Research 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, eight new projects were selected for funding in FY20 - three by UWS and two by DNR and two by DATCP and one co-funded by UWS and 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 (WRI) 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 on-line.

Information and Outreach Activities

For the 14th year in a row, groundwater workshops for teachers were taught jointly by GCC Outreach and Partnership Subcommittee members from the DNR, WGNHS and the Center for Watershed Science and Education (CWSE) at Stevens Point. Teacher applications to participate continue to fill all available workshop space and equipment. The workshop leaders instructed teachers on using a groundwater sand-tank model and provided additional resources to incorporate groundwater concepts into their classroom. Educators who attended the workshops received a free model. With funding from a U.S. Environmental Protection Agency (EPA) wellhead protection grant, over 300 groundwater models have been given to schools and nature centers since 2001 and over 600 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 FY19 meetings:

- DNR, Per and Polyfluoroalkyl substances (PFAS) Update
- DNR, Evaluation of recent private water supply well nitrate sampling results
- DNR, Evaluation of compliance options for noncommunity public water supply systems with nitrate MCL exceedances
- WGNHS, Southwest Wisconsin Groundwater and Geology Study

- DNR, Central Sands Lakes Study - progress evaluating and modeling potential impacts of groundwater withdrawals on lakes in the Central Sands region
- All, Speaker's Task Force on Water Quality Goals – State Representative Novak & Shankland (Chair and Co-Chair)

More information on these topics and the coordinating efforts of the GCC can be found in the FY19 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 FY19. Detailed discussions of the groundwater activities of each agency can be found at the agency activities tab in the on-line report.

CONDITION OF THE RESOURCE: Groundwater Quality

Major groundwater quality concerns in Wisconsin are summarized below and detailed in the on-line report.

Nitrate
Nitrate is Wisconsin's most widespread groundwater contaminant and is increasing in extent and severity. Nitrate levels in groundwater above 2 milligrams per liter (mg/L) indicate a source of contamination such as agricultural or turf fertilizers, animal waste, septic systems, and wastewater. While nitrate in agricultural use has benefits such as larger crop yields, high concentrations in groundwater lead to public health concerns. Approximately 90% of total nitrate inputs into our groundwater originate from agricultural sources.

Approximately 253 public water supply systems (mostly systems like mobile home parks, restaurants and taverns) exceeded the nitrate drinking water standard of 10 mg/L in 2019 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.

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 agents can cause acute illness and result in life- threatening conditions for young children, the elderly, and those with chronic illnesses. In one assessment (Warzecha et.al., 1994), approximately 23% of private well water samples statewide tested positive for total coliform bacteria, an indicator species of other biological agents. 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.

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

Many sampling surveys initiated by DATCP, the DNR and other agencies in the mid-1980s to early 1990s are still ongoing today. The longest running survey on pesticides in Wisconsin 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. Most recent testing in this survey confirms that the metabolites of metolachlor and alachlor are the two most common pesticides products detected in groundwater near the monitoring well sites. Sample results from 2016 also show that there has been an increase in the number of monitoring wells that contain one or more detections of the neonicotinoid insecticides clothianidin, imidacloprid and thiamethoxam. DATCP has shared its neonicotinoid data with U.S. EPA as they further 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 survey, 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).

Arsenic

Naturally occurring arsenic has been detected in wells throughout Wisconsin. DNR historical data show that about 4,000 public wells and over 3,000 private wells have detectable levels of arsenic. About 10% of these wells exceed the federal drinking water standard of 10 µg/L. Although arsenic has been detected in well water samples in every county in Wisconsin, the problem is especially prevalent in northeastern Wisconsin where increased water use has likely released arsenic from rocks and unconsolidated material into the groundwater. GCC member agencies and partners continue to proactively address arsenic concerns through well drilling advisories, health studies, well testing campaigns, and studies aimed at improving geological understanding and developing practical treatment technologies.

Volatile Organic Compounds (VOCs)
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
Naturally-occurring radionuclides, including uranium, radium, and radon, are an increasing 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.

CONDITION OF THE RESOURCE: Groundwater Quantity

Groundwater quantity conditions are summarized below and detailed in the *on-line 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 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, on-going efforts that require continued support, and emerging challenges that will need to be addressed in the near future.

Priority 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 on-line 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 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

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

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.

<u>Ongoing Recommendations</u>
Without ongoing attention to the following needs, Wisconsin cannot address the priority recommendations (see above) or begin to understand emerging issues (see below).

Support implementation of the Statewide Groundwater Monitoring Strategy. Chapter 160 of the Wisconsin Statutes requires the DNR to work with other agencies and the GCC to develop and operate a system for monitoring and sampling groundwater to determine whether harmful substances are present (s. 160.27, Wis. Stats.). The strategy has been incorporated into the DNR Water Monitoring Strategy, but needs are constantly evolving as new problems emerge. For example, food processors, homeowners, municipalities, and well drilling contractors need more information about the origin and extent of naturally occurring contaminants such as arsenic, other heavy metals, acidic conditions, sulfate, total dissolved solids, radium and uranium. Wisconsin should improve the accessibility of current data and continue to encourage research efforts that will provide information for addressing these issues. State agencies, the university, and federal and local partners should continue to implement and modify this strategy to efficiently meet monitoring objectives.

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 and people seeking business locations, as well as homeowners and local governments. Options for sharing data about groundwater and groundwater vulnerabilities should include accessible formats including on-line mapping tools.

Continue to support applied groundwater research. Focus on investments to identify and test cost-effective groundwater protection strategies that can prevent groundwater problems before they need to be remediated at a much greater cost. State agencies should work to maximize collaboration to answer the key groundwater questions facing Wisconsin water suppliers. To maintain adequate levels of support, agencies should seek leveraging partnerships for applied analysis and innovation.

Emerging Challenges

Perfluoroalkyl and polyfluoroalkyl 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 certain types of industrial and aviation fire-fighting foams. These chemicals do not easily break down in the environment and have been known to accumulate in the environment and humans. 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.

Under the Safe Drinking Water Act's third Unregulated Contaminants Monitoring Rule (UCMR-3), select municipal water systems were asked to test for six PFAS (PFOA, PFOS PFNA, PFHxS, PFHpA and PFBS), between 2013 and 2015. Levels 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, and PFAS has also been found in groundwater near the Johnson Controls International/Tyco facility (Marinette), former Mirro plants (Manitowoc and Chilton) and Department of Defense sites (i.e. Wisconsin Air National Guard facilities at Truax Field and Volk Field) in Wisconsin.

Currently, there are no state or federal groundwater protection standards for PFAS. In 2018 DNR formally requested that DHS provide recommendations for groundwater enforcement standards for two PFAS compounds, PFOA and PFOS as part of Cycle 10. In June 2019, based on review of available peer-reviewed toxicity studies, DHS recommended a groundwater enforcement standard of 20 parts per trillion (ppt) for combined levels of PFOA and PFOS. In April 2019, DNR transmitted a list of 40 substances (including 34 PFAS compounds) detected in, or likely to reach, groundwater (Cycle 11) to DHS for their review to possibly recommend updates to existing or adding new NR 140 health-based groundwater standards.

The DNR is formulating a strategy address PFAS in the State. This will include a request for voluntary sampling of influent and effluent by WPDES permitted municipal wastewater treatment plants. PFAS may be present in municipal wastewater treatment facilities' biosolids that have been regularly applied to agricultural lands throughout the state. The DNR intends to investigate the fate and transport of PFAS in biosolids. Additional statewide PFAS biosolids and sludge testing may be requested in the coming years Wisconsin will be drawing on the examples and experiences of other states to guide future PFAS efforts at State agencies that protect groundwater resources within the State.

Livestock industry expansion. Since 2010, many animal feeding operations that house thousands of animals have been sited or proposed in Wisconsin. These operations require large quantities of groundwater for both animals and animal food crops and must also dispose of large amounts of animal waste. Wisconsin agencies should develop efficient and effective ways for measuring groundwater quality and quantity conditions in and around these operations. Agencies, industry and local governments should partner to develop policies and innovations that allow for effective siting and efficient operation of these facilities, while still protecting groundwater quality and quantity. There is growing interest from the livestock interest in developing the capacity to compost manure to reduce the volume of waste applied and create different products for other markets.

Evaluate potential impacts of climate change on Wisconsin's groundwater. Climate change will likely increase 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.

Metallic mining. Lead, zinc, iron and copper deposits exist around Wisconsin. These deposits may be mined in the future and are located in sparsely-populated regions where background information on groundwater resources are often incomplete. The state should support background data collection and groundwater assessments so that future decisions about potential mining operations can be made most efficiently.

DEPARTMENT OF NATURAL RESOURCES

DNR establishes the groundwater quality standards for the state and coordinates their implementation by diverse agencies and programs (ch. 160, Wis. Stats.). DNR works with operators of landfills, land spreading of waste, remediation and redevelopment of contaminated sites, to ensure that standards are met that avoid 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. DNR manages groundwater quantity (ss. 281.11, 281.12, 281.34, and 281.346, Wis. Stats.) 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 on an annual groundwater work plan.

Ozone generator inspection at a public water supply system.

FY 2019 Highlights

- DNR transmitted a list of 40 substances detected in, or likely to reach, groundwater (Cycle 11) to DHS for their review to possibly recommend updates to existing or adding new NR 140 health-based groundwater standards. The Cycle 11 list contains 34 PFAS compounds and six pesticides. DNR received DHS recommendations for the Cycle 10 list of 27 substances (Including PFOS and PFOA) and will propose rulemaking to incorporate the recommendations into NR 140.

- DNR is formulating a strategy to address PFAS in the State. This will include a request for voluntary sampling of influent and effluent by WPDES permitted municipal wastewater treatment plants. PFAS may be present in municipal wastewater treatment facilities' biosolids that have been regularly applied to agricultural lands throughout the state. Wisconsin will be drawing on the examples and experiences of other states to guide future PFAS efforts at State agencies that protect groundwater resources within the State.

- Public comment was solicited in late 2018 for proposed revisions to chapter NR 812, Wis. Adm. Code. The revisions will update well construction standards based on modern equipment and techniques, streamline approval procedures and reflect recent statutory changes.

- DNR committed $100,000 in FY19 to continue to operate and maintain the Wisconsin Groundwater Level Monitoring Core Network in collaboration with USGS and WGNHS. This 'Core Network' includes 92 long-term monitoring groundwater wells and 2 spring flow gages and is operated and maintained by the USGS and the WGNHS.

- DG and Community Financial Assistance staff issued 65 grants to low-income private well owners, providing over $139,000 to help replace contaminated wells or fill and seal unused wells.

- *Central Sands Lakes Study* – 2017 Wisconsin Act 10 requires DG to complete a *study* to model and evaluate Plainfield Lake, Pleasant Lake and Long Lake in Waushara County. Lake levels have been of keen interest to stakeholders in Central Wisconsin, particularly in the last decade. The department is taking the necessary steps to identify the components of the water budget driving the fluctuation in each of the three named lakes. Results are expected no later than June 2021.

Details of Ongoing Activities

The DNR programs that protect and manage groundwater are as follows:

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 Chapter 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* and *https://dnr.wi.gov/topic/Groundwater*.

Remediation and Redevelopment (RR) – Oversees response actions at spills, hazardous substance discharge sites, sites impacted by environmental pollution, 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 animal waste has affected private wells. See *https://dnr.wi.gov/topic/Brownfields/* and *https://dnr.wi.gov/topic/Brownfields/Cleanup.html*.

Waste and Materials Management (WMM) – Regulates and monitors groundwater at proposed, active, and inactive solid waste facilities and landfills. WMM reviews investigations of groundwater contamination and implementation of remedial actions at active solid waste facilities and landfills. WMM 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 impacting 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 clean-up 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/Watersheds*, *https://dnr.wi.gov/topic/SurfaceWater* and *https://dnr.wi.gov/topic/Waterways*.

Drinking Water and Groundwater Program

Groundwater Quality Standards Implementation

Chapter 160, Wis. Stats., requires the DNR to develop numerical groundwater quality standards which consists 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 (*https://docs.legis.wisconsin.gov/code/admin_code/nr/100/140*), establishes these groundwater standards and creates a framework for their implementation. Groundwater quality standards are set for 138 substances of public health concern, 8 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. DHS then prepares 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. DHS responded with recommendations to DNR in June 2019. DNR will propose rulemaking to incorporate the recommendations into NR 140. A plain language summary of each of the compounds in Cycle 10 is available at *DHS's Recommended Groundwater Enforcement Standards [exit DNR]*. The DHS Cycle 10 recommendations include a recommended groundwater quality Enforcement Standard of 20 parts per trillion (ppt) for the combined concentration of two PFAS compounds, PFOS and PFOA. The DNR has also submitted a list of 40 substances, designated “Cycle 11", to DHS in April 2019. The Cycle 11 list of substances includes 34 PFAS compounds detected, or potentially present, in Wisconsin groundwater.

To help ensure awareness of known health risks, DNR updated its *table* listing health and welfare based enforcement standards (ch. NR 140), state public drinking water standards (ch. NR 809) and established health advisory levels (HALs) for substances in water to reflect new or revised health advisory levels set this year. This table of regulatory standards and advisory levels provides a useful source of information to members of the public concerned about the safety of their drinking water, and it is also a valuable resource for agency staff and consultants involved with groundwater contamination and remediation actions. Links to resource web sites allows users to obtain additional toxicological and health related information on many of the substances listed in the table.

DNR continued to provide training to new staff in runoff management and drinking water programs on implementation of groundwater quality standards, including training for landspreading discharge permit writing and animal waste drinking water well contamination response. Groundwater and runoff program staffs 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.

DNR staff actively participated in the NRCS newly formed Source Water Protection Subcommittee. This subcommittee will provide 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 fire protection well, that, together with all other wells on the same property, except for residential wells and fire protection wells, have 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 and 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. To improve efficiency and consistency of review, DNR implemented a 'lean' project in 2013. The project increased efficiency by streamlining high capacity application and approval forms and eliminated duplication within the review process.

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. 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. 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 to review each application for a new high capacity well to determine whether the well, along with other high capacity wells on the contiguous property, would result in significant adverse environmental impacts to waters of the state – which includes all streams, lakes, wetlands, public and private wells. Section NR 820.12(19), Wis. Adm. Code defines significant adverse environmental impact as:

> *Alteration of groundwater levels, groundwater discharge, surface water levels, surface water discharge, groundwater temperature, surface water temperature, groundwater chemistry, surface water chemistry, or other factors to the extent such alterations cause significant*

degradation of environmental quality including biological and ecological aspects of the affected water resource.

If the DNR determined the proposed well could directly result in significant adverse environmental impacts, 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. 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, 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 through the adoption of 2011 Act 21 (§ 227.10(2m)), "[t]he Legislature has defined the parameters in which DNR can act to protect the state's navigable waters and additionally has clarified the ways in which DNR can regulate non-navigable waters." (OAG ¶52). 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 percent 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)). According to Attorney General Schimmel, the Department lacks explicit authority to review the environmental impact of wells outside of those specific categories identified in Wis. Stat. § 281.34. High capacity well reviews are conducted in accordance with June 2016 Attorney General opinion.

- 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 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 does 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 is due to the legislature in June 2021.

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' consent. DNR water use section staff implements Compact-related programs including authorizing permits, 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, DNR receive 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. 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 7 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 WDNR prior to withdrawing groundwater or surface water. This is typically done in conjunction with other approval or permitting procedures.

WDNR 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 percent in 2008 to 79 percent in 2010. These improvements continued so that the reporting response rate for 2013 – 2018 is 96 percent annually.

Water Withdrawal Registrations by Source Type and Major Basin (2019)

	Great Lakes Basin	Mississippi River Basin	**Total**
Groundwater	3663	9795	13,458
Surface Water	393	670	1,063
Total	4056	10465	14,521

Persons with registered withdrawals must measure or estimate their monthly withdrawal volumes and report the previous calendar years' 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 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 per day or more. 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.

DNR is developing a statewide set of conservation standards for agricultural irrigation with partners including the University of Wisconsin, environmental non-profit organizations and the Wisconsin Potato and Vegetable Growers. Participation in the Conservation Standards Program will require growers to report specific data such as cropping rotations, acreages and irrigation practices. Some growers will also develop conservation plans to target conservation practices in a manner that best suits their operation. In addition, analysis will be undertaken of economic factors so that the savings and efficiencies from water conservation can be calculated. DNR staff are supporting the UW-Madison/UW-Extension's development of an online course to train conservation professionals about irrigation practices that conserve water.

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. Chapter NR 860, Wis. Adm. Code prescribes a review process for the individual permits requires and additional environmental review. Since December 8, 2011, 207 permits have been issued to new or increased withdrawals in the Great Lakes Basin.

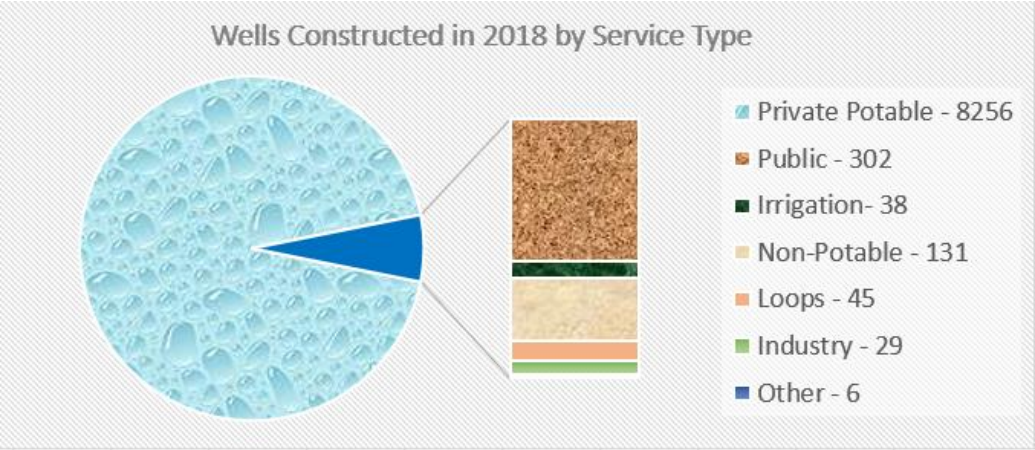
Water Use Fees

Wisconsin Act 28 contained 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 that 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 directed 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. Rulemaking continued in 2018 to revise NR 812 to update well construction standards based on modern equipment and techniques, to correct and clarify rule language, to streamline approval procedures and to be consistent with changes in other statutes and codes. Proposed rule revisions were open for public comment in late 2018, and final revisions are expected to go into effect in early 2020.

More than 8000 new or replacement wells were constructed in Wisconsin in 2018, including 302 public drinking water wells. Advance notification to 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 and reviewing well construction reports and associated sampling results. During 2018, staff conducted 998 compliance inspections of wells under construction, and additional inspections of pump installation and well filling/sealing work. initiated enforcement action on multiple violations including: failure to collect required water samples, failure to fill and seal unused wells, 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.

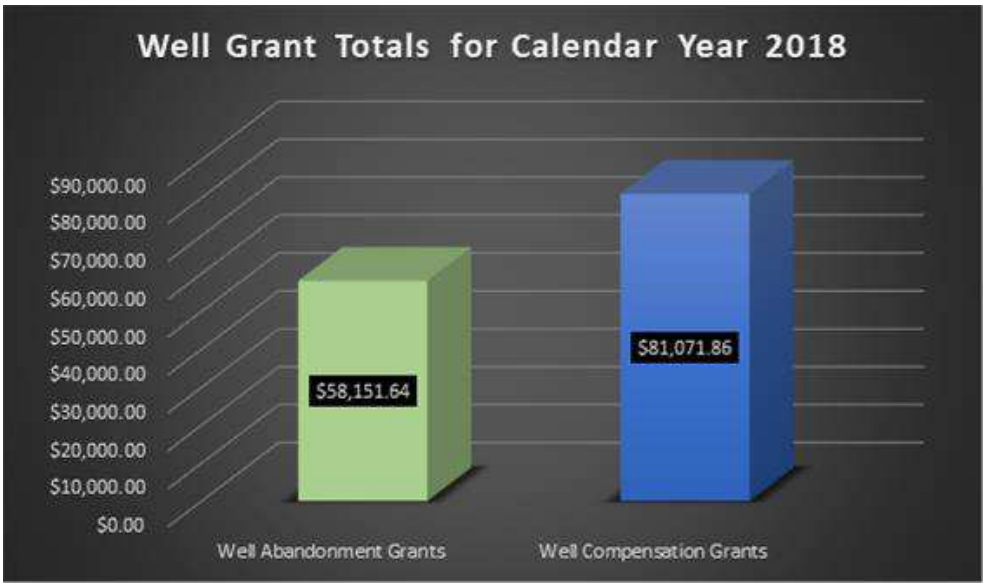
DG Private Water Supply staff coordinated with DATCP in 2018 to support the shared goal of increasing well compliance for Grade A and Grade B dairies through the dairy license process. DG developed new customer fact sheets and provided NR 812 training to DATCP staff, dairy plant representatives and dairy producers.

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 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 licenses well drillers, heat exchange drillers and/or pump installers each year under ch. NR 146, Wis. Adm. Code. Individuals demonstrate experience and take a one-time examination to obtain a license, then attend training each year to earn required continuing education credits. 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.
In all, 1229 individuals held an active Water Well Driller, Heat Exchange Driller and/or Pump Installer license during the 2018 calendar year.

License/Registration Type	Number of License/Registration Holders
Pump Installer	1196
Well Driller	254
Heat Exchange Driller	32

DG encourages private well owners to test their wells annually for bacteria, and other contaminants they may be concerned about. DG maintains the popular web page titled "*What's Wrong with My Water*?" to answer commonly-asked questions about private well water, help well owners diagnose their aesthetic water quality problems and provide suggested options. DG and Community Financial Assistance staff awarded a combined total of over $139,000 in well abandonment and well compensation grants in 2018. Well compensation grants provided cost-sharing funds to help nine owners replace wells due to Arsenic (4), Metals (3), Manganese (1), and Nitrate (1) contamination. Additionally, 56 well abandonment grants were issued around the state to help fund filling and sealing of unused wells.



DG continues to develop new or enhanced electronic tools to help well drillers, well owners and others to find information and comply with well construction and well filling and sealing requirements. DG launched the new "*Well Driller Viewer*" tool in January 2018, providing 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. A mid-year survey of drillers and installers showed that more than 85% of drillers and installers are very satisfied with the WD Viewer and use it at least once a month to review well construction reports or prepare for an inspection. "*Online WCR*" is the new electronic system for submitting Well Construction Reports to DNR, released in May 2018. Online WCR checks for common errors to make sure the report is complete and submits the data directly to DNR without the need to send in a paper report. The system reduces time and errors for both well drillers and DNR staff and is resulting in more accurate data. More than 40% of WCRs are now submitted using this new system.

The well driller viewer was launched in 2018.

Public water systems

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).

DNR maintains an electronic data system (EMOR) 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 usage for treatment, 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. Municipal 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, 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*.

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), 7 communities completed WHP plans this year (3 required and 4 voluntarily, with a total of 13 wells).

DNR and WRWA are working together on pro-active strategic interventions to support wellhead protection actions in selected communities with wells susceptible to contamination. 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. The village of Luck, WI, in response to contaminant plumes that have the potential to affect the village's two municipal wells, has updated its WHP plan, participated in groundwater teacher workshops, and is evaluating new spill prevention and remediation and redevelopment opportunities with support from DNR and WRWA.

DNR continues to measure and report to US EPA on the percent of public water systems that are protected by substantial implementation of wellhead protection. In 2018, 35% 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 50.5% of the municipally served population is covered by source water protection plans with accompanying implementation ordinances.

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

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.

For the fourteenth year in a row, DNR staff worked with the Groundwater Center at the Center for Watershed Science and Education (CWSE) and the Wisconsin Geological and Natural History Survey (WGNHS) to sponsor three groundwater workshops for teachers in January and February. Educators from 24 schools' centers took part in the workshops and were able to take a free groundwater model back to 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 300 schools or nature centers since 2001 and nearly 600 educators have received hands-on training in using the model effectively.

DNR and WRWA staff continues 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 reviewed draft plans and ordinances and provided technical advice to local officials responsible for carrying out wellhead protection.

Groundwater Information and Education

In 2014, the Groundwater Coordinating Council Report to the Legislature went on-line in interactive format. Web visits and time spent at the site increased substantially. Phone inquiries about the subject matter in the report were received for the first time in over five years.

Well drillers and pump installers, water testing providers, local health and conservation departments, health care providers and many individuals requested and received hundreds of thousands printed publications on groundwater. Among the most-frequently requested items were: Nitrate, *Groundwater: Wisconsin's Buried Treasur*e 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 that may impact groundwater are conducted.

Based on measured stream flow and groundwater levels, the Little Plover River groundwater flow model published in 2017 was developed to help people understand the groundwater system and inform management decisions.

Eight *new projects* were selected through the Joint Solicitation process for funding in FY20. Final reports and 2-page research summaries are available for many projects from the *Water Resources Institute website*.

In addition, DNR committed $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 92 long-term monitoring groundwater wells and 2 spring flow gages. The long-term monitoring provides data that build 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. The Core Network is operated and maintained by the USGS and the WGNHS.

In addition to supporting the statewide groundwater level monitoring network, DNR also supports monitoring of streams, lakes and springs to understand groundwater influences on these surface water resources. In FY19 WGNHS, with funding from the DNR, continued monitoring reference springs and evaluate the vegetation and macroinvertebrates associated with each of the reference springs. As part of the Central Sands Lakes Study, DNR added 21 project groundwater level monitoring wells – or short-term monitoring wells – to the Central Sands region.

Groundwater Data Management

DNR's consolidated Groundwater Retrieval Network (*GRN*) accesses groundwater data from database systems in the Waste & Materials Management and Drinking Water & Groundwater 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 continued 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.

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 Fund, Petroleum Environmental Compensation Fund Act, contaminated sediments and at closed landfills. The RR program provides technical assistance, helps to clarify legal liability, provides financial assistance primarily to local governmental units 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 provides technical assistance on cleanups conducted by consultants at the direction of responsible parties. In addition, RR staff contract and direct consultants on state-funded cleanups and assessments funded with federal brownfields grants. The RR Program also provides assistance for spill response, sometimes with the aid of a contractor; 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 EPA with the remediation of contaminated sediments in the Great Lakes areas of concern.

Cleanup of Groundwater Contamination

As of June 30, in FY18, the program spent over $800,000 in Environmental Fund dollars to initiate or continue environmental cleanup actions at 15 locations where groundwater contamination is known or

suspected. 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 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.

Under the Safe Drinking Water Act's third Unregulated Contaminants Monitoring Rule (UCMR-3), select municipal water systems were asked to test for six PFAS (PFOA, PFOS PFNA, PFHxS, PFHpA and PFBS), between 2013 and 2015. Levels 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, and PFAS has also been found in groundwater near the Johnson Controls International/Tyco facility (Marinette), former Mirro plants (Manitowoc and Chilton) and Department of Defense sites (i.e. Wisconsin Air National Guard facilities at Truax Field and Volk Field) in Wisconsin.

The DNR is formulating a strategy to address PFAS in the State. At present, the DNR is in the initial stages of identifying PFAS sources and their potential impacts to municipal and private water supplies, groundwater and other environmental media in Wisconsin. This will include a request for voluntary sampling of influent and effluent by WPDES permitted municipal wastewater treatment plants. PFAS may be present in municipal wastewater treatment facilities' biosolids that have been regularly applied to agricultural lands throughout the state. The DNR intends to investigate the fate and transport of PFAS in biosolids. Additional statewide PFAS biosolids and sludge testing may be requested in the coming years.

Wisconsin will be drawing on the examples and experiences of other states to guide future PFAS efforts at State agencies that protect groundwater resources within the State. The DNR is in the process of hiring two new PFAS research scientists to assist the state in this effort. The DNR received funding in the state budget to conduct a survey of fire departments and airports to evaluate the potential for PFAS contamination from firefighting foam. The DNR is also putting together a PFAS GIS screening tool to prioritize sites for potential sampling based on the likelihood of those substances being used and the susceptibility of nearby receptors (e.g., drinking water wells, wildlife, etc.).

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.

The RR Program also provides redevelopment assistance at brownfield sites with groundwater contamination. Program staff assists local governments and private businesses with the cleanup and

redevelopment of brownfields by providing technical assistance. In many cases, these properties have groundwater contamination or soil contamination that poses a threat to groundwater.

The RR program also provides a number of different types of assurance, comfort, or general liability clarification letters related to properties with groundwater contamination. Collectively, these letters facilitate the reuse and development of properties. Since 1994, the RR program 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.

After a person has conducted an environmental investigation of the property and cleaned up soil and groundwater contamination, the DNR will issue a "Certificate of Completion" which provides a release from future liability for any contamination that occurred on the property prior to approval of the site investigation. Since 1994, the DNR issued over 180 certificates of completion with no reopeners.

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 230 sites in the program, with 156 at various stages of investigation and cleanup and 74 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 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, as well as site specific information pertaining to investigation and cleanup of the 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. Th 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 the Trade and Consumer Protection are also included in BRRTS on the Web and RR Sites Map.

The database is to be used with well construction requirements for private wells, and with a setback distance for new municipal wells. Before drilling, well drillers are asked to consult the DNR Well Driller Viewer (available online) to determine if a well is proposed for a property listed as having residual contamination and/or continuing obligations. If the proposed well is located on a closed remediation site, then the driller must contact regional Drinking Water and Groundwater staff prior to any well construction activities 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

Waste and Materials Management Program (WMM) 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. Should conditions warrant, staff require groundwater investigation reports that include proposals for further evaluations and recommendations for remediation at landfills that exceed groundwater standards. 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.

WMM accepts only electronic submittal of environmental monitoring data from landfill owners, labs and consultants. The electronic data submittals are currently uploaded by DNR to the WMM Groundwater and Environmental Monitoring System (GEMS) database. WMM provides access to the environmental monitoring data contained in GEMS by using "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, WMM is seeking resources to program a web interface, possibly using the Department's Data Portal and/or Web Access Management System, so that facilities can upload environmental monitoring data into GEMS.

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

WMM 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.

WMM continues to be a participant in the Interagency Pharmaceutical Waste Working Group, with the Department of Agriculture, Trade and Consumer Protections 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 landspreading or septic systems.

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 (Chapter 293, Wis. Stats.) and ferrous mining projects (Chapter 295, Wis. Stats.). The regulatory framework for ferrous mining projects was recently created through enactment of 2013 Wisconsin Act 1 in March of 2013. The law created a process by which iron

mining projects are evaluated and 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 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. In 2015, DNR issued 10 new permits for municipal and industrial facilities that discharge directly to land disposal (groundwater), bringing the total number of such permits to 214.

DNR also regulates the land application of organic industrial wastes, municipal biosolids and septage (chapters NR 214, 113, and 206) 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, 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 insure 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/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.

DNR continues to monitor the Nondomestic Wastewater to a Subsurface Soil Absorption System general permit it reissued in 2011; the general permit is in use at 25 sites. The requirements for requesting a permit, and for renewing permit coverage, revisit the setback requirements for changes due to new water supply wells during the previous permit period. The general permit is renewed every five years. The renewal process provides for identifying land use changes that may have occurred. This will serve as a check on groundwater and public health protection 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. NR 113 relates to septage management and ch. NR 204 governs the treatment quality, use and disposition of municipal wastewater treatment plant sludge. Ch. NR 113 and ch. NR 204 incorporate federal septage and 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.

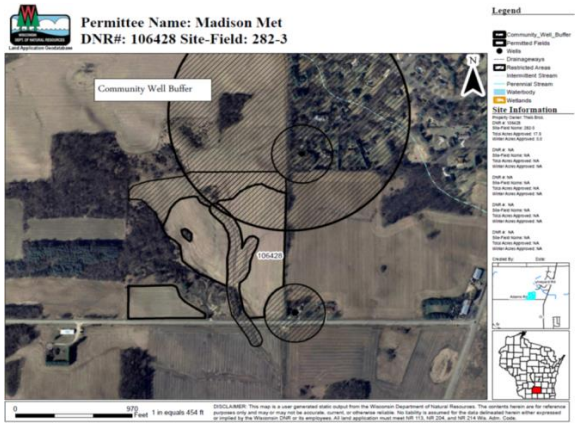
Results of federal and state septage audits identified the need for compliance training in the area of septage management. Cooperation with U.S. EPA led to the on-going creation of better training tools and implementation of numerous compliance classes. Recent septage operator certification code changes 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 industry continues to explore more economical 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 proposed 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.

Proposed efforts to modify the multiple land application codes (NR 113, NR 204, and NR 214) have been stalled for the time being to focus on streamlining issues. However, these code changes are only temporarily stalled as the following need to be addressed: creating consistency within these land application codes and between other related codes such as runoff management; providing a clearer

understanding of code requirements; implementing best management practices consistent with total maximum daily loadings (TMDLs) of phosphorus; and modifying code language to be consistent with current practices employed by industry and contractors.

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.



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

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 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 carries 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.

<u>Agricultural runoff and groundwater quality</u>

Chapter NR 243 Wis. Adm. Code covers Wisconsin Pollutant Discharge Elimination System (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 as a requirement at selected sites. In response to monitoring, significant groundwater contamination is being addressed in 2014 by renovation of a feedlot through DNR compliance processes. The DNR also promotes groundwater protection through the implementation of agricultural performance standards 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).

Currently 248 livestock operations are covered under discharge permits issued (87% dairy; 4% poultry; 5% swine; 4% beef). Regional and central office staff have successfully maintained the permit backlog at less than 15%. 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. DNR staff are participating in the NRCS effort to updates 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 (*www.snapplus.net*) 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 that voluntarily apply for new or altered manure storage facilities when the local regulation requires development and implementation of a nutrient management plan.

As part of the effort to address groundwater issues and protect drinking water and public health across Wisconsin, 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 [exit DNR]*. The NR 151 rule modification developed targeted 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 Chapter NR 216, Wis. Adm. Code. Chapter NR 216 requirements include: 1) permits for nearly 220 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 Chapter NR 151, Wis. Adm. Code, the DNR has developed runoff performance standards for MS4s and construction sites that are implement 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. The general permit to regulate storm water discharges from construction sites was reissued on September 30, 2011. There are 5 general permits that cover industrial activity, including heavy manufacturing, light manufacturing, scrap recycling, vehicle dismantling, and non-metallic mining.

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 2019 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.
- Analyzed more than 200 groundwater samples for 100 pesticide compounds plus nitrate.
- Provided cost-sharing for the installation and implementation of 1,076 conservation practices in 2018. These practices provided soil erosion control and helped manage manure and nutrients.
- Creating a new technical standard 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.
- Awarded grants to 11 producer-led groups for FY 2017 funding, grants to 19 producer-led groups for FY 2018 funding and grants to 24 producer-led groups for FY19 funding through the Producer Led Watershed Protection Grant program.

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 nearly 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 three corn herbicides used. The decline in use may have been a result of the atrazine management rule and concern 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 Resource Management program, 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. In 2018, DATCP adopted an updated USDA-NRCS 590 Nutrient Management Standard (2015) via administrative rule, ATCP 50, to meet DNR's nutrient management performance standard.

The nutrient management rules apply to all Wisconsin farmers who engage in agriculture and mechanically apply N-P-K nutrients from manures or 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 be compelled to 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 nitrogen, phosphorus, or potassium (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.

The NRCS 590 Nutrient Management Standard was updated in 2015 to improve management of nitrogen, protect groundwater quality, require winter spreading plans, prohibit applications on areas that provide a direct conduit to groundwater and wells, limiting how and when to surface apply manure in certain areas and certain soils, including frozen or snow-covered soils. 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*.

Like other agricultural performance standards, the nutrient management standard is "designed to achieve water quality standards by limiting nonpoint source water pollution." Limiting applications of nitrogen to the University of Wisconsin fertilizer recommendation rates, in conjunction with other practices, is meant to limit nonpoint pollution of groundwater. Currently, 36.6% of agricultural land in Wisconsin is covered by an approved nutrient management plan (Figure 1).

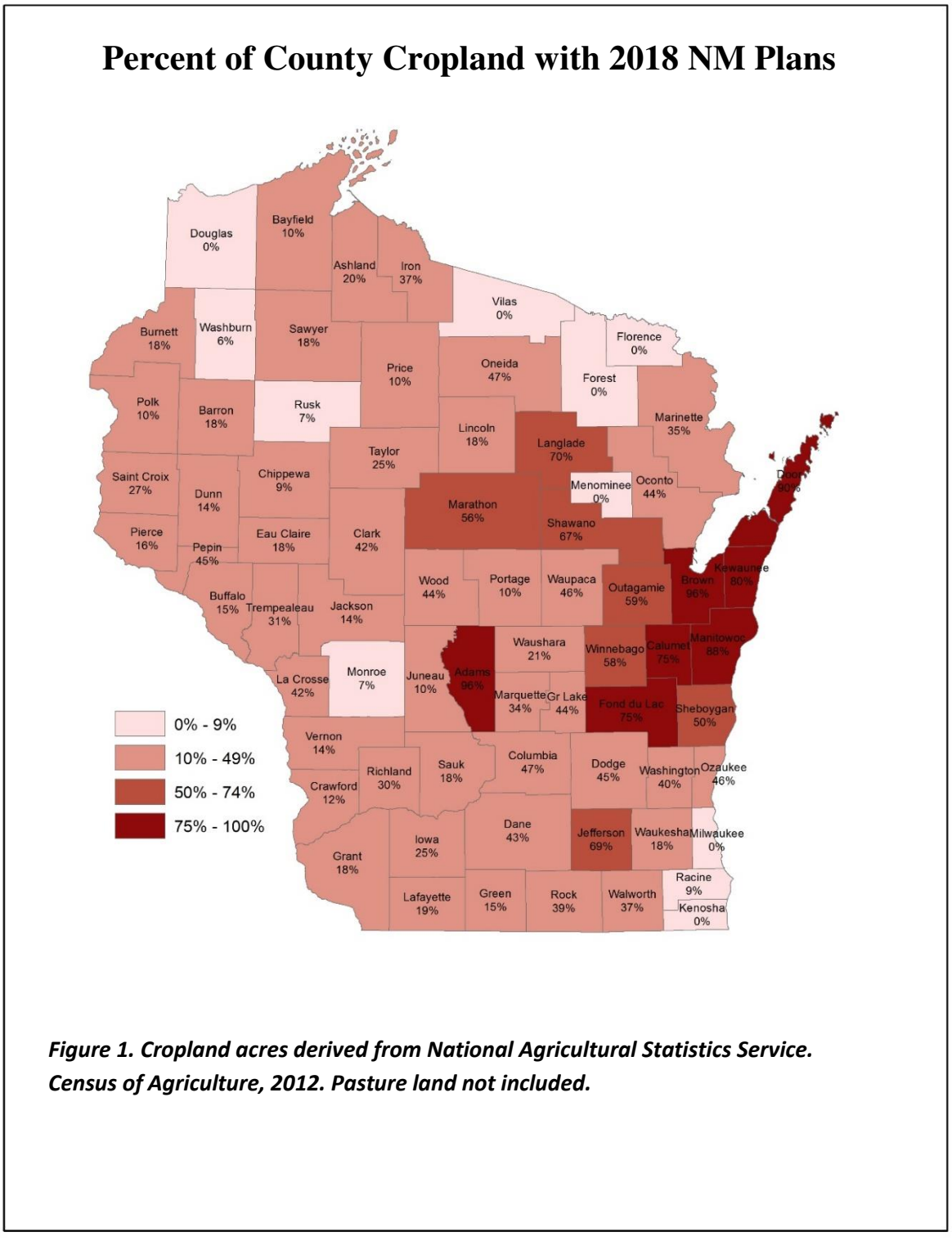


Figure 1. Cropland acres derived from National Agricultural Statistics Service. Census of Agriculture, 2012. Pasture land not included.

Increasing attention on the role of land use practices in achieving water quality goals was recognized in the 2008-2009 state budget through an increase in funding for cost-sharing. Although available funding has decreased since then, cost-share funding currently remains in the $2-3 million range in each of the subsequent biennium.

The DATCP allocated it's annual appropriation from the 2017-19 budget of $3.035 million in SEG funds "for cost-sharing grants and contracts under the soil and water resource management program under s 92.14." This allocation provides $2,177,520 to counties for landowner cost-sharing, $206,491 to fund grants for farmer training (Nutrient Management Farmer Education grant program), and $650,989 awarded to supporting partners, including UWEX/CALS, to enhance the statewide infrastructure fundamental to implementing state conservation activities, with an emphasis on development of the SnapPlus nutrient management planning software.

In 2018, total requests from counties for SEG funds for landowner cost-sharing exceeded available funds by $1,012,000. The lack of sufficient funds has practical implications to implementing agricultural performance standards, and can also impact conservation compliance efforts for farmers' participating in the Farmland Preservation Program.

The DATCP annual appropriation in the 2017-19 budget of $3,027,200 in GPR funds and $5,936,900 in SEG funds provides "for support of local land conservation personnel under the soil and water resource management program." DATCP would need an increase of about $3.2 million in its annual appropriations to reach the statutory goal of funding 3 positions at 100, 70 and 50 percent, resp. DATCP's 2018 final allocation plan under the Soil and Water Resource Management Grant Program is summarized in Table 1 below.

Table 1. Summary of Requests and Allocations for Grant Year 2018.

Funding Category	Total Requests	Unmet Requests	Final Allocations
County Staff/Support	$16,602,493	$7,638,393	$8,964,100
County LWRM Cost-Share (Bond)	$8,102,000	$4,547,000	$3,555,000
Bond Cost-Share Reserve (Bond)	$350,000	$0	$350,000
LWRM Cost-Share (SEG)	$3,198,520	$1,012,000	$2,177,520
Project Contracts (SEG)	$911,701	$260,712	$650,989
NMFE Training Grants (SEG)	$206,491	$0	$206,491
Total	**$29,371,205**	**$13,467,105**	**$15,904,100**

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. In 2015, the restriction maps were integrated directly into the SnapPlus program allowing the software to automatically identify and import field information from the maps. 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 began to meet in February 2019 and will create a new technical standard for use in verifying and documenting land features when a landowner wishes to contest the current depth to bedrock categorization of cropland specifically for the purposes of applying manure as a crop nutrient. Currently available depth to bedrock information varies by county and consists of a combination of information from multiple sources. The standard will establish valid methods and technologies for taking measurements, the appropriate scale for identifying features, and the qualifications of persons who may perform verification.

Program to Address Agricultural Nonpoint Contributions (ATCP 52)

The Producer-Led Watershed Protection Grant program was created to provide farmer-led groups financial incentives of up to $40,000 each from a $250,000 annual allocation (in 2016 and 2017). The Legislature increased program funding for the 17-19 biennium by $500,000 for a total of $750,000. The first awards were made in 2016 to 14 different groups around the state for a total of $242,550 and 11 producer-led groups were awarded $197,065 for 2017 funding. DATCP awarded 19 groups $558,246 for 2018 grants. The goal of the program is for the producer-led groups to work on projects that have the potential to prevent and reduce runoff from farm fields, while encouraging other farmers to participate in conservation activities. Although the program does not address groundwater quality specifically, the activities of the groups may have a positive impact on, or provide some protection to, groundwater. (See Figure 3).

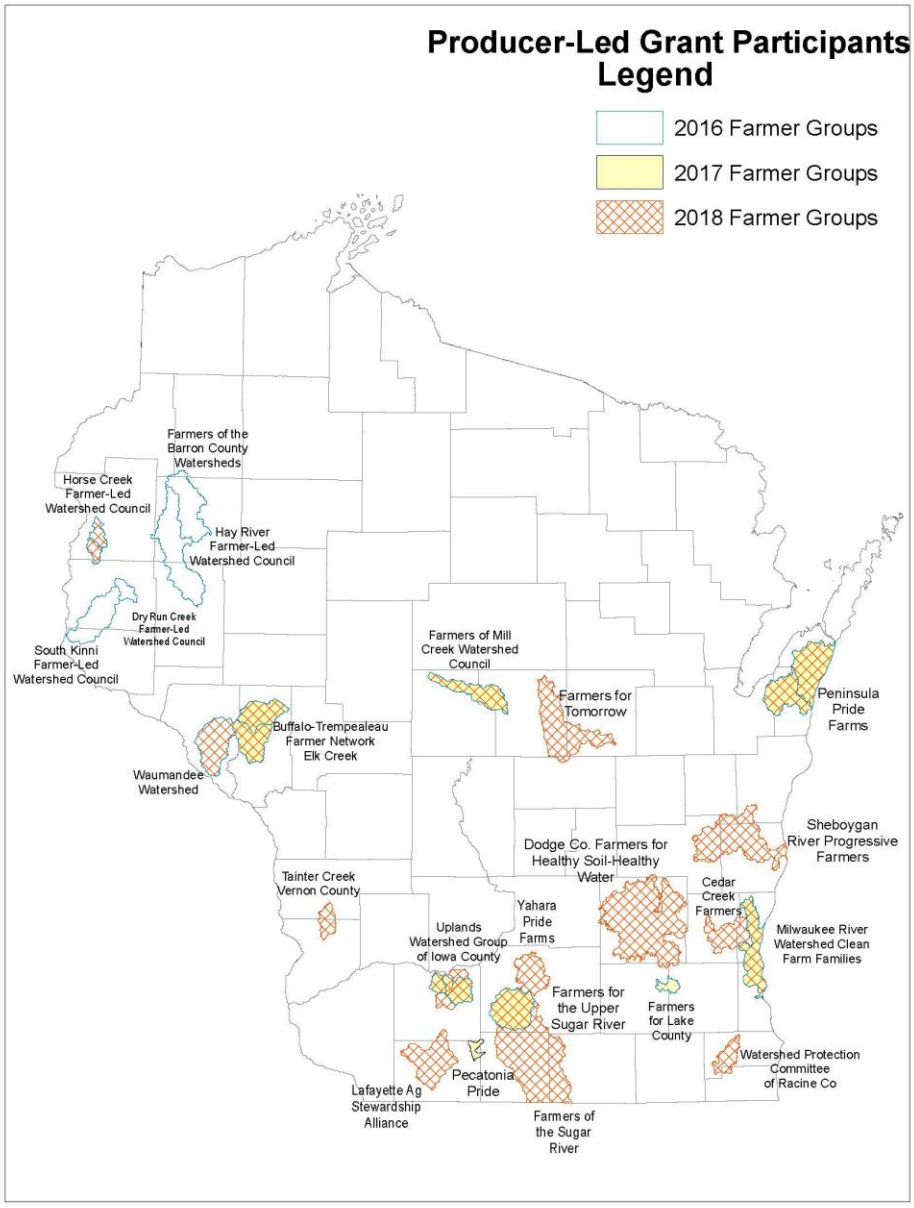


Figure 3. The location of the 2016-2018 producer-led watershed initiatives that were awarded a DATCP grant.

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 2018, 88 grants were issued: 25 for agricultural waste, 36 for household hazardous waste and 27 for the collection of unwanted prescription drugs. There were nearly 860 farmers and 9 agricultural businesses that brought in nearly 128,000 pounds of agricultural waste, 9% less than 2017. 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 appears to be holding steady overall, ranging 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 amount of household hazardous waste collected remained steady from 2017. More than 2.2 million pounds were collected in 2018 from approximately 62,000 residents. Lead and oil-based paints are the most common waste collected from households. Nearly 748,000 pounds were taken in for disposal this year. The next category is solvents and thinners with nearly 384,000 pounds collected. Pesticides are the third-most collected waste with just over 331,000 pounds. Wisconsin residents 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 almost 38,000 pounds of unwanted pharmaceuticals, a decline of about 2,000 pounds from the previous year. This decline in Clean Sweep grant supported collections could be attributed to more drug drop boxes available at retail pharmacy chains or drop boxes in pharmacies located in hospitals and clinics. Despite the decline in the amount of unwanted prescription drugs collected through Clean Sweep supported projects, Wisconsin overall collected and disposed of nearly 132,000 pounds of drugs through take back events coordinated by the Wisconsin Department of Justice. The pharmaceuticals collected through clean sweep projects are included in this total.

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, nearly 600 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 clean ups at more than 1,000 acute agrichemical

spill locations. The ACCP has received nearly 1,400 reimbursement applications totaling about $45 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.

Publications of DATCP surveys are available on the web at: *https://datcp.wi.gov/Pages/Programs_Services/GroundwaterReports.aspx* .

Research Funding

In 2018, DATCP began funding a two-year research project to evaluate lawn care pesticides in groundwater in the Milwaukee metropolitan area. The project will be completed in July of 2020. The agency recently agreed to fund three additional research projects, each to begin in June 2019. Two of these projects will assess different aspects of neonicotinoid insecticides and their impacts on shallow streams in the Central Sands Region. The third will test a combination of newly applied technologies to map the presence of thin soils over karst features in Kewaunee County, features known to accelerate the movement of surface contaminants to groundwater. DATCP currently funds groundwater research at about $150,000 and fertilizer research at approximately $200,000 per year, respectively.

Groundwater Data Management

DATCP maintains the groundwater data it collects 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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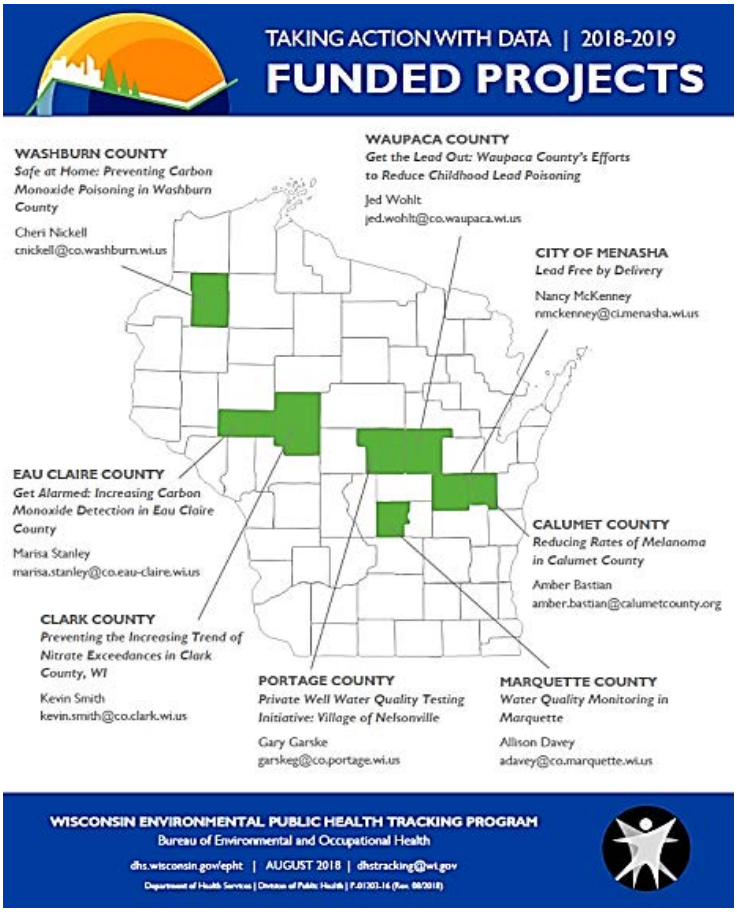
DEPARTMENT OF HEALTH SERVICES (DHS)

FY2019 Highlights

- In FY2019, DHS received a request from DNR to recommend NR 140 groundwater quality enforcement standards for 40 substances. DHS is reviewing available scientific information regarding the health effects of these substances to use in the development of the standards.
- In FY2019, multiple DHS programs provided health education and information related to several groundwater contamination sites in Wisconsin, including one in which per- and polyfluoroalkyl substances (PFAS) were found in private wells in Marinette County. DHS toxicologists and public health educators characterized health risks from PFAS, participated in technical discussions, and shared these findings in public meetings to help address health concerns regarding the contamination.
- In FY2019, DHS toxicologists and public health educators reviewed technical information on 27 substances on request from the DNR and recommended NR 140 groundwater quality enforcement standards.
- Wisconsin Environmental Public Health Tracking (Tracking) Program gives mini-grants to local public health agencies and tribal health agencies to increase overall environmental public health improvement initiatives. In 2018-2019, three local public health agencies (LPHAs) completed projects to address well water quality. Along with providing funding, Tracking staff offered each mini-grantee connection to subject matter experts and provided technical assistance related to epidemiology, communications, and evaluation as requested.



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 water quality information and human health implications of groundwater and drinking water issues 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 with 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 organic vapor intrusion when shallow groundwater is contaminated with volatile substances, such as benzene and vinyl chloride, that 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 exposure biomonitoring, 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 enforcement standards for substances found in groundwater and specifies the protocol for developing the recommendations. Recommended standards are sent to the DNR and are submitted through the rule-making process as amendments to Wis. Admin. Code ch. NR 140.

In FY2018, DHS received a request from DNR to recommend NR 140 groundwater quality enforcement standards for 27 substances, called Cycle 10. In FY2019, DHS reviewed available scientific information regarding the health effects of these substances and provided recommendations to the DNR to use in the development of the standards.

Cycle 10 Substances

New Substances

- Chromium, Hexavalent
- Strontium
- Thiamethoxam
- Imidacloprid
- Clothianidin
- Isoxaflutole
- Isoxaflutole DKN degradate

Substances with NR 140 standards

- Trichloroethylene (TCE)
- Tetrachloroethylene (PCE)
- 1,2,3-Trichloropropane (1,2,3-TCP)
- 1,1-dichloroethane (1,1-DCA)
- Boron
- Molybdenum
- Aluminum

- Isoxaflutole BA degradate
- Thiencarbazone-methyl
- Dacthal TPA & MTP degradates
- Glyphosate
- Glyphosate AMPA degradate
- Sulfentrazone
- Bacteria, *Escherichia coli* (*E. coli*)
- Perfluorooctanoic Acid (PFOA)
- Perfluorooctanesulfonic Acid (PFOS)
- Cobalt
- Barium
- 1,4-Dioxane
- Bacteria, Total Coliform

In FY2019, DHS received a request from DNR to recommend NR 140 groundwater quality enforcement standards for 40 substances, called Cycle 11. DHS is reviewing available scientific information regarding the health effects of these substances to use in the development of the standards.

Cycle 11 Substances

- Metalaxyl
- Chlorantraniliprole
- Flumetsulam
- Fomesafen
- Hexazinone
- Saflufenacil
- Perfluorotridecanoic acid
- Perfluorotetradecanoic acid
- Perfluorobutanoic acid
- Perfluoropentanoic acid
- Perfluorohexanoic acid
- Perfluoroheptanoic acid
- Perfluorononanoic acid
- Perfluorodecanoic acid
- Perfluoroundecanoic acid
- Perfluorobutane sulfonic acid
- Perfluorohexane sulfonic acid
- Perfluoroheptanesulfonic acid
- Perfluorooctane sulfonamide
- Perfluorododecanoic acid
- 6:2 Fluorotelomer sulfonic acid
- 8:2 Fluorotelomer sulfonic acid
- Perfluorodecane sulfonic acid
- Perfluoropentane sulfonic acid
- Perfluoro-2-methyl-3-oxahexanoic acid
- 4:2 Fluorotelomer sulfonic acid
- 10:2 Fluorotelomer sulfonic acid
- Perfluorohexadecanoic acid
- Perfluorooctadecanoic acid
- Dodecafluoro-3H-4,8-dioxanonanoate
- 9-chlorohexadecafluoro-3-oxanonane-1-sulfonate
- Perfluorododecanesulfonic acid
- Perfluorononane sulfonic acid
- N-Methyl perfluorooctane sulfonamide
- N-Ethyl Perfluorooctane sulfamide
- N-Methyl perfluorooctane sulfonamido acetic acid
- N-Ethyl perfluorooctane sulfonamidoacetic acid
- N-Methyl perfluorooctane sulfonamidoethanol
- N-Ethyl perfluorooctane sulfonamidoethanol
- GenX

Providing Public Health Support for Manure Contamination Events that Impact Drinking Water
Every year, microbial contamination of drinking water wells occurs as a result of agricultural landspreading or accidental discharge of animal waste. Problems can occur when there are spills of stored or transported waste, when there is waste runoff due to excessive rain or snowmelt, or when waste is improperly applied.

Responding to problems related to landspreading livestock waste is a focus area for federal, state, and local agencies that have a regulatory role in agricultural practices. DHS does not have a defined regulatory role for agricultural activities, but environmental health experts from DHS frequently

participate in multi-stakeholder workgroups that examine agricultural practices related to manure storage, handling, and landspreading. Past and ongoing partnerships include the University of Wisconsin-Extension; the Department of Agriculture, Trade and Consumer Protection (DATCP) (Livestock Siting Review Committee); and DNR ad hoc groups. As a participant, DHS contributes public health expertise and perspectives during workgroup discussions.

In addition, through its Groundwater Standards Development program and On-Call Chemical and Natural Disasters Emergency Response Team, DHS provides support to LPHAs responding to a broad range of groundwater contamination events, including those related to manure contamination. Such responses include:

- Determining appropriate public health recommendations for users of affected drinking water wells.
- Developing and implementing health outreach efforts (through advisory letters, public meetings, fact sheets, etc.).
- Providing technical assistance to LPHAs and tribal health clinics that are responding to issues of groundwater and drinking water contamination.
- Facilitating communication between LPHAs and various state partners (for example, DNR and DATCP).
- Providing well water testing capacity through the Basic Agreement with the Wisconsin State Laboratory of Hygiene for LPHAs conducting public health investigations in affected communities.

Responding to Private Citizen Calls, Questions, Concerns, and Complaints

DHS receives hundreds of inquiries each year regarding various environmental health concerns. Many of these calls from the public are specifically about groundwater and drinking water concerns. Some of the inquiries are related to concerns at individual residences while others are related to concerns regarding active environmental cleanup projects. Those related to environmental cleanup projects can result in DHS conducting or supporting a comprehensive public health response for the site. These responses are often carried out by the DHS Site Evaluation Program, which provides site-specific technical assistance to state, local, and tribal agencies for testing, health assessment, and outreach on groundwater and drinking water contamination from present or past commercial or industrial practices or accidents. One example of this effort is a project that DHS is working on with the DNR and Marinette County Health and Human Services Department assessing health risks from PFAS groundwater contamination in the Town of Peshtigo.

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

DHS continually seeks to provide data and resources to LPHAs and assist them in making positive public health improvements in their communities. The Wisconsin Tracking Program continued its successful mini-grant program and issued a request for applications for LPHAs and tribal health clinics in 2017. Funds were used by grantees to explore data from the Environmental County Health Profiles and the Tracking data portal to identify an environmental health concern in their jurisdiction. LPHAs developed and implemented environmental health initiatives within their communities.

The Wisconsin Tracking Program and other DHS staff provided ongoing support, technical assistance, and guidance to LPHAs on epidemiology, communications, and evaluation throughout the project period. LPHAs were empowered to carry out their projects with support and assistance from the Tracking Program as needed. Some examples of technical assistance the Tracking Program provided LPHAs include: sharing examples of work completed by grantees working on water topics during past

grant years; providing guidance on surveys and data visualization; and assisting in writing up success stories.

One LPHA conducted a project related to contaminants in groundwater that are described in the Tracking program report excerpt below. Results from the project were shared at the annual Wisconsin Public Health Association Conference.

> ***La Crosse County: Moving Local Nitrate Data to Focused Solutions***
> La Crosse County funded a coordinator to create a nitrate task force to review current data, collect additional data, and research potential policy solutions. When their project concluded on July 31, 2018, they offered an implementation plan for the best policy solution to address their county's root causes of nitrate contamination of private wells.

Climate and Extreme Weather Vulnerability Assessment

The DHS Climate and Health Program (CHP), funded by the Centers for Disease Control and Prevention, 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 events.

Gaps identified previously by the Climate and Health Profile Report have led to the development of several flood-related projects, with the goal of enhancing understanding of flood risk in specific watersheds and populations vulnerable to flooding events. Flooding events can have negative effects on groundwater quality and public health, such as well contamination, impacts to aquifers from flood runoff, and chemical releases. 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 (WEM), and a number of LPHAs. The findings from these flood-related projects have helped inform LPHA and local emergency management planning processes.

CHP is currently working on two flood-related strategies to assist local public health departments, tribal health agencies, local emergency management, tribal emergency management, and municipal government officials and planners in better understanding flood vulnerability in Wisconsin:

- A Flood Resilience Scorecard is in the final stages of development before dissemination later this year. 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 infrastructure improvement that will reduce the negative health impacts from flooding events.
- The Wisconsin Flood Toolkit is currently being 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 will eventually be translated into Spanish.

A third flood-related strategy was launched in March of 2019. The Wisconsin Flood Risk Mapping Application (WFRMA) provides an online user-friendly interface for assessing a community's risk and vulnerability during a flooding event. This tool helps local emergency management, local emergency preparedness, and LPHAs plan and prepare for flooding events, as well as inform future educational dissemination projects designed for 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. These monitoring programs show the following:

- Environmental radioactivity levels have been trending downward in the time period since the 1950s-1960s' atmospheric nuclear testing and such radiological incidents as the Chernobyl nuclear reactor incident of 1986.
- During FY2018 additional environmental monitoring occurred around the decommissioning of La Crosse Boiling Water Reactor due to tritium concentrations detected in site groundwater. No elevated levels were detected in off-site samples taken by the DHS EM program.

DHS's 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.

For more information

Visit the DHS Water Quality webpage at *https://www.dhs.wisconsin.gov/water/index.htm*.

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Sarah Yang, 608-266-9337
Department of Health Services
Bureau of Environmental and Occupational Health
1 W. Wilson St., Rm. 150
Madison, Wisconsin 53701

WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY

The Wisconsin Geological & Natural History Survey (WGNHS), University of Wisconsin-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.

WGNHS and DNR staff examine rotosonic core from central Wisconsin, collected as part of the central sands lakes study. *Photo: Ken Bradbury*

FY 2019 Highlights (see *https://wgnhs.wisc.edu/2018-year-in-review/*; also see this story map describing the projects in more detail: *https://arcg.is/1aCrXG*)

- Investigating groundwater quality in southwestern Wisconsin
- Developing a groundwater atlas for Bayfield County
- Building background hydrogeology for the central sands lakes study
- Completing a study of groundwater resources in the Chequamegon-Nicolet National Forest
- Investigating changes in nitrate concentrations in groundwater beneath agricultural fields and near the Village of Waupaca
- Conducting new geologic mapping in Bayfield, Dodge, Jefferson, and Waushara Counties
- Conducting new geologic mapping in Wisconsin's Driftless Area
- Investigating groundwater-surface water relationships in Wisconsin streams, lakes, and wetlands
- Upgrading Wisconsin's statewide groundwater monitoring network

Details of Ongoing Activities

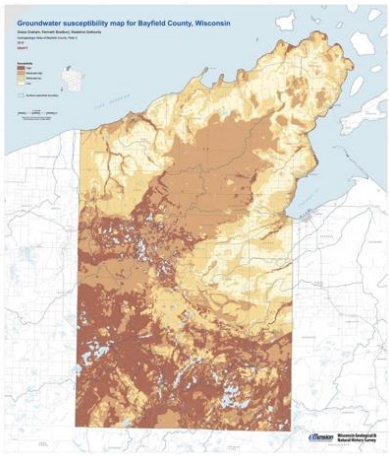
Groundwater-Level Monitoring Network

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. 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 2018 in eight 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/)

- ***Bayfield County groundwater atlas***. In FY 2016, the Bayfield County Board requested WGNHS assistance to complete characterization of their groundwater resources, including a water well database, recharge analysis, depth to bedrock and groundwater contamination potential. Project completion is scheduled for 2019; interim products are available here: http://wgnhs.wisc.edu/pubs/wofr201702/.



Example map showing groundwater susceptibility from the Bayfield Groundwater Atlas.

- ***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. More information: 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.
- ***Hydrogeology of the frac-sand mining district in western Chippewa County***. This five-year study, commissioned by the Chippewa County Department of Land Conservation and Forest Management in 2012, is a cooperative effort between the USGS and WGNHS. The project evaluates potential impacts to groundwater resources from industrial sand mining and irrigated agriculture. This effort includes development of a groundwater flow model and a series of annual informational meetings to update the public about study results and water resources in this region of Wisconsin. A final WGNHS bulletin documenting this work was released in early 2019: https://wgnhs.wisc.edu/pubs/b112/.
- ***Water quality indicators of human impacts to the wetlands of Door County*.** Door County is home to wetlands that are important habitat for endangered species such as the Hines Emerald dragonfly, as well as nesting and spawning areas for waterfowl and fish. Most of these wetlands depend on groundwater inputs to maintain water levels and quality. We collected groundwater discharging to the wetlands and tested it for human and agricultural indicators such as artificial sweeteners (indicators of septic waste) and pesticides. We are determining whether these indicators are linked to land use with the hope that they will serve as early detection for potential human and agricultural impacts to the water quality of these wetlands.
- ***Bedrock geology of Dodge County.*** With cooperative funding from the USGS STATEMAP program, the WGNHS is conducting new mapping of the bedrock geology and bedrock topography of Dodge County. This work is scheduled for completion in FY2019.
- ***Bedrock geology of Fond du Lac County.*** The WGNHS completed new mapping of the bedrock geology and depth to bedrock of Fond du Lac County. These maps were released in early 2019: https://wgnhs.wisc.edu/pubs/000963/.

Regional Groundwater Studies

Regional groundwater studies usually span multiple counties. During 2018 the WGNHS was involved in several regional projects, including the following:

- ***Hydrogeology of the Chequamegon-Nicolet National Forest*.** In cooperation with the USGS, and with funding from the U.S. Forest Service, the WGNHS completed a multi-year study of the hydrogeology of Wisconsin's National Forests. This effort consists of characterization of the groundwater system and development of groundwater flow models to improve management of forest resources. The project covers four forest units across eight counties in northern Wisconsin. A comprehensive technical report for each forest unit was released in early 2019, see https://wgnhs.wisc.edu/pubs/000961/.

Cover images of the four hydrogeology reports produced for the Chequamegon-Nicolet National Forest.

- ***Groundwater flow in the Mukwonago Basin*.** In cooperation with the USGS, and with funding from The Nature Conservancy, the WGNHS built and calibrated a groundwater flow model. This model will be used to understand the impacts of possible land use changes and groundwater pumping to groundwater dominated wetlands in the Mukwonago Basin. The model has been used to estimate potential impacts to selected wetlands, streams and lakes in the basin from increased pumping. The results will be part of a decision support tool for land use planning in the basin. That tool will be web based and directly provide users with an understanding of how a proposed well will affect stream flow and water levels of surface waters and wetlands in the basin.

- ***Multi-instrument Stream Surveys.*** Improved modelling of groundwater and surface water interactions are needed now more than ever as we need to understand the complex interactions between societal, agricultural and natural systems. We have developed methodology to continuously measure water chemistry, depth and sediment type along with video of streams using instruments mounted in a canoe. We have begun collecting data on a series of five smaller streams located across Wisconsin. The data is expected to show locations of groundwater inflow and impacts. The goal is to provide data over miles of the streams that can be collected in less than a day that would otherwise not be available.

- ***Central Sands Lakes Study.*** In early 2018, the Wisconsin Geological and Natural History Survey was contracted by the DNR to assist them in a 4-year study to evaluate and model the hydrology of Long and Plainfield Lakes in Waushara County, and Pleasant Lake along the border of Waushara and Marquette Counties. The WGNHS is coordinating efforts with DNR staff, as well as researchers at UW–Stevens Point, and USGS. The WGNHS' primary objectives are to improve the geologic and hydrogeologic characterization of the Central Sands, develop a hydrogeological framework for groundwater modeling and collect water-level measurements for use in model calibration.

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 areas during 2018 included the following:

- ***Radium studies***. In 2018, WGNHS scientists completed an investigation of geologic sources of radium to groundwater in Wisconsin's sandstone aquifer. The work demonstrated that geologic sources of radium are common throughout the aquifer stratigraphy, but geochemical conditions, such as dissolved oxygen levels, control radium concentrations in groundwater. These findings and ongoing related studies address a significant problem for many municipal water supply systems, such as the City of Waukesha, where deep wells produce water with elevated radium.

When sulfide nodules like these occur near the water table, private wells may be contaminated with metals. We're tracking the horizontal and vertical distribution of these minerals. *Photo: Jay Zambito, WGNHS.*

- ***Nitrate study***. In 2018, WGNHS continued to assist the DNR with source water protection at public supply wells impacted by elevated nitrate. The WGNHS operates monitoring systems at two sites. The WGNHS is continuing this research in partnership with cooperating land managers to quantify nitrate loading to the underlying aquifer under an irrigated corn crop. In addition, the WGNHS supported field research and modeling to determine nitrate sources and movement near municipal wells at Waupaca, Wisconsin.

- ***Groundwater/surface water interactions in the Marengo watershed in the Chequamegon National Forest.*** Water temperature is important to the health and habitat of streams. Groundwater discharge to the stream helps moderate and cool a stream. That cooler water provides improved habitat for trout. We are working with the U.S. Forest Service to collect data on temperatures, flows and water quality in the Marengo River in northern Wisconsin. These data will be used to construct a groundwater/temperature model of the river. The model will allow the U.S. Forest Service to understand how temperatures in the stream might change in the future and how managing stream conditions such as increasing shade or placing structures in the channel will affect the stream temperature.

Collecting water-quality data in the Marengo River as part of a study to help the U.S. Forest Service manage trout habitat in response to climate change. *Photo: Laura Schachter, WGNHS*

- ***Mapping the base of the Cambrian aquifer through geophysical modeling of Precambrian topography, southern Wisconsin.*** The Survey's bedrock geologists are using geophysical techniques combined with field mapping to determine the base of the Cambrian sandstone aquifer in parts of Columbia and Sauk Counties. This project, funded through the Wisconsin Joint Solicitation, is critical for determining aquifer thickness for use in hydrogeologic analyses.
- ***Investigations of natural groundwater contamination by trace metals in western Wisconsin.*** Water-quality tests of private wells drawing water from the rocks where the Wonewoc Formation meets the Tunnel City Group have found elevated concentrations of arsenic, cadmium, lead, and other trace metals. We sampled the elemental composition of these rock formations across west-central, south-central, and southwest Wisconsin. The regional geochemical and mineralogical database developed in this study provides evidence that the rocks of the Wonewoc–Tunnel City contact interval in west-central Wisconsin are a potential natural source of trace metal concentrations observed in some process-water ponds at industrial sand mines and groundwater in private wells that draw water from these rocks. d https://wgnhs.wisc.edu/pubs/wofr201901/.

Groundwater Data Management and Support

In 2018 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:

- ***An updated springs inventory for the state of Wisconsin.*** The WGNHS completed a 3-year effort to inventory the springs of Wisconsin. This inventory resulted in a comprehensive database with information on flow rate, water quality and other physical attributes relevant to the classification of springs. The database (*https://dnrmaps.wi.gov/H5/?viewer=Water_Use_Viewer*) is used by the DNR for approving high-capacity well permits. In addition to developing this database, WGNHS staff began a long-term monitoring program of eight reference springs. These springs were selected in representative hydrogeological and ecological settings to provide a more robust understanding of springs and potential impacts from land use and groundwater withdrawals. A two-year extension for the baseline monitoring began in September 2017. The analysis includes quarterly measurements of spring flow and water chemistry and surveys of aquatic plants and animals. In 2019 the WGNHS will release a published report on the statewide survey and also guidelines for surveying springs.

One of the many springs inventoried as part of our multiyear project inventorying the springs of Wisconsin. *Photo: Grace Graham, WGNHS.*

- ***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.

- ***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 FY 2016, WGNHS released a new interactive map, providing online access to these historical WCRs for state agencies, consulting firms and private well owners. 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 51,000 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 UW-Extension. WGNHS produces and serves as a distributor of many groundwater educational publications from our sales counter at our office and from our website (*https://wgnhs.wisc.edu*). We also distribute information about Wisconsin groundwater on our website at *https://wgnhs.uwex.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 2018, WGNHS staff members participated in groundwater educational meetings in counties where mapping and/or hydrogeologic studies are in progress, particularly in Bayfield, Chippewa and Trempealeau Counties. 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/**

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DEPARTMENT OF TRANSPORTATION

As a result 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 59 rest area and seasonal waysides. Other DOT groundwater related activities or assistance include: contaminated property groundwater investigation or remediation; compensatory wetland restoration; storm water management; and groundwater level monitoring points for the Wisconsin Groundwater-Level Monitoring Network at several locations.

FY 2019 Highlights

- Continue to research the effectiveness of brine chemicals and brine application rates for varying weather conditions (Clear Roads National Research Consortium *https://clearroads.org/*).
- Created the Brine Technical Advisory Committee (TAC) in 2018.
- Pilot tested Mostly Liquid Routes in four Counties including one Interstate application route for the entire winter.
- Preliminary results of new brine application techniques are showing significant reduction in salt use while maintaining clear roads and level of service for the traveling public.

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 1,308 salt storage site locations listed in the database with a total of over 2,642 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 64 locations 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. Last winter, four counties implemented route optimization where trucks are strategically routed based on shop location, salt supply and fuel location. These changes resulted in fuel and time efficiencies. An additional 30 counties will implement route changes next winter based on a uniquely designed map for each of those counties.

The newest DOT initiative in winter maintenance is called “Mostly Liquid Routes” (MLRs). Four 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 pilot projects resulted in a reduction of about 50% road salt application while still achieving the “time to bare/wet” goals. Next winter additional MLRs will be tested on more state highway routes.

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

For more information

Visit the following web site (https://wisconsindot.gov/)

Contact Bob Pearson, Bureau of Technical Services - Environmental Services Section

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UNIVERSITY OF WISCONSIN SYSTEM

The University of Wisconsin System (UWS) has research, teaching, and outreach responsibilities. These three missions are integrated through cooperation and joint appointments of research, education, and Extension personnel who work on groundwater issues. UWS staff members work with state and federal agencies and with other partners to solve groundwater resource issues. Research is coordinated through the University of Wisconsin Water Resources Institute, which conducts annual calls for proposals followed by rigorous peer 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 University of Wisconsin Environmental Resources Center* (affiliated with 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 at Land Grant universities across the nation with core funding provided and administered by the U.S. Department of the Interior through the U.S. Geological Survey. It promotes research, training, and information dissemination focused on Wisconsin's and the nation's water resources problems.

FY 2019 Highlights

- In support of the Wisconsin Groundwater Research and Monitoring Program, provided UWS funding to six research projects focused on groundwater contaminants, including arsenic and nitrate; water quantity challenges in the Central Sands; geochemistry and microbiology; groundwater-surface water interactions; and new monitoring techniques, and supported graduate and undergraduate students at UW-Milwaukee, UW-Madison, and UW-Platteville.
- Coordinated the Request for Proposals and the review process for the FY20 Joint Solicitation for the Wisconsin Groundwater Research and Monitoring Program.
- Supported a full-time state Water Resources Science-Policy postdoctoral fellow in partnership with the Wisconsin Geological and Natural History Survey (WGNHS) and Wisconsin Department of Natural Resources (DNR) working on groundwater nitrate contamination. Supported an additional postdoctoral fellow in partnership with the DNR working on stream water quality. Recruited a new Water Resources Science-

The Central Sands region irrigates its fields using high-capacity wells, affecting the overall nitrogen budget. Photo: Chris Kucharik.

Policy postdoctoral fellow to work on the Central Sands Lakes Study (study requested by the legislature).

- Supported the annual Wisconsin Chapter of the American Water Resources Association meeting by leading and funding the writing, editing, graphic design, printing, and mailing of a conference registration brochure and the writing, editing, graphic design, and printing of the conference program. WRI joined other conference sponsors—the University of Wisconsin-Stevens Point Center for Watershed Science and Education, DNR, WGNHS, and the U.S. Geological Survey's Wisconsin Water Science Center—to stage the 2019 event that attracted about 200 people, including resource managers, researchers, industry and consultants, and students.
- Maintained the *Wisconsin Water Library*, providing access to more than 30,000 volumes of water-related information. Library staff visited 35 locations and reached nearly 1,600 people, many K-12 aged, with in-person events this past year.
- Maintained the *WRI website* as an information portal for research requests for proposals, news, and past research.
- Produced and distributed four issues of the *Aquatic Sciences Chronicle* highlighting water research and the people who conduct water research and outreach. The *Chronicle*'s dedicated readers consist of roughly 5,500 online and print subscribers, which includes local and state water-management agencies and water-related non-governmental organizations. Readers are found in Wisconsin and across the country. The newsletters are also posted online. At *aqua.wisc.edu/chronicle*, all issues of the publication are archived and searchable.
- Supported the production of 23 final project reports, 13 theses, and 56 peer-reviewed publications over the past five years.
- Assisted in curating an art installation that focused on the intersection of water science, fish and the arts in Fond du Lac.

The Wisconsin Water Library's Senior Special Librarian Anne Moser helped curate an art installation in Fond du Lac that encouraged visitors to consider the intersection of art and science. Photo: Thelma Sadoff Center for the Arts.

- Created all-inclusive kits for children in pre-K to fourth grade to teach age-appropriate STEM concepts with a water theme. The kits are booked out for months into the future for use in classroom or story-time settings.

Research

The Groundwater Coordinating Council's research efforts touch all corners of the state. University of Wisconsin-Madison researcher Eric Booth is using partial and full-range imaging spectrometers to assess the health of fens, a type of wetland, in southeastern and south-central Wisconsin.

The WRI research portfolio is supported by UW System funding for the Wisconsin Groundwater Research and Monitoring Program and includes interdisciplinary projects in four broad 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. Key areas of emphasis in FY19 included research focused on groundwater microbiology and geochemistry, groundwater-surface water interactions, new monitoring techniques, groundwater quantity challenges, and various groundwater contaminants, including arsenic.

During FY19, the WRI directed a wide-ranging program of priority groundwater research consisting of three 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. These six projects, funded by the UWS, provided training in several disciplines for several graduate student research assistants and undergraduate students at UW-Milwaukee, UW-Madison, and UW-Platteville. Groundwater issues investigated during the past year included:

The latest statistics from the U.S. Department of Agriculture peg Wisconsin's potato production as third in the nation. The bountiful Central Sands area also yields vegetables like green beans, cabbage, peas and beets. Sustaining these valuable crops—and the agricultural economy they underpin—means sustaining resources needed for their cultivation, such as water. Photo Pixabay

- The impact of dissolved organic matter composition on the formation of disinfection byproducts in groundwater. Christina Remucal, UW-Madison. (new)
- Improving water and nitrogen use efficiency under changing weather variability in the Central Sands. Christopher Kucharik, Matthew Ruark, UW-Madison. (new)
- Dynamics of Arsenic concentration and speciation in Wisconsin private drinking water wells. Shangping Xu, Yin Wang, UW-Milwaukee. (new)
- Linking groundwater and nutrients to monitor fen ecosystems using airborne imaging spectroscopy. Eric Booth, Steven Loheide, UW-Madison. (continuing)
- Historic changes in groundwater use by trees in Wisconsin due to high-capacity groundwater pumping and climate variability. Steven Loheide, UW-Madison. (continuing)
- New proxy-based hydrological reconstructions over the past five centuries in southwest Wisconsin. Christopher Underwood, Evan Larson, UW-Platteville. (continuing)

For FY20 (July 1, 2019 - June 30, 2020), the UWS selected three new groundwater research projects from proposals submitted in response to the Joint Solicitation for Wisconsin Groundwater Research and Monitoring Program and will continue three projects selected from the previous years' solicitations. The projects are based at UW-Madison and UW-Milwaukee and include:

- Impact of changing snow cover and frozen ground regimes on groundwater recharge. Steven Loheide, UW-Madison. (new)
- Assessment of the source and mobility of phosphorus in the hydrologic system in western Wisconsin. Sarah Vitale, J. Brian Mahoney, UW-Eau Claire. (new)
- Microbially-mediated oxidation of trace element-bearing sulfide minerals in sandstones of Trempealeau County, WI. Eric Roden, Matthew Ginder-Vogel, UW-Madison. (new)
- The impact of dissolved organic matter composition on the formation of disinfection by-products in groundwater. Christina Remucal, UW-Madison. (continuing)
- Improving water and nitrogen use efficiency under changing weather variability in the Central Sands. Christopher Kucharik, UW-Madison. (continuing)
- Dynamics of arsenic concentration and speciation in Wisconsin private drinking water wells. Shangping Xu, Yin Wang, UW-Milwaukee. (continuing)

Additionally, the WRI receives an annual federal 104(B) allocation that can be used to advance groundwater and other water resources research and initiatives. In FY19, this allocation was matched 50:50 by the WGNHS and DNR Drinking and Groundwater Bureau and used to fund a Wisconsin Water Resources Science-Policy postdoctoral fellow working on groundwater nitrate contamination. In addition, another postdoctoral fellowship was created with the DNR Water Quality Bureau; this postdoctoral fellow was recruited and began work on predicting stream nutrient and total suspended solids. This allocation also augmented a project selected through the state groundwater competition, freeing up state resources to invest in additional strong proposals submitted to the groundwater competition.

Teaching

Institutions within the UWS continue to offer undergraduate- and graduate-level courses and programs 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 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

The Water Resources Institute views continuing education for P-12 teachers as an important component of its outreach and training effort. It offers resources to teachers in the form of STEM curriculum kits on water-related topics geared toward children up to 4th grade. These kits circulate throughout Wisconsin and have received positive feedback for their instructional capacities and ease of use. Photo: Chris Hynes.

teaching water-related science in P-12 classrooms. The curricula are available for checkout by all teachers and residents in Wisconsin. The librarian also has extensive experience in working with young 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. A unique challenge associated with fully utilizing these kits in the past has been the difficulty in physically distributing them. Now, the WRI has devised an efficient distribution system through the public interlibrary loan system.

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 FY19, WRI transitioned to a new 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 given access to anonymous reviews and original proposals to help decide which proposals to recommend for funding. The website provides a framework for consistently capturing the same information from all the prospective investigators and reviewers, thus helping to ensure that all proposals are treated equally.

Information 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.

WRI's video catalog includes "What is a spring?," "Streams neutralize nitrates in groundwater," "A new measure of groundwater flow," "Got oaks?," and one of the most popular videos on the WRI's *YouTube channel*, "Testing well water for microorganisms." To date it has nearly 12,000 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 way of sharing water science information. It offers three multi-part series on topics such as groundwater, mercury in aquatic environments, and aquifers and watersheds.

During this reporting period, WRI staff were integral to the content-population of *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 exploration.

Water Resources Publications

The program offers easily accessible publications through an online site, recently redesigned and relaunched to enhance visitors' experience, with free information or information available for a nominal cost. Topics include nitrates in groundwater, siting rain gardens, and arsenic. 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.

AWRA Annual Conference

The WRI was once again integral to the planning and staging of the American Water Resources Association (AWRA)-Wisconsin Section's annual conference. The theme of the 43rd conference was Clearing the Waters: Effective Science and Communication. Areas covered included groundwater modeling, water quality, agricultural hydrology, and groundwater and surface water management. The Wisconsin Section is dedicated to mentoring future leaders in water resources and offers a student workshop and an opportunity for students to showcase their academic work. In addition to WRI, the meeting was supported by academic and governmental partners, including the Center for Watershed Science and Education, UW-Stevens Point Wisconsin; DNR; Wisconsin Water Science Center, U.S. Geological Survey; and WGNHS.

Student mentoring is a critical aspect of the annual American Water Resources Conference. Pictured are water scholars associated with the Water Resources and Sea Grant Institutes and who benefit from learning and networking at an annual statewide conference. Photo: Jennifer Smith.

Wisconsin's Water Library Outreach Activities

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 continued its outreach 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.

To build water literacy, staff reached more than 900 Wisconsin youth through 27 events conducted at public libraries, Head Start, and other early-childhood programs, or as part of other informal learning activities. Library staff also delivered presentations to Head Start staff, environmental education instructors, and other librarians.

Library Websites

The library maintains several information transfer tools to reach library patrons. The most frequently accessed is the *library's website*, which had about 15,500 visitors this year.

In addition to its website, Wisconsin's Water Library uses other technology tools to reach library patrons. Using email, the library sends out a bimonthly *Recent Acquisitions List* to about 600 contacts. The message includes recent updates to the library website and contact information for users to ask any water-related question. The library also supports an email at askwater@aqua.wisc.edu, which is monitored daily. Anyone with a water-related query can pose a question and receive a response in a timely manner.

The library has been using social media tools to reach new library users and to raise visibility of the library. *Facebook* is used often to announce events and display interesting links to its followers. The library's Facebook page currently has more than 550 likes. The library's Twitter tool has been in use since June of 2009 and now has more than 2,000 followers. Both tools have seen increased use by library patrons and both have loyal and increasing numbers of followers.

Technical Research Publications Resulting from Recent WRI Groundwater Research and Monitoring Program-Sponsored and Other WRI-funded Projects (Past five years):

Water Resources Institute Reports

Bahr, J., M. Gotkowitz, and J. Olson. 2017. Long-term alterations in groundwater chemistry induced by municipal well pumping. Final report, Water Resources Institute, University of Wisconsin-Madison. WR15R002.

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

Choi, W., and C. Wu. 2016. Impacts of climate and land use changes on streamflow and water quality in the Milwaukee River Basin. Final report, Water Resources Institute, University of Wisconsin-Madison. WR13R004.

Ginder-Vogel, M., and C. Remucal. 2016. Effect of source chemistry on Mn-bearing solid dissolution and reactivity in municipal water systems. Final report, Water Resources Institute, University of Wisconsin-Madison. WR15R009 and WR14R004.

Gorski, P., M. Shafer, J. Hurley, S. Zana, and J. Swarthout. 2015. Hexavalent chromium (Cr(VI)) in WI groundwater: identifying factors controlling the natural concentration and geochemical cycling in a diverse set of aquifers. Final report, Water Resources Institute, University of Wisconsin-Madison. WR12R005.

Grundl, T., L. Fields-Sommers, and J. Graham. 2016. Groundwater-surface water interactions caused by pumping from a riverbank inducement well field. Final report, Water Resources Institute, University of Wisconsin-Madison. WR13R002.

Hauxwell, J. 2016. Wisconsin Water Resources Fellowship. Final report, Water Resources Institute, University of Wisconsin-Madison. WR15R006.

Larson, E.R., and S.A. Allen. Establishing the long-term range of variability in drought conditions for southwest Wisconsin. Final report, Water Resources Institute, University of Wisconsin-Madison. WR13R003.

Larson, R., and M. Holly. 2015. Silage storage runoff water quality assessment and design recommendations to limit environmental impacts Final report, Water Resources Institute, University of Wisconsin-Madison. WR11R007.

Loheide, S., and C.B. Voter. 2015. Effects of nuanced changes in lot layout and impervious area connectivity on urban recharge. Final report, Water Resources Institute, University of Wisconsin-Madison. WR12R002.

McIntyre, P.B. 2016. Climate change impacts on stream temperature and flow: consequences for Great Lakes fish migrations. Final report, Water Resources Institute, University of Wisconsin-Madison. WR11R002.

Nitka, A., P. McGinley. 2017. Investigating the impact of nitrate contamination on uranium and other elements of emerging concern in Wisconsin groundwater. Final report, Water Resources Institute, University of Wisconsin-Madison. WR16R002.

Noguera, D. M. Anderson, I. Tejedor, J. Wouters. 2017. Phosphorus and Arsenic sensors for real time environmental monitoring. Final report, Water Resources Institute, University of Wisconsin-Madison. WR15R001.

Potter, K. 2015. Quantifying and communicating uncertainty in products of the USGS National Water Census. Final report, Water Resources Institute, University of Wisconsin-Madison. WR14R005.

Scherber, K.S., and S.P. Loheide. 2017. Hydraulic impacts of the loss of Wisconsin's winter on surface water – groundwater interactions. Final report, Water Resources Institute, University of Wisconsin-Madison. WR14R003.

Sellwood, S.M., D.J. Hart, M.B. Gotkowitz, and J.M. Bahr. 2015. Identifying the controls on flow and contaminant distribution in siliciclastic bedrock aquifer systems. Final report, Water Resources Institute, University of Wisconsin-Madison. WR12R001.

Stelzer, R., and T. Scott. 2017. Predicting the locations of nitrate removal hotspots at the groundwater-surface water interface in Wisconsin streams. Final report, Water Resources Institute, University of Wisconsin-Madison. WR15R003.

Stewart, E.K., J. Rasmussen, J. Skalbeck, L. Brengman, M. Gotkowitz. 2018. Mapping the base of the Cambrian aquifer through geophysical modeling of Precambrian topography, southern Wisconsin. (University of Wisconsin-Extension). Final Report, University of Wisconsin Water Resources Institute. 15p. WR17R003.

Thompson, A., K.G. Karthikeyan, R. Stenjem, D. Hyndman, A. Kendall, and A. Parish. 2015. Implications of climate change and biofuel development for Great Lakes regional water quality and quantity. Final report, Water Resources Institute, University of Wisconsin-Madison. WR10R008.

Ventura, S., and S. Cardiff. 2016. Advances in monitoring and analysis of trace metals: a workshop to address applications in the Upper Great Lakes. Final report, Water Resources Institute, University of Wisconsin-Madison. WR14R001.

Wu, C. 2016. Uncertainty and variability of Wisconsin lakes in response to climate change. Final report, Water Resources Institute, University of Wisconsin-Madison. WR11R003.

Xu, S., and L. Feriancikova. 2015. Transport of manure-derived *Escherichia coli* within naturally-fractured dolomite. Final report, Water Resources Institute, University of Wisconsin-Madison. WR12R003.

Zambito IV, J.J., L.D. Haas, M.J. Parsen, and P.I. McLaughlin. 2016. The Wonewoc and Tunnel City: A potential natural source of groundwater contamination in west-central Wisconsin. Final report, Water Resources Institute, University of Wisconsin-Madison. WR15R004.

Theses

Cardiff, Scott. 2016. Cumulative land cover and water quality impacts of large-scale mining in Lake Superior Ojibwe Treaty-ceded Territories. Ph. D. Thesis. University of Wisconsin-Madison.

Childress, Evan S. 2014. Cross-ecosystem delivery of nutrients to streams: the role of fish migrations and processes. Ph.D. Thesis. Freshwater and Marine Sciences, University of Wisconsin-Madison.

Feriancikova, Lucia. 2014. The spread of emerging contaminants in the soil-groundwater system. Ph. D. Thesis. University of Wisconsin-Milwaukee.

Fields-Sommers, Laura. 2016. Assessing the effects of riverbank inducement on a shallow aquifer in southeastern Wisconsin. M.S. Thesis. Freshwater Sciences and Technology, UW –Milwaukee, Milwaukee, WI. 211p.

Gerdts, N. 2015. Seasonal evaporation of polymictic and dimictic lakes under changing climate. M.S. Thesis. University of Wisconsin-Madison.

Hamby, A., 2018. The effects of faults and changing water levels on confined sandstone aquifer water chemistry in northeastern Wisconsin. MS Thesis. University of Wisconsin-Green Bay, Green Bay, WI.

Li, Wenliang. 2016. Large-scale urban impervious surfaces estimation through incorporating temporal and spatial information into spectral mixture analysis. Ph.D. Thesis. Department of Geography, University of Wisconsin-Milwaukee, Milwaukee, WI. 110p.

Magee, Madeline. 2016. Simulation of lake thermal structure, ice cover, and fish habitat in response to changing climate. Ph. D. Thesis. University of Wisconsin-Madison. 171p.

Michaud, 2018. Long term performance of radon barrier in limiting radon flux from four uranium mill tailings containment facilities. MS Thesis, University of Wisconsin-Madison.

Polich, Michael. 2015. Surface runoff, soil, and nutrient fluxes of cellulosic biofuel cropping systems. M.S. Thesis, University of Wisconsin-Madison.

Sellwood, Stephen M. 2015. Characterization of groundwater flow in sandstone aquifers using heat as an in-well tracer. Ph.D. Thesis. Geoscience, University of Wisconsin-Madison.

Sijan, Zana. 2014. Novel approaches for assessment of factors influencing human health impacts of chemicals in the environment. M.S. Thesis. Environmental Chemistry and Technology, University of Wisconsin-Madison.

Stefani, Nick. 2016. Field and Laboratory Measurement of Radon Flux and Diffusion for Uranium Mill Tailings Cover Systems. M.S. Thesis. Geological Engineering, UW-Madison.

Other Publications

Allen, S., and E.R. Larson. 2014. The Driftless Oaks: An environmental history of southwest Wisconsin. Wisconsin Natural Resources 38: 6–7. [available: *http://dnr.wi.gov/wnrmag/2014/10/Oak.htm*].

Balgooyen, S., P.J. Alaimo, C.K. Remucal, and M. Ginder-Vogel. 2017. Structural transformation of MnO_2 during the oxidation of bisphenol A. Environmental Science & Technology 51:6053-6062. DOI: 10.1021/acs.est.6b05904.

Benson, C.H., W.H. Albright, M. Fuhrman, W.J. Likos, N. Stefani, K. Tian, W.J. Waugh, and M.M. Williams.2017. Radon fluxes from an earthen barrier over uranium mill tailings after two decades of service.Proc. WM2017 Conference, March 5-9, 2019, Phoenix, Arizona.

Bero, N.J., M.D. Ruark, and B. Lowery. 2014. Controlled-release fertilizer effect on potato and groundwater nitrogen in sandy soil. Agronomy, Soils & Environmental Quality 106:359-368.doi:10.2134/agronj2013.0331.

Bero, N.J., M.D. Ruark, and B. Lowery. 2016. Bromide and chloride tracer application to determine sufficiency of plot size and well depth placement to capture preferential flow and solute leaching. Geoderma 262:94-100. *https://doi.org/10.1016/j.geoderma.2015.08.001*.

Cardiff, S.G., and R. F. Lepak. 2015. Summary of the Workshop on Trace Metals Monitoring in the Lake Superior Basin. *http://www.lic.wisc.edu/glifwc/workshops/tracemetals.html*.

Chang, P.-H., Z. Li, J.-S. Jean, W.-T. Jiang, Q. Wu, K.-H. Lin, and J. Kraus. 2014. Desorption of tetracycline from montmorillonite by aluminum, calcium and sodium: an indication of intercalation stability. International Journal of Environmental Science and Technology 11:633-644. doi:*10.1007/s13762-013-0215-2*.

Chang, P-H, Z. Li, W-T Jiang, C-Y Kuo, and J-S Jean. 2015. Adsorption of tetracycline on montmorillonite: influence of solution pH, temperature, and ionic strength. Desalination and Water Treatment 55:1380-1392. DOI:10.1080/19443994.2014.924881.

Childress, E., and P.B. McIntyre. 2014. Multiple nutrient subsidy pathways from a spawning migration of iteroparous fish. Freshwater Biology 60: 490–499. doi:10.1111/fwb.12494.

Childress, E., J.D. Allan, and P.B. McIntyre. 2014. Nutrient subsidies from iteroparous fish migrations can enhance stream productivity. Ecosystems 17:522-534. Doi: 10.1007/s10021-013-9739-z.

Childress, E.S., and P.B. McIntyre. 2015. Multiple nutrient subsidy pathways from a migration of iteroparous fishes. Freshwater Biology 60: 490-499. doi: 10.1007/s10021-013-9739-z.

Childress, E.S., and P.B. McIntyre. 2016. Life history traits and spawning behavior modulate ecosystem-level effects of nutrient subsidies from fish migrations. Ecosphere 7(6):e01301. 10.1002/ecs2.1301.

Childress, E.S., R. Papke, and P.B. McIntyre. 2015. Spawning success and early life history of longnose suckers in Great Lakes tributaries. Ecology of Freshwater Fish 25:393-404. doi: 10.1111/eff.12220.

Choi, W., F. Pan, and C. Wu. 2017. Impacts of climate change and urban growth on the streamflow of the Milwaukee River (Wisconsin, USA). Regional Environmental Change 17:889-899. doi:10.1007/s10113-016-1083-3.

Deng, Y., and C. Wu. 2016. Development of a class-based multiple endmember spectral mixture analysis (CMESMA) approach for analyzing urban environments. *Remote Sensing*, in press.

Dunkle, K.M., M.P. Anderson, and D. Hart. 2015. New ways of using well construction reports for hydrostratigraphic analyses. Groundwater. DOI: 10.1111/gwat.12326.

Federman, T., et al. 2017. Developing new tree-ring chronologies from eastern redcedar (Juniperus virginiana) to seek insight to variations in groundwater resources in central Wisconsin. Proceedings of the Annual Meeting of the American Association of Geographers, Online Abstracts and Programs.

Grasby, S.E., W. Shen, R. Yin, J.D. Gleason, J.D. Blum, R.F. Lepak, J.P Hurley, and B. Beauchamp. 2016.Isotopic signatures of mercury contamination in latest Permian oceans. Geology 45:55-58. doi:10.1130/G38487.1.

Hamilton, D.P., Magee, M.R., Wu, C.H., Kratz, T.K. 2018. Ice cover and thermal regime in a dimictic seepage lake under climate change. Inland Waters 8:3, 381-398. DOI: *10.1080/20442041.2018.1505372*.

Holly, M.A., R.A. Larson, E. Cooley, and A. Wunderlin. 2018. Silage storage runoff characterization: Annual nutrient loading rate and first flush analysis of bunker silos. Agriculture, Ecosystems, and Environment 264:85-93.

Lepak, R.F., R. Yin, D.P. Krabbenhoft, J.M. Ogorek, J.F. DeWild, T.M. Holsen, and J.P. Hurley. 2015. Use of stable isotope signatures to determine mercury sources in the Great Lakes. Environmental Science & Technology Letters 2015, 2:335-341. DOI: 10.1021/acs.estlett.5b00277.

Li, W., C. Wu, and W. Choi. 2017. Predicting future urban impervious surface distribution using cellular automata and regression analysis. Earth Science Informatics 11:19-29.

Luczaj, J., and H. Huang. 2018. Copper and sulfur isotope ratios in Paleozoic-hosted Mississippi Valley-type mineralization in Wisconsin, USA. Applied Geochemistry 89:173-179. *https://doi.org/10.1016/j.apgeochem.2017.12.013*.

Luczaj, J.A., M.J. McIntire, and M.J. Olson Hunt. 2016. Geochemical characterization of trace MVT mineralization in Paleozoic sedimentary rocks of northeastern Wisconsin, USA. Geosciences 6:29.doi:10.3390/geosciences6020029.

Lv, G., L. Wu, Z. Li, L. Liao, and M. Liu. 2014. Binding sites of chlorpheniramine on 1:1 layered kaolinite from aqueous solution. Journal of Colloid and Interface Science 424:16-21. *doi:10.1016/j.jcis.2014.03.010*.

Lv, G., Z. Li, N. Hoeppner, L. Wu, and L. Liao. 2014. Interactions between sulfa drug sulfadiazine and hydrophobic talc surfaces. Colloids and Surfaces A: Physicochemical and Engineering Aspects 446:172-178. *doi:10.1016/j.colsurfa.2014.01.014.*

Lv, G., Z. Li, W.-T. Jiang, P.-H. Chang, and L. Liao. 2015. Interlayer configuration of ionic liquids in a Ca-montmorillonite as evidenced by FTIR, TG-DTG, and XRD analyses. Materials Chemistry and Physics 162:417-424. *doi:10.1016/j.matchemphys.2015.06.008*.

Lv, G., Li, Z., Elliott, L., Schmidt, M.J., MacWilliams, M.P., Zhang, B. 2018. Impact of tetracycline-clay interactions on bacterial growth. Journal of Hazardous Materials in press. *http://doi.org/10.1016/j.jhazmat.2017.09.029*

Lyons, J., A.L. Rypel, P.W. Rasmussen, T.E. Burzynski, B.T. Eggold, J.T. Myers, T.J. Paoli, and P.B. McIntyre. 2015. Trends in the reproductive phenology of two Great Lakes fishes. Transactions of the American Fisheries Society 144:1263-1274. DOI: 10.1080/00028487.2015.1082502.

Magee, M., C.H. Wu, D.M. Robertson, R.C. Lathrop, and D.P. Hamilton. 2016. Trends and abrupt changes in 104-years of ice cover and water temperature in a dimictic lake in response to air temperature, wind speed, and water clarity drivers. Hydrology and Earth System Sciences 20:1681-1702. doi:10.5194/hess-2015-488.

Magee, M.R. and Wu, C.H. 2017. Effects of changing climate on ice cover in three morphometrically different lakes. Hydrological Processes 31:308-323. DOI: 10.1002/hyp.10996.

Magee, M.R. and Wu, C.H. 2017. Response of water temperature and stratification to changing climate in three lakes with different morphometry. Hydrology and Earth System Sciences 21:6253-6274. *https://doi.org/10.5194/hess-21-6253-2017*.

Magee, M.R. P.B. McIntyre, and Wu, C.H. 2017. Modeling oxythermal stress for cool-water fishes in lakes using cumulative dosage approach. Canadian Journal of Fisheries and Aquatic Sciences. *https://doi.org/10.1139/cjfas-2017-0260*.

Masarik, K.C., J.M. Norman, and K.R. Brye. 2014. Long-term drainage and nitrate leaching below well-drained continuous corn agroecosystems and a prairie. Journal of Environmental Protection 5:240-254. doi: *10.4236/jep.2014.54028*.

Mason, L.A., C.M. Riseng, A.D. Gronewold, E.S. Rutherford, J. Wang, A. Clites, S.D.P. Smith, and P.B. McIntyre. 2016. Fine-scale spatial variation in ice cover and surface temperature trends across the surface of the Laurentian Great Lakes. Climatic Change 138:71-83. DOI: 10.1007/s10584-016-1721-2.

McDaniel, A., M. Harper, D. Fratta, J.M. Tinjum, C.Y. Choi, and D.J. Hart 2016. Dynamic Calibration of a Fiber-Optic Distributed Temperature Sensing Network at a Distric-Scale Geothermal Exchange Borefield. GeoChicago.

McIntyre, P.B., C. Reidy Liermann, E. Childress, E.J. Hamann, D. Hogan, S.R. Januchowski-Hartley, A.A. Koning, T.M. Neeson, D.L. Oele, and B.M. Pracheil. 2016. Conservation of migratory fishes in freshwater ecosystems. Pp. 324-360. In: Closs, G.P., M. Krkosek, and J.D. Olden (eds.): Conservation of Freshwater Fishes. Cambridge University Press. Cambridge, United Kingdom.

Melching, C.S., J. Liang, L. Fleer, and D. Wethington. 2015. Modeling the water quality impacts of the separation of the Great Lakes and Mississippi River basins for invasive species control. Journal of Great Lakes Research 41:87-98. *doi:10.1016/j.jglr.2014.11.009*.

Pan, F. and W. Choi. 2018. Effects of urban imperviousness scenarios on simulated storm flow. Environmental Monitoring and Assessment 190:499. *https://doi.org/10.1007/s10661-018-6874-1*.

Rothenberg, S.E., R. Yin, J.P. Hurley, D.P. Krabbenhoft, Y. Ismawati, C. Hong, and A. Donohue. 2017.Stable mercury isotopes in polished rice (Oryza sativa L.) and hair from rice consumers. Environmental Science and Technology. In press. DOI: 10.1021/acs.est.7b01039.

Sellwood, S.M., D.J. Hart, and J.M. Bahr. 2015. An in-well heat-tracer-test method for evaluating borehole flow conditions. Hydrogeology Journal 23:1817-1830. DOI: 10.1007/s10040-015-1304-8.

Sellwood, S.M., D.J. Hart, and J.M. Bahr. 2015. Evaluating the use of in-well heat tracer tests to measure borehole flow rates. Groundwater Monitoring & Remediation 35:85-94. DOI:10.1111/gwmr.12134.

Stefani, N., W.J. Likos, and C.H. Benson. 2016. Evaluation of two methods for measuring radon flux from earthen radon barriers. Proc. GeoChicago 2016: Sustainability, Energy, and the Geoenvironment, Chicago, IL.

Stelzer, R.S., J.T. Scott, L.A. Bartsch. 2015. Buried particulate organic carbon stimulates denitrification and nitrate retention in stream sediments at the groundwater–surface water interface. Freshwater Science 34:161-171. DOI: 10.1086/678249.

Stelzer, R.S., E.A. Strauss, and M. Coulibaly. 2017. Assessing the importance of seepage and springs to nitrate flux in a stream network in the Wisconsin sand plains. Hydrological Processes 31:2016-2028. 10.1002/hyp.11161.

Stelzer, R.S., J.T. Scott, L.A. Bartsch, and T. B. Parr. 2014. Particulate organic matter quality influences nitrate retention and denitrification in stream sediments: evidence from a carbon burial experiment. Biogeochemistry 119:387-402. DOI 10.1007/s10533-014-9975-0.

Voter, C.B. and S.P. Loheide II. 2018. Urban residential surface and subsurface hydrology: Synergistic effects of low-impact features at the parcel scale. Water Resources Research *54*, 8216–8233. *https://doi.org/10.1029/2018WR022534*.

Wu, Q.F., T. Zhang, Z. Li, H.L. Hong, K. Yin, J.S. Jean, and W.T. Jiang. 2014. Using probing compounds to investigate adsorption mechanism of ciprofloxacin on montmorillonite. Materials Technology Advanced Performance Materials 29:B100-B107. *http://dx.doi.org/10.1179/1753555714Y.0000000154.*

Yin, R., D.P. Krabbenhoft, B.A. Bergquist, W. Zheng, R.F. Lepak, and J.P. Hurley. 2016. Effects of mercury and thallium concentrations on high precision determination of mercury isotope composition by Neptune Plus multiple collector inductively coupled plasma mass spectrometry. Journal of Analytical Atomic Spectrometry, DOI: 10.1039/C6JA00107F.

Yin, R., X. Feng, J.P. Hurley, D.P. Krabbenhoft, R.F. Lepak, R.Z. Hu, Q. Zhang, Z.G. Li, and X.W. Bi. 2016.Mercury isotopes as proxies to identify sources and environmental impacts of mercury in sphalerites. Scientific Reports. 2016, 6:18686. doi:10.1038/srep18686.

Yin, R., R.F. Lepak, D.P. Krabbenhoft, and J.P. Hurley. 2016. Sedimentary records of mercury stable isotopes in Lake Michigan. Elementa: Science of the Anthropocene 2016;4:000086. DOI: *http://doi.org/10.12952/journal.elementa.000086*.

Zambito, J., P.I. McLaughlin, L.D. Haas, E.K. Stewart, S.E. Bremmer, and M.J. Hurth. 2016. Sampling methodologies and data analysis techniques for geologic materials using portable x-ray fluorescence (pXRF) elemental analysis: Wisconsin Geological and Natural History Survey Open-File Report 2016-02, 12 p., 5 appendices.

For more information on the WRI:
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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 part of UW-Madison's Division of Extension and is housed in the College of Natural Resources at UW-Stevens Point. 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. Recent policy work focuses on groundwater pumping and its impacts on surface waters. The center is part of the Center for Watershed Science and Education, an office of UW-Extension Cooperative Extension Service, and the UW-Stevens Point College of Natural Resources. More information can be found at *https://www.uwsp.edu/cnr-ap/watershed/*.

Well Water Testing & Outreach

In calendar year 2018, the center helped 5,120 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. Fourteen drinking water education programs helped 1,652 well users in twelve counties understand potential remedies for any problems found and the relationship of land-use practices to groundwater quality. Participants of these programs able to have well water tested and attend an educational program where they learn about their individual results and the community results.

In addition, nitrate screening and information on well water testing was provided at the Midwest Renewable Energy Fair.

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 810,000 individual test results for approximately 105,666 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. In 2018, 8,918 people accessed the viewer. In 2018 the Viewer was migrated into a new platform. Currently the Center is updating the viewer with additional data, including nearly 60,000 new samples from the DNR collected as a condition of new well construction/well or pump work. This process is expected to be completed by the end of 2019.

Nitrate in Groundwater

The Center is finishing a project investigating the impact of various cropping practices on groundwater quality in the Central Sands. 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 fertility or leaching studies often only focus 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. The work is a collaboration with Dr. Chris Kucharik and 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

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

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 Central Sands region.

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 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.

Groundwater Phosphorus

Water samples collected through water education programs have been used to better understand the distribution, concentration, and sources of groundwater phosphorus in Wisconsin. This is one of the largest sources of groundwater phosphorus information available in the state, and it helps fill an important gap in understanding the sources of phosphorus to surface water resources. Results have been used by agencies and consultants studying Wisconsin surface waters, and they have also been summarized at several Wisconsin meetings and workshops.

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.

County Groundwater Quality Inventories

Starting in 2019, the Center has begun working with Chippewa, Green, and Sauk County to begin citizen-based groundwater monitoring programs in each county. We will be recruiting 200-300 rural land owners in each county to test their wells annually for parameters such as nitrate, chloride, alkalinity, pH, hardness, and conductivity. The goal is to collect data that can be used to understand trends in rural groundwater quality over time. By testing the same wells annually, we will be better able to assess where/why groundwater quality changes. The projects are similar to *trend analysis/testing* that we have been conducting in partnership with the Kewaunee County Land Conservation Department in the Town of Lincoln.

The Center assisted Waupaca County in the summer of 2017/2018 with a private well water inventory of the county. In total they sampled almost 800 wells for coliform bacteria, nitrate, chloride, pH, total hardness, alkalinity, and conductivity.

Waushara County tested 110 wells in the summer of 2018 and hopes to sample an additional 200 wells in 2019 for both nitrate and chloride.

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. Professor Emeritus George Kraft, Kevin Masarik and University of Wisconsin Water Quality Specialist Paul McGinley are participating in workgroups for the Wisconsin DNR Central Sands Lake Study. Kevin Masarik serves on the Nitrate Workgroup organized by State Rep. Joel Kitchens. The Center also hosted Lt. Governor Mandela Barnes and Rep. Katrina Shankland for a water laboratory tour where they were able to learn about various work that the University of Wisconsin, Division of Extension and University of Wisconsin-Stevens Point provide to rural landowners.

Partnerships

The center continues to work closely with state agencies, local governments, land conservation departments, UW-Extension's county faculty and natural resource educators, and many local watershed-based groups.

Recent Publications and Reports

Kraft, G.J., D.J. Mechenich, K. Clancy, and J. Haucke. 2012. Information support for groundwater management in the Wisconsin Central Sands, 2009-2011. A Report to the Wisconsin Department of Natural Resources, Project NMA00000253.

Kraft, G.J., D.J. Mechenich, K. Clancy, and J. Haucke. 2012. Irrigation effects in the northern lake states – Wisconsin central sands revisited. *Ground Water Journal* 50:308-318. DOI: 10.1111/j.1745-6584.2011.00836.x

Kraft, G.J., D.J. Mechenich, and J. Haucke. 2014. Information support for groundwater management in the Wisconsin central sands, 2011-2013. Report to the Wisconsin Department of Natural Resources. Center for Watershed Science and Education, University of Wisconsin – Stevens Point / Extension. *http://www.uwsp.edu/cnr-ap/watershed/Documents/kraft_cs_2011_2013.pdf.*

Nitka, A.L. and P.M. McGinley. 2017. Investigating the impact of nitrate contamination on uranium and other elements of emerging concern in Wisconsin groundwater. Report to the Water Resources Research Institute in partial fulfillment of UWS Project WR16R002.

Luczaj, J., and K. Masarik. 2015. Groundwater quantity and quality issues in a water-rich region: Examples from Wisconsin, USA. *Resources* 2015 4:323-357. *doi*:*10.3390/resources4020323.*

Masarik, K., M. Mechenich, A. Nitka and G. Kraft. 2018. Portage County Well Water Quality – 2017. Report in partial fulfillment of Portage County Project. Masarik, K.C. 2016. Design of a field-scale approach for evaluating nitrogen management practices impacts to groundwater. Report in partial fulfillment of DNR Project #15_BMP_01.

Masarik, K., J. Norman, and K. Brye. 2014. Long-term drainage and nitrate leaching below well-drained continuous corn agroecosystems and a prairie. *Journal of Environmental Protection* 5:240-254. doi: *10.4236/jep.2014.54028*.

McGinley, P., K. Masarik, M. Gotkowitz, and D. Mechenich. 2016. The impact of aquifer geology and anthropogenic acidification on groundwater phosphorus. *Applied Geochemistry.* 72:1-9. *http://www.sciencedirect.com/science/article/pii/S088329271630097X*

McGinley, P.M., W. M. DeVita, and A.L. Nitka. 2016. Evaluating chemical tracers in suburban groundwater as indicators of nitrate-nitrogen sources. Final Report prepared for the Wisconsin Department of Natural Resources.

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University of Wisconsin Environmental Resources Center (ERC) / Land & Water Programs within Extension Natural Resources Institute (NRI)

With the integration of UW Extension into UW-Madison in 2018-2019, the UW Environmental Resources Center (*ERC*) has been transitioning all of its programs into the new Division of Extension Natural Resources Institute (NRI). As such, those Land & Water Programs within NRI involve state and local specialists addressing water resources, land and water conservation, forestry, conservation professional training, citizen engagement, and volunteer monitoring. NRI/ERC also coordinates a number of regional and national programs addressing water resources and water-education initiatives related to groundwater. ERC will dissolve into this new structure as of July 1, 2019.

ERC/NRI Regional Water Programs and Conservation Professional Development

ERC/NRI hosts the *North Central Regional 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 an array of water resource issues, including groundwater quantity and quality.

This regional collaboration has led to a partnership providing multi-state professional development to conservation professionals (*https://erc.cals.wisc.edu/programs/conservation-professional-training-program/*). 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 the 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.
- 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.

ERC/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.

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 resulted in a total of 54,893 volunteer hours providing nearly $1.2 million dollars in value to the state in the first five years of the program. Fifty-one host organizations have partnered with the program by having 115 individuals trained as instructors who have trained 663 volunteers statewide. There is a presence of Master Naturalists in 63 of Wisconsin's 72 counties. Nearly 100% of survey respondents consistently report that their knowledge of Wisconsin's natural resources increases after taking the course. 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.

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

Other projects include the National Extension Water Outreach Education project to develop and promote best education practices for water education and to improve access to education resources and strategies. Involvement with the national youth water initiatives, *Give Water a Hand*, Water Equals, and *Educating Young People about Water,* continues, and those programs formed the basis for a new *Thinkwater* initiative through the UWEX Program Development and Evaluation unit. Find links to these programs on the ERC website at *https://erc.cals.wisc.edu/*.

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

UWEX's Regional Natural Resources Program

The University of Wisconsin System cooperates on community-focused educational programs with other state agencies involved with water resources and natural resource issues. Since 1998, UWEX has worked in partnership to support state, county, and local efforts to protect and improve surface and groundwater quality and quantity across the state. Locally situated natural resource educators develop and conduct programs that reach local and statewide audiences, 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.

More information on the Regional Natural Resources Program can be found here: *https://erc.cals.wisc.edu/programs/regional-natural-resources-education-program/*.

For more information on NRI/Land & Water programs related to groundwater:
Contact Chad Cook, NRI Land & Water Program Manager
445 Henry Mall, Room 202
Madison, WI 53706
Phone (608) 262-0020, fax (608) 262-2031, email *chad.cook@wisc.edu*

University of Wisconsin Nutrient and Pest Management (NPM) Program

Mission Statement

The University of Wisconsin's Nutrient and Pest Management (NPM) Program works with a wide range of partners to promote agricultural practices for protecting water quality while maintaining or improving farm profitability. The NPM Program serves Wisconsin farmers and the agricultural professionals who assist them. The program links farmers and researchers allowing for the exchange of knowledge on the profitability, practicality, and environmental impact of crop production practices and cropping systems.

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, land 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, and distribute 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 2018 show that as a result of local delivery of the curriculum, more than 7,609 producers farming approximately 2,181,753 acres in 55 counties have received in-depth education on nutrient management planning. In 2018, approximately 465 farmers operating about 130,000 acres in more than 18 Wisconsin counties added to this accomplishment list. Data are currently being collected for 2019 accomplishments.

- *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 (50 total), 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 425 copies requested and delivered in December of 2018. In addition to creating SnapPlus educational products, NPM staff actively train farmers, agronomists, and others to use SnapPlus.

- *Educational support to numerous Wisconsin watershed projects*. Activities include coordination and delivery of individual nutrient management plans, phosphorus index model calibration and ground-truthing, manure spreader calibrations, edge of field surface water runoff monitoring, cover crop and soil health education. In 2018, NPM staff served as key members of farmer-led, performance-based watershed projects in 23 Wisconsin counties. Additional duties included, in northwest Wisconsin, the coordination of four separate county farmer watershed councils.

- *On-farm demonstrations, field plot research and subsequent educational programs* on various topics including: corn nitrogen rates, cover crops, conservation tillage, manure applications, etc. Occurred in six counties in 2018.

Pest Management

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

- The *Waterhemp Weed Control Project* involves statewide field trails evaluating the effectiveness of various herbicides and herbicide application timings for the control of waterhemp. Waterhemp is a very aggressive weed that is wreaking havoc across the nation's cropland fields. The project goal is to develop control strategies for containing the spread of this weed that can severely impact farm profitability. In 2018, NPM conducted on-farm research waterhemp trials in Chippewa and Grant Counties.

- *Waterhemp Management Challenge Field Days.* In 2018 NPM staff in conjunction with Dr. Rodigo Werle of the UW-Madison Dept. of Agronomy hosted three field days at the Lancaster Ag Research Station educating 220+ farmers and agronomists about herbicide resistant waterhemp and its spread across 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.

- *Combine Cleaning Clinics*: The NPM Program along with UW-Madison faculty and local county partners organized two combine cleaning clinics to educate 50 farmers and agronomists in 2018 about the need to prevent the spread of herbicide resistant weeds.

Food Systems

- *Cover Crops Research, Education and Outreach.* NPM partnered with UWEX county agents, USDA-NRCS, county Land Conservation Departments, non-governmental organizations, and CALS specialists to deliver cover crop education in 31 Wisconsin counties. Activities include development and instruction of cover cropping practices, as well as fielding inquires and providing advice on cover crop selection and management. This includes recommendations of cover crop species, planting dates and seeding rates to match the planting window and supplemental forage and soil conservation needs. Special emphasis has recently been placed on interseeding cover crops into existing row crops.

- *Soil Health Education.* Soil health is a critical component to sustainable cropping systems. Over 2,100 adults (farmers, agency personnel, ag professionals, community members) and 1,700 youth were trained in 21 counties by NPM program staff in 2018. Many educational events were outdoor field days and included exploration of soil properties via soil pits and/or field tools.

NPM Program Northeast Regional Specialist, Jamie Patton, discusses soil health with a group farmers and natural resources conservation staff. *Photo:* Dairy Business Association.

- *Healthy Grown / Healthy Farms.* The Healthy Grown Program, which was expanded to the Healthy Farm Program, has been a national model of sustainable production systems, exemplifying integrated pest management and reduced pesticide systems for potato production. There is also an innovative ecosystem conservation component to restore privately owned landscaped in Wisconsin. Utilizing the Healthy Farm concept, additional commodities are developing sustainability standards. In 2018, ten growers were certified and over 8,000 acres of fresh market potatoes (about 25% of Wisconsin's fresh market acres) were verified as "Healthy Grown." NPM staff are involved in similar efforts for pea, sweet corn and soybean crops.

- *Water Stewardship Program and Wis. Potato and Vegetable Growers Association Water Task Force.* The NPM Program is a partner with many stakeholders in both the Water Task Force and Water Stewardship Program with the goal of promoting research and education on water quality and

quantity in the Central Sands, as well as recognition of famers who have adopted crop management practices to improve water stewardship.

- *Frac Sand Mining Site Reclamation*. 2018 marked the fifth and final year of a frac sand mining reclamation site restoration project. This project, located in Chippewa County, is in cooperation with the Chippewa County Land Conservation Dept., UW-River Falls and the mining company. The intent is to investigate the remediation of mining sites to natural/native and agricultural land use.

- *First Nation Sustainable Food Production and Food Sovereignty Initiatives*. NPM has partnered with Francisco Arriaga in the UW-Madison Dept. of Soil Science and the College of Menominee Nation and Stockbridge-Munsee Tribal Community in two projects aimed at developing a sustainable agriculture curriculum (B.S. and A.S. levels) and sustainable food production practices, including soil fertility and soil health, to promote food sovereignty.

Outreach and Communication

- *Mobile Applications*. The NPM Program is creating mobile applications (apps) for hand-held devices (Apple and Android). In 2018-19 one new app was created (*Sporebuster* – which assists soybean growers in making profitable fungicide application decisions) and our eight previously released apps were updated. Currently available mobile apps include: *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*. Collectively, these apps have been downloaded by more than 115,000 users from across the world. All apps are created in collaboration with UW-Madison faculty and are promoting agricultural best management practices.

- *YouTube Videos*. More than 240 YouTube educational videos featuring UW-Madison-CALS specialists have been prepared and released by the NPM Program over the past six 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 1,000 worldwide per day. (Over 1,250,000 total views as of January 22, 2019.) This educational outreach channel's viewership has grown by 200% since 2016. There are over 5,000 subscribers to NPM's YouTube channel. In a recent random stakeholder survey, 75% of respondents found these videos very valuable. Eighteen new videos were created in 2018 on topics including herbicide resistant weeds, corn disease management, cover crops, etc.

- *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 1,200 recipients, with 20,000 PDF downloads in 2018. 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 2018, 28 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/*.

- *Farm Technology Days 2018.* NPM was part of a team that organized and staffed the pest management booth, provided field plot demonstration assistance, and created and staffed an interactive photo booth demonstrating mobile technology use for agriculture.

For more information on the NPM program:
Visit the website (*https://ipcm.wisc.edu/*)
Contact Scott Sturgul, Wisconsin 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). 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 Department of Health Services 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 is developing and validating methods for measurement of "PFAS" chemicals in various matrices, including groundwater/drinking water. As interest increased and the science and toxicology of PFAS is better characterized, this work is likely to continue and accelerate. The State Laboratory would be happy to partner with others and share information as appropriate to collectively advance these issues.

- Interpretation of GC-MS and LC-MS analysis of sterols as a chemical source tracking indicator. Sterols are the excreted metabolites of hormones (plant and animal) that are ingested by animals or metabolized from endogenous sources (e.g., human synthesis and metabolism of cholesterol). Depending upon the sterol detected, and in what quantity, the source may be inferred. For example, a high level of coprostanol, relative to background, indicates anthropogenic contamination of a surface water sample. Detection of cholesterol along with plant sterols, such as beta-sitosterol and stigmasterol, would be indicative of fecal contamination by animals utilizing a mixed diet. Detection of the plant sterols alone would possibly occur with herbivore fecal contamination. Sterol source tracking data should correlate to orthogonal methodologies, such as the microbial source tracking protocols, in making a final determination.

- 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 was deployed in 2018 to assist in characterizing a possible contamination and the system worked as designed.

Water Microbiology Section

- Source Assessment Requirement under the Revised Total Coliform Rule - WSLH continues to develop and 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 has been acquired and capability has been developed to use 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.

- 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 have become important in monitoring because they have been associated with specific geological formations and conditions in northeastern Wisconsin. For further study, the lab also has separated arsenic into its oxidation states and measured their relative concentrations. Detectable concentrations of arsenic have been more routinely measured in drinking water sourced from Wisconsin groundwater. Recent updates to Wisconsin regulations have increased monitoring requirements under certain scenarios. Arsenic in groundwater and drinking water has received increased attention in general.

- 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/*)
Contact David Webb, Deputy Director, Wisconsin State Laboratory of Hygiene
2601 Agriculture Drive
Madison, WI 53718
Phone (608) 224-6200, email *David.Webb@slh.wisc.edu*

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 2019 Highlights

- The statewide private on-site wastewater treatment systems (POWTS) inventory was completed and more than 96% of counties are operating a maintenance program for all POWTS in their jurisdiction.
- The Department developed and, in early 2018, began implementing a training program to train county inspection staff basic and advanced level POWTS plan review training. That program continued in 2019.
- The Department partnered with a technical college to offer and provide instruction for a 2.5-day class developed for prospective and current soil testers to properly identify and evaluate soil and site conditions for the placement of POWTS systems.

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. Counties must also initiate new or enhance existing reporting programs related to inspection, maintenance and servicing events by October 1, 2019.

For further information:
Visit the following web site (https://dsps.wi.gov/pages/Home.aspx)
Contact: Bradley Johnson
Phone: 920-492-5605
E-mail: mailto:Bradley.Johnson@Wisconsin.gov

Report of the Governor's Representative
Steve Diercks, Coloma, WI

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

As many people now know, Wisconsin's Central Sands region is one of the most productive irrigated vegetable areas in the United States with top three rankings for potatoes, sweet corn, green beans, peas, carrots and several other specialty vegetable crops. Annual production is valued at over $5.8 billion and the industry generates over 30,000 jobs in the area. At the same time, concerns have been raised over the potential impact of irrigated agriculture, climate, urbanization, and other factors on the groundwater aquifer and surface waters of the Central Sands. In response, the WPVGA formed the Water Task Force to bring together resources and expertise to foster the sustainable use of water resources. It is an example of collaboration involving GCC member agencies and the agriculture industry.

The group's diverse membership includes: representatives of potato and vegetable farms from all parts of Wisconsin; major potato and vegetable processors (McCain Foods, Del Monte Foods and Seneca Foods); rural communities (Village of Plover); University of Wisconsin Research and Extension Specialists from the Departments of Soil Science, Horticulture, Entomology, Plant Pathology, and Biological Systems Engineering, as well as the Nelson Institute and the Wisconsin Institute for Sustainable Agriculture; and support expertise from WPVGA, Wisconsin Department of Natural Resources, Wisconsin Geological and Natural History Survey, USDA-Natural Resources Conservation Service, the Wisconsin Wetlands Association, the US Fish and Wildlife Service, irrigation businesses and other groups that are called on as needed.

Voluntary conservation practices, groundwater monitoring and applied research are the focal points of the WPVGA Water Task Force. The group 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:

- 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 will improve the health of the Little Plover River (LRP) and the quality of life of the surrounding community. The WPVGA kick-started the project with a contribution of over $60,000 to achieve the following goals: Increase the flow and improve the aquatic health of the LPR; improve surface and groundwater connections and water retention across the LPR watershed; alleviate storm water-driven flooding; improve and expand fish and wildlife habitat; and increase public recreation opportunities and access. 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 will ensure the project's success. Boots on the ground work began last fall in the Little Plover River watershed and has continued this

spring and summer. An official groundbreaking ceremony was held on October 4, 2018 at one of the project's restoration sites.

- Working with the Wisconsin Institute for Sustainable Agriculture (WISA), collecting and posting 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. This project has been co-funded by WISA and the WPVGA since 2013.
- Collaboration with the Wisconsin DNR on the data collection and posting from the WISA monitoring wells in the Plainfield and Coloma areas. Beginning in early 2018, the WPVGA agreed to allow the DNR to begin collecting and posting the data from these monitoring wells as part of the lakes study component of 2017 Wisconsin Act 10, related to the potential impacts of groundwater withdrawals in the Central Sands. If the department determines that the potential for significant impacts exists, several steps will be taken including a public hearing, economic impact analysis and providing recommendations to the Legislature for special measures to mitigate those impacts on the Long Lake, Plainfield Lake and Pleasant Lake watersheds.
- Collaboration on a three-year research project with the UW Atmospheric and Oceanic Sciences Department looking at newer, more accurate and advanced methods of measuring evapotranspiration (ET). This project is being led by Dr. Ankur Desai and officially began on July 1, 2018. It involved the purchase of an eddy covariance flux system to measure ET in an irrigated vegetable field as well as using another flux 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. Additional funding from the Wisconsin DNR will be used by the Desai lab to accomplish tasks related to the lakes study component of 2017 Wisconsin Act 10.
- Funding a research project led by Dr. Chris Kucharik, UW Professor of Agronomy and Environmental Studies, looking at nitrate and chloride concentration in irrigation water applied as well as total loads during the growing season in the Central Sands. The research results will provide important information for studies investigating nitrogen use efficiency, developing improved nutrient management programs, or those investigating leaching losses to groundwater.
- Funding software maintenance to keep the Wisconsin Irrigation Scheduling Program (WISP) and the Agricultural Weather Data Service operational. Work is being conducted at the direction of John Panuska at the UW Biological Systems Engineering Dept. The existing WISP software tracks a daily soil water balance to assist growers with irrigation water management.
- Collaboration with and funding of UW scientists in the evaluation of drip irrigation, deferred and deficit irrigation methods to conserve water. Deferred and deficit irrigation involve optimization strategies whereby irrigation water is applied during drought-sensitive growth stages of a crop. Among the useful results, drip irrigation demonstrated use of 15% less water with minimal impact on potato yield and quality, while deficit irrigation was effective and had less than a 5% yield impact on corn production.

- 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 the WPVGA and may be accessed subject to WPVGA guidelines.
- WPVGA is collaborating with the University of Wisconsin and the DNR on a new initiative to recognize and reward irrigation expertise. 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.

All of these WPVGA Water Task Force projects are working toward sustainable groundwater quantity and quality through evaluating and implementing strategies to increase the efficiency of irrigation while maintaining or improving water quality.

In 2019, the WPVGA is also funding applied research in the area of nitrogen use efficiency. Under the leadership of UW Soil Scientist Dr. Matt Ruark and UW Horticulturist Dr. Yi Wang, the WPVGA is cooperating on four on-farm nitrogen use studies to determine the optimum rates and timing of N to use on several different potato varieties. Slow release nitrogen products will also be studied, and groundwater samples will be taken to test for N leaching.

As the Governor's Representative, I am pleased to report these examples of support for achievement of Wisconsin's important groundwater management recommendations to the people of Wisconsin and seek broad input from all concerned parties to determine potential solutions to groundwater issues.

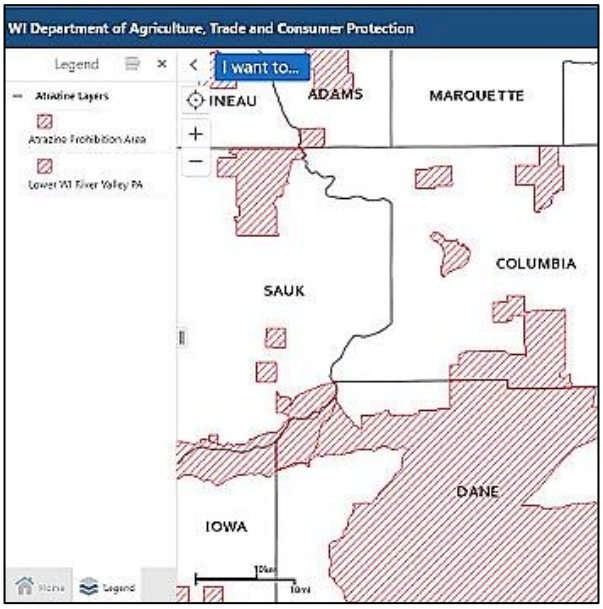
Highlights of over 30 years of GCC-funded research

Projects funded have provided valuable information regarding the Wisconsin's groundwater resources, helped evaluate existing programs, increased the knowledge of the movement of contaminants in the subsurface and developed new methods for groundwater evaluation and protection. A complete compilation of all GCC funded projects can be found at UW Water Resources Institute searchable repository (https://www.wri.wisc.edu/wgrmp-repository/). While the application of the results is broad, some areas where the results of state-funded groundwater research and monitoring projects have been successfully applied to groundwater problems in Wisconsin include:

Pesticides

Background

- Serious concerns about pesticide contamination were first raised in 1980 when aldicarb, a pesticide used on potatoes, was detected in groundwater near Stevens Point.
- Occurrences of the commonly used corn herbicide atrazine were also found in monitoring and private drinking water wells. A subsequent study found that atrazine was present in 12% of Grade A Dairy Farm wells.
- In total GCC has funded 30 studies on pesticides - including 14 on atrazine - on the sources, groundwater susceptibility and presence of pesticides in our groundwater.



Map showing the approximate boundaries of Atrazine Prohibition Areas in Wisconsin.© DATCP.

Outcomes

- Aldicarb was withdrawn from use in Wisconsin.
- Low cost screening methodologies for detecting the presence of atrazine and its break-down products in drinking water were developed.
- Knowledge from the intensive research and monitoring efforts allowed DATCP to adopt management strategies for reducing atrazine contamination and create the Atrazine Rule.
- Follow-up studies demonstrated that where atrazine use has been prohibited by the Atrazine Rule, there is a clear reduction in atrazine levels, which generally drop below the groundwater standard in 2 - 7 years.

Arsenic

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

Background

- Naturally-occurring arsenic was discovered in Winnebago & Outagamie Counties groundwater in 1989 during a routine investigation conducted by the DNR.
- Sampling of thousands of private wells found approximately 4% of private wells exceeded the federal drinking water standard.

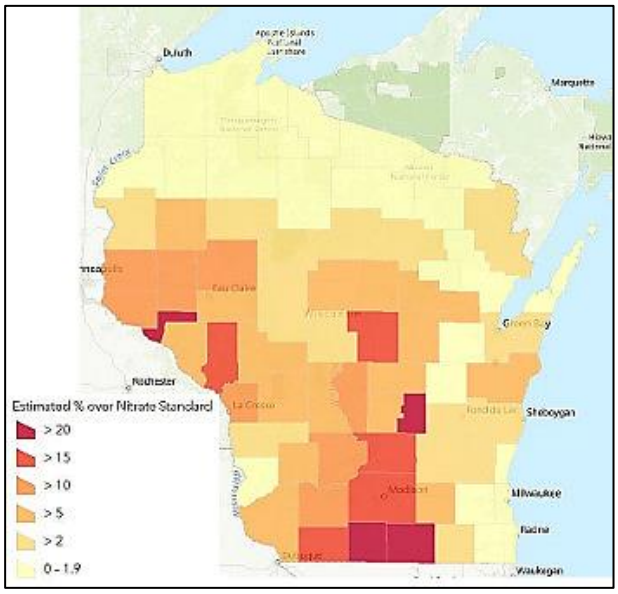
Outcomes

- More than 15 GCC funded studies documented arsenic above the enforcement standard (ES) in the groundwater in every Wisconsin county.
- Innovative and inexpensive arsenic removal technology for public & private water supplies were created.
- Detection methods for arsenic were improved, including the development of an on-site measurement apparatus which reduced costs.
- Revised well-disinfection techniques were developed to ensure that arsenic levels are kept below the safe drinking water standard when treating a well for bacteria.
- Residents were informed of health risks of arsenic in drinking water and educational materials to help homeowners with reducing arsenic levels in their drinking water were developed.
- Educational outreach to well drillers continues to improve well drilling and construction techniques to minimize arsenic levels in private wells.

Nitrate

Background

- Nitrate is the most widespread groundwater contaminant in Wisconsin.
- Statewide, about 10% of private well samples exceed the maximum contaminant level (MCL) for nitrate.
- Around 90% of nitrogen inputs to groundwater in Wisconsin can be traced to agricultural sources.
- An estimated 42,000 private wells exceed the nitrate health standard; well replacement costs likely exceed $446 million dollars to provide safe water .



Map of Estimated Percentage of Private Wells over Nitrate Standard by County. © DNR.

Outcomes

- DHS expanded their health recommendation from pregnant women and children under 6 months, to include everyone drinking water with nitrate above the standard.
- In 2014, the private well code was changed to require sampling for nitrate in newly constructed wells and wells with pump work.
- Since 1985, GCC through the Joint Solicitation process has funded more than 35 studies on Nitrate. Numerous studies show that nutrient management plans do not meet the health-based standard for Nitrate.

Viruses

Background

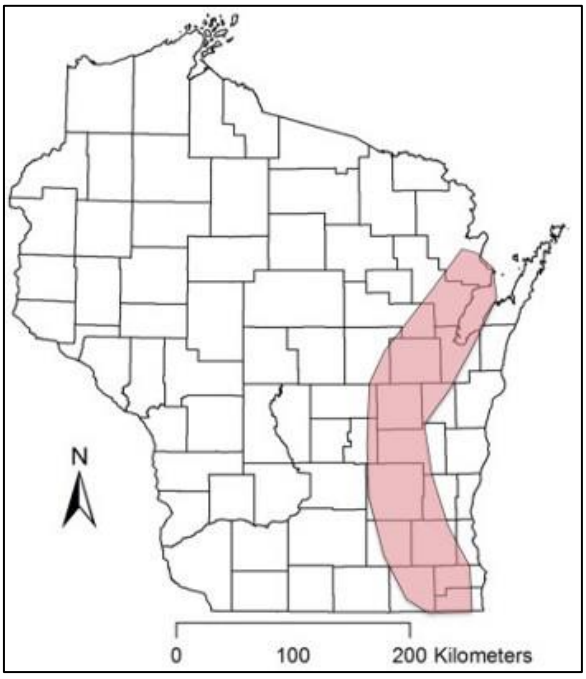
- Protecting groundwater from microbial contamination is a top public health priority.
- Limited statewide groundwater virus occurrence data exists because testing is expensive, not routinely performed, and levels cannot be reliably inferred from total coliform results.
- Viruses were found in deep bedrock wells that were thought to be protected, suggesting that deep groundwater is more vulnerable to virus contamination than previously thought.
- Public water systems are increasingly contaminated by viruses and other microbial agents.
- The incidence of virus contamination in private wells may affect 4-12% of private wells in the state.
- GCC has funded 10 research projects on viruses because of concern of presence of viruses in drinking water wells.

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

Outcomes

- Because of research funded by GCC, virus testing that used to take three months to complete can now be accomplished in an afternoon.
- Evidence indicating that disinfection with chlorine or ultraviolet light reduces the risk of illness from viruses and other microbial sources led DNR to amend a rule to require disinfection of municipal drinking water, but rule change 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 to gather information to support future drinking water protection.

Radium



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 intersects the Maquoketa shale. Figure: Luczaj and Masarik, 2015.

Background

- In eastern Wisconsin wells that draw from a very deep sandstone aquifer often have levels of radium above the MCL.
- These high levels of radium primarily affect public wells, since drilling deep enough to reach this aquifer is usually prohibitively expensive for smaller private systems.
- About 80 public water systems have exceeded a radionuclide drinking water standard at some point in time.
- Seven studies have been funded by the GCC on Naturally Occurring Radioactive Elements, including Radium, since 1987.
- Water level drawdown due to pumping in southeastern Wisconsin have shown some of the largest decreases in Wisconsin. These decreases have raised concerns about increases of radium in wells above drinking water standards and leading to increased costs to supply safe water meeting standards.

Outcomes

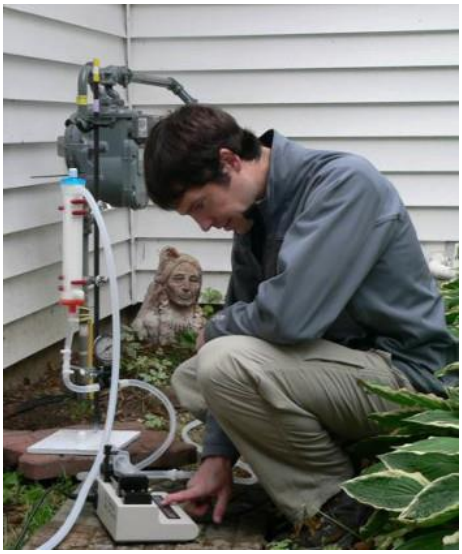
- DNR has been working with public water systems since 2003 to ensure that they develop a compliance strategy and take corrective action, currently less than 10 systems remain that are providing water in exceedance of the radium standards.
- Leveraging new models and knowledge about groundwater flow patterns in the Waukesha area, researchers found the relationship between radium and sulfate minerals in the area, collecting much needed information on the geochemical makeup of the region.
- 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 a diversion of Lake Michigan water with return flow.

Innovative lab methods

Background

- Groundwater quality testing can be expensive and limited analytical methods can be available.
- Projects funded by GCC have led to the development of new methods for groundwater evaluation and protection that take less time and are more cost efficient.

Outcomes


Dr. Sam Sibley, UW-Madison Department of Soil Science, collects a well water sample from a residential home to analyze using new MST tools. © Carolyn Betz, UW ASC.

- Research funded by GCC documented that holding times and higher temperatures do not affect the quality of E-coli samples. This finding led to a decrease in the number of samples rejected by laboratories and saved water systems a significant amount of time and money. The Department estimates that water systems are saving $300,000 to $600,000 per year in shipping costs alone.
- Laboratory techniques that have made it possible to discern whether bacteria are from human, animal or other sources have been developed. 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).
- Developed an analysis that can successfully detect bovine adenoviruses to indicate bovine fecal contamination of groundwater. The DNR has been using these tools as they become available to determine the source of fecal contamination in private wells. DNR and DATCP are working to find ways of controlling this major source of contamination and working on revised performance standards and prohibitions related to manure land application in areas of the state with carbonate bedrock and shallow soils.
- Virus testing that used to take three months to complete can now be accomplished in an afternoon.
- Improved detection techniques for arsenic have been developed, including the development of on-site measurement apparatus to reduce laboratory costs.
- Low cost screening methodologies for detecting the presence of atrazine and its break-down products in drinking water have been developed.

Methylmercury

Background

- Methylmercury (MeHg) is one of the most toxic and persistent substances in the environment.
- Funded research has focused on how MeHg forms from inorganic mercury deposited from atmospheric sources such as coal combustion.
- Measured MeHg concentrations are likely produced in situ and are not from legacy sources.
- GCC has funded five studies on Methylmercury in groundwater.

Outcomes

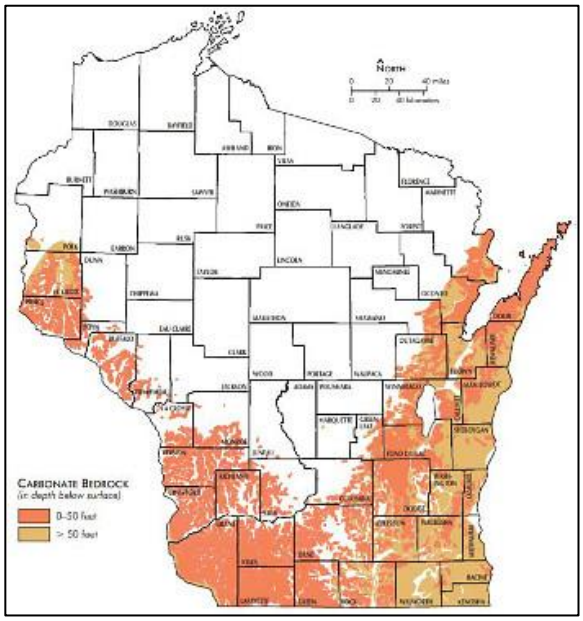
- Information advancing our understanding of mercury transport and methylation in groundwater that will help us interpret the watershed response to changing conditions in the hyporheic zone.

- Any variation in groundwater levels, whether due to climate change or conjunctive use of groundwater and surface waters, will likely influence MeHg production in both natural and engineered wetlands.

Fracture flow and karst

Background

- Karst features, including a variety of sinkholes, cavities and solution openings, commonly occur in carbonate rock (limestone and dolomite).
- Environmental problems associated with karst features include rapid groundwater contamination, unpredictable groundwater flow, difficulty in groundwater monitoring and unexpected failure or collapse of surface structures such as roads and foundations.
- There has been increased concern about the hazards and effects of karst features in many parts of Wisconsin, but little published information has been available.
- Fourteen studies have been funded through GCC regarding fracture flow and karst.



Areas with carbonate bedrock within 50 feet of the land surface are particularly vulnerable to groundwater contamination. © WGNHS.

Outcomes

- A karst database for the state has been created. This includes geophysical surveys near some of these features in order to characterize their depth and extent.
- The results of studies have been used by municipalities for planning purposes and selecting options for sinkhole remediation.
- A program of research and public education on groundwater movement in fractured rocks was developed and has provided assistance to various agencies facing carbonate-rock problems.
- Funded project led to the development of a professional short courses on fractured-rock hydrogeology.

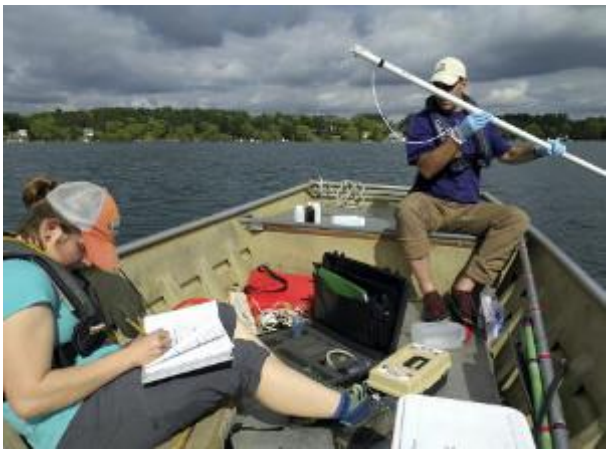
Groundwater/surface water interactions

Background

- 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 groundwater 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,

and disconnect from, surface water resources that rely on the water from the aquifer. The result of the disconnection can impact the ecosystems of groundwater dependent surface water features such as springs, streams, wetlands and seepage lakes.

- The opposite can also occur, resulting in a higher than normal water table. Groundwater flooding occurs when frequent, sustained rainfall leads to excessive recharge of local groundwater levels and the water table rises above the land surface.



Water chemistry samples are collected from the study lakes and from nearby monitoring wells to understand groundwater-surface water interactions. DNR staff collecting water quality on Pleasant Lake © DNR

Outcomes

- The inventory and evaluation of groundwater levels (e.g. wells) and groundwater dependent surface water features (springs, lakes, and headwater streams). The inventory of those features and data associated with each feature is displayed on the DNR's Water Quantity Data Viewer.
- To understand the role of groundwater withdrawals on headwater streams, a groundwater flow model for the Little Plover River watershed in Portage County was completed. 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.
- To understand the lake level variation and the extent groundwater withdrawals have on lakes, a study of three lakes in Waushara County (Central Sands Lakes Study) is being conducted.

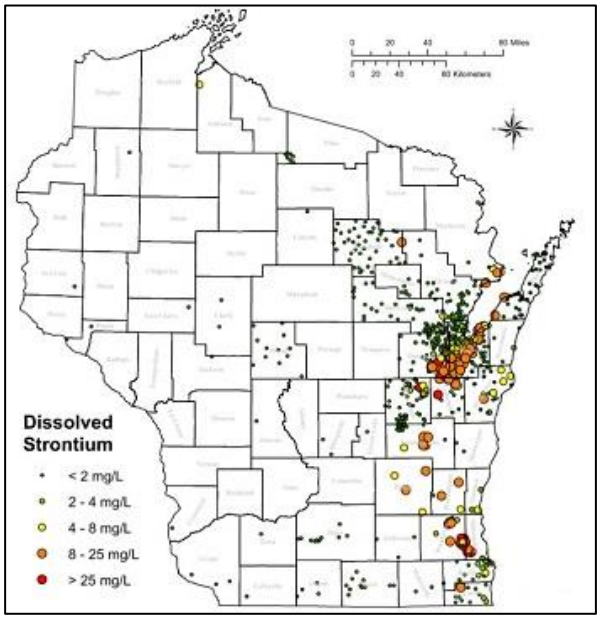
Emerging groundwater contaminants

Background

- Emerging contaminants are compounds that are increasingly being detected in groundwater and may have harmful human health or environmental impacts.
- Emerging contaminants often enter groundwater from wastewater from municipal, industrial or agricultural sources, although some come from naturally occurring sources.
- Examples include: chloride, pharmaceuticals, such as antibiotics, birth control pills or other prescription medicines are a large group of emerging contaminants from human-generated waste streams; personal care products (PCPs), which include shampoos, detergents and "over-the-counter" non-prescription medicines; and other broad classes of emerging contaminants include viruses and agricultural pesticides and their metabolites.
- 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. In response to this need, over 20 studies have been funded by GCC.

Outcomes

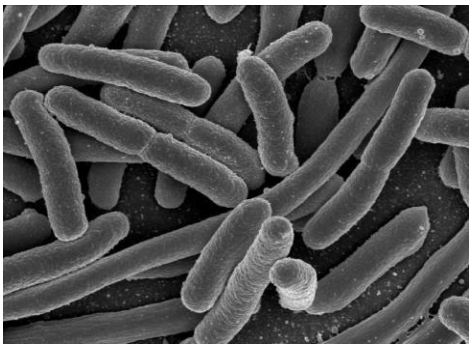
- In Wisconsin law, there is an established process that facilitates regular review of groundwater monitoring data and identification of contaminants of emerging concern (WI 160.27). A fundamental component of this process is the long-term groundwater monitoring data, so maintenance and expansion of current networks is an ongoing priority for the GCC.
- 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.
- Strontium is emerging as a trace element of concern in eastern Wisconsin, particularly in the Brown and Outagamie county areas. A study detected strontium above the US EPA's health advisory limit in about 63% of well samples from this area, but the full extent of groundwater with high strontium levels is not well documented, nor are the potential health effects.



Statewide distribution of dissolved strontium in Wisconsin's aquifers. © Luczaj et al., 2013

Pathogens

What are they?



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

Pathogens are organisms or other agents that can cause disease, including microorganisms such as bacteria, viruses and protozoa that can cause waterborne disease. Groundwater contamination by pathogens can often be traced to human or livestock fecal wastes that seep into the ground from sources such as 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 "indicators" – microbes that are not necessarily harmful themselves, but are a warning sign that other, potentially pathogenic, microorganisms may be present.

There are no groundwater standards for pathogenic microorganisms in Wisconsin, but standards have been established in ch. NR 140 for total coliform bacteria, a microbial pathogen indicator. Both the ch. NR 140 preventive action limit (PAL) and enforcement standard (ES) for total coliform bacteria are zero coliform bacteria present in a tested sample. Public drinking water systems are regularly monitored for total coliform bacteria (WI NR 809.31-809.329) these systems may also be tested for fecal indicators such as *E. coli*, enterococci or coliphages if coliform bacteria are found.

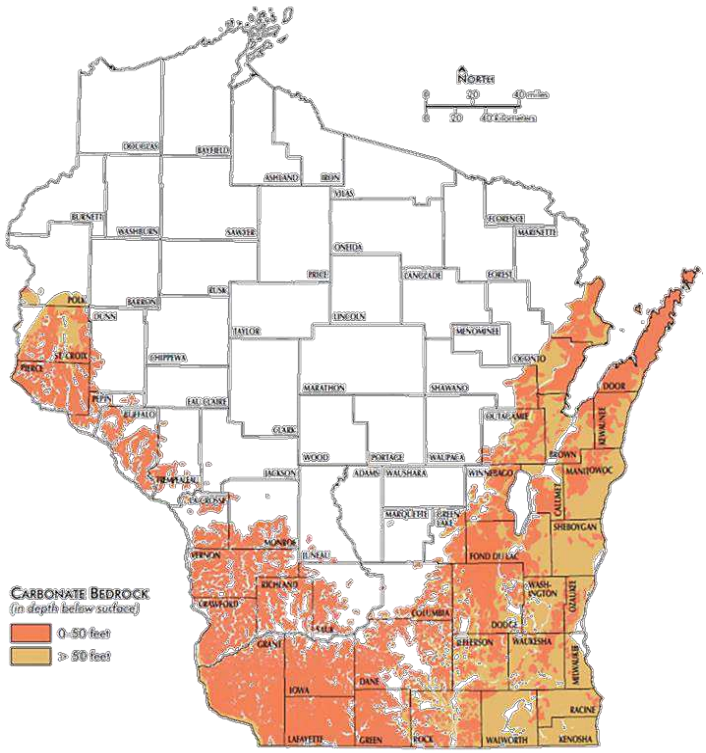
Coliforms are a broad class of bacteria that are naturally present in the environment and are used as an indicator that other potentially harmful microorganisms may be present. Fecal indicators, such as *E. coli*, enterococci and coliphages, are microbes whose presence more specifically indicates that water may be contaminated with human or animal wastes. Pathogenic microorganisms in drinking water can make people very sick and can result in death. Common symptoms include diarrhea, cramps, nausea and headaches. Microbial contamination may pose a special health risk for infants, young children, the elderly and people with severely compromised immune systems.

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 at Milwaukee's surface water-sourced drinking water system resulted in 69 deaths and more than 403,000 cases of illness before the epidemic and its source were recognized. 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).

Occurrence in Wisconsin

In Wisconsin, it is well known that groundwater in areas with karst geology – soluble carbonate bedrock, with many large fractures through which water flows rapidly, sometimes with karst surficial features, such as sinkholes, caves and disappearing streams present – is vulnerable to microbial contamination and needs special consideration and protection. In these areas, particularly where there

is also thin soil cover and shallow groundwater levels, there is little opportunity for soil to slow and attenuate the transport of microbes. This results in a greater risk that pathogens will remain viable when they reach water supply wells. Soluble carbonate bedrock with karst potential can be found in some parts of the state. Door County and parts of Kewaunee County are especially vulnerable since these areas additionally have very thin soils. An estimated 17% of private water supply wells statewide test positive for total coliform bacteria (Knobeloch et al., 2013). Sampling of private water supply wells in Kewaunee County (Kewaunee Co., 2014) has suggested that, in some parts of the county, wells are testing positive for total coliform bacteria at percentages much higher than the statewide average.



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

A more recent, emerging concern is the potential presence of viruses in drinking water wells, including norovirus, adenovirus and enterovirus. Virus contamination may not necessarily correlate well with total coliform bacteria detection in groundwater (Borchardt et al., 2003b) because viruses have different transport properties than bacteria.

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 polymerase chain reaction (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 inactivated, nonviable viruses (Donia et al., 2009).

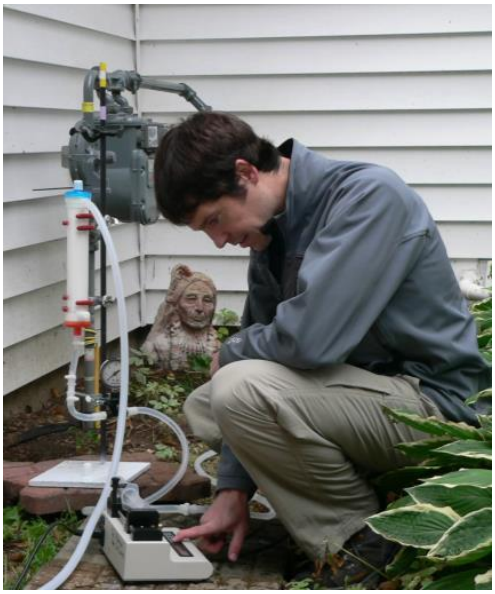
Research studies, utilizing PCR methods, have detected human enteric virus genomic material in both public and private wells in Wisconsin (Borchardt et al., 2003a, 2004, and 2007). There is limited statewide groundwater virus occurrence data since testing for viral genomic material is expensive, not routinely perform, 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 because municipal wells are generally completed in areas with sanitary sewers.

The risk of finding pathogens in groundwater is seasonably variable but typically highest following spring snowmelt or large rainstorms that generate runoff, since these events 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. Over 60 private wells have had to be replaced due to manure contamination at a cost to the state of over $500,000 since 2006 (Source: DNR Well Compensation Fund records).

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 supplies.

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.



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*

Funding from the Wisconsin Groundwater Research and Monitoring Program (WGRMP) has supported the development of laboratory techniques that have made it possible to discern whether bacteria are from human, animal or other sources (Pedersen et al., 2008; Long and Stietz, 2009). These microbial source tracking (MST) tools include tests for *Rhodococcus coprophilus* (indicative of grazing animal manure), *Bifidobacteria* (indicative of human waste) and *Bacteroides* (indicative of recent fecal contamination by either humans and/or grazing animals). A more recently developed analysis can successfully detect bovine adenoviruses to indicate bovine fecal contamination of groundwater (Sibley et al., 2011).

The DNR has been using these tools as they become available to determine the source of fecal contamination in private wells. 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.

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.

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*

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.

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

Further Reading

DNR overview of bacteriological contamination in drinking water [link]

DNR overview of cryptosporidium in drinking water [link]

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

WGNHS overview of karst landscapes [link]

WGNHS report on municipal drinking water safety [link]

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

References

Borchardt, M. A., P. D. Bertz, S. K. Spencer, D. A. Battigelli. 2003a. Incidence of enteric viruses in groundwater from household wells in Wisconsin. Applied and Environmental Microbiology, 69(2):1172-1180. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC143602/

Borchardt, M. A., P. H. Chyou, E. O. DeVries, E. A. Belongia. 2003b. Septic system density and infectious diarrhea in a defined population of children. Environmental Health Perspectives, 111(5):742-748. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1241485/

Borchardt, M.A., N. L. Haas, R. J. Hunt. 2004. Vulnerability of drinking-water wells in La Crosse, Wisconsin, to enteric-virus contamination from surface water contributions. Applied and Environmental Microbiology, 70(10): 5937-5946. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC522136/

Borchardt, M.A., K. R. Bradbury, M. B. Gotkowitz, J. A. Cherry, B. L. Parker. 2007. Human enteric viruses in groundwater from a confined bedrock aquifer. Environmental Science & Technology 41(18):6606-6612.

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

Borchardt, M. A., S. K. Spencer, B. A. Kieke, E. Lambertini, F. J. Loge. 2012. Viruses in nondisinfected drinking water from municipal wells and community incidence of acute gastrointestinal illness. Environmental Health Perspectives 120(9):1272:1279. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3440111/

Bradbury, K.R., M. A. Borchardt, M. B. Gotkowitz, S. K. Spencer, J. Zhu, R. J. Hunt. 2013. Source and transport of human enteric viruses in deep municipal water supply wells. Environmental Science & Technology, 47(9):4096-4103.

Donia, D., Bonanni, E., Diaco, L., Divizia, M. 2009. Statistical correlation between enterovirus genome copy numbers and infectious viral particles in wastewater samples. The Society for Applied Microbiology, Letters in Applied Microbiology, 50 (2010): 237-240.

Hunt, R. J., T. B. Coplen, N. L. Haas, D. A. Saad, M. A. Borchardt. 2005. Investigating surface water–well interaction using stable isotope ratios of water. Journal of Hydrology, 302 (1-4):154-172.

Hunt, R.J., M.A. Borchardt, K.D. Richards, and S.K. Spencer. 2010. Assessment of sewer source contamination of drinking water wells using tracers and human enteric viruses. Environmental Science and Technology, 44(20):7956–7963.

Kewaunee Co., 2014. Kewaunee County Public Health and Groundwater Protection Ordinance, Ordinance No. 173-9-14. Available at http://www.co.kewaunee.wi.gov/docview.asp?docid=17410&locid=192

Knobeloch, L., P. Gorski, M. Christenson, H. Anderson. 2013. Private drinking water quality in rural Wisconsin. Journal of Environmental Health, 75(7):16-20.

Lambertini, E., M. A. Borchardt, B. A. Kieke, S. K. Spencer, F. J. Loge. 2012. Risk of viral acute gastrointestinal illness from nondisinfected drinking water distribution systems. Environmental Science & Technology 46(17):9299-9307.

Long, S. and J.R. Stietz. 2009. Development and validation of a PCR-based quantification method for Rhodococcus coprophilus. Wisconsin groundwater management practice monitoring project, DNR-206. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.LongProject

Pedersen, J. T. McMahon, S. Kluender. 2008. Use of human and bovine adenovirus for fecal source tracking. Wisconsin groundwater management practice monitoring project, DNR-195. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.KluenderUse

Sibley, S.D., T. L. Goldberg, J. A. Pederson. 2011. Detection of known and novel adenoviruses in cattle wastes using broad-spectrum primers. Applied and Environmental Microbiology, 77(14):5001-5008.

Ueijo, C. K., S. H. Yale, K. Malecki, M. A. Borchardt, H. A. Anderson, J. A. Patz. 2014. Drinking water systems, hydrology, and childhood gastrointestinal illness in central and northern Wisconsin. American Journal of Public Health, 104(4):639-646. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4025711/

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 a 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.

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 nitrates 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).

Adverse environmental effects are also well documented. 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.

Occurrence in Wisconsin

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

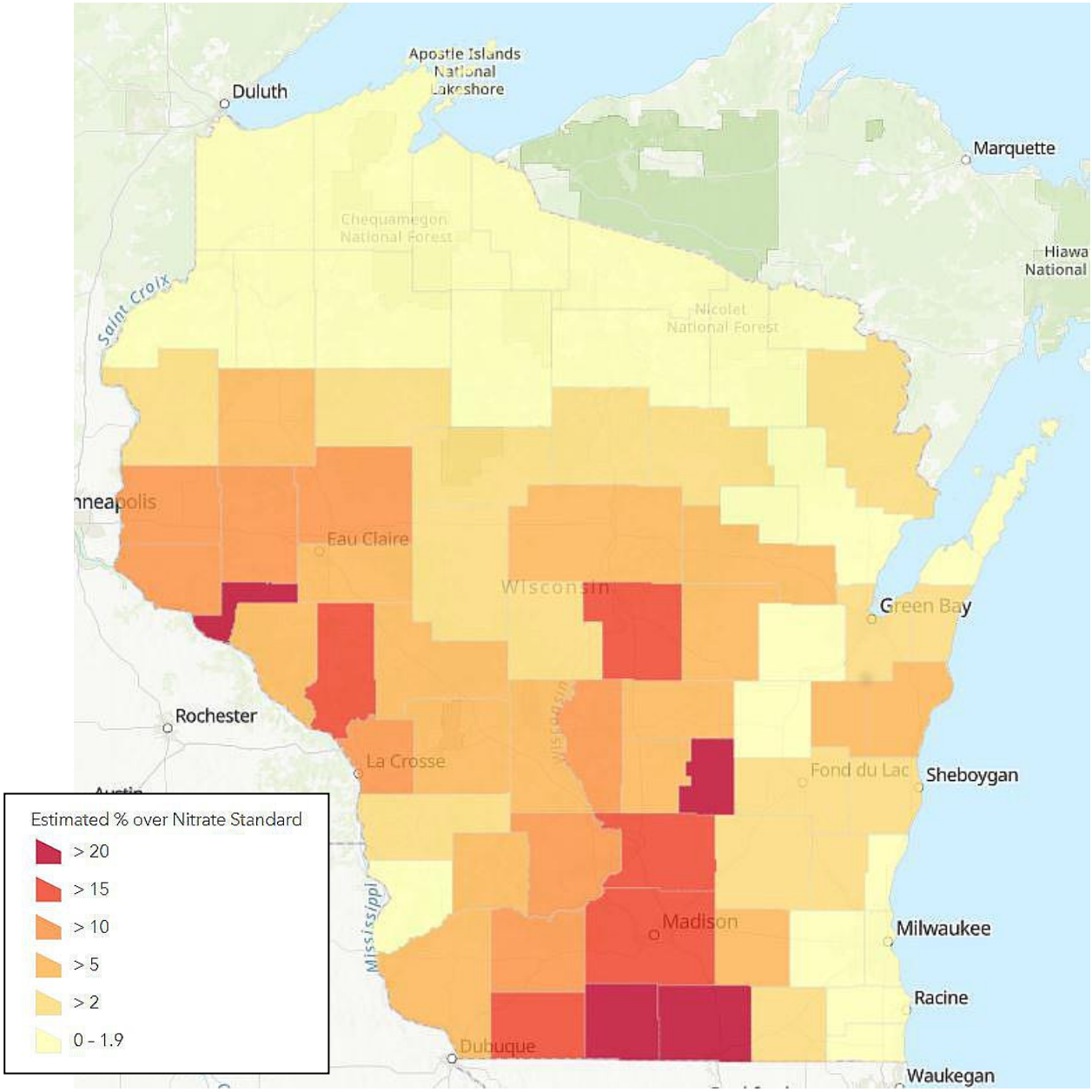
Nitrate is Wisconsin's most widespread groundwater contaminant. Nitrate contamination of groundwater is increasing in extent and severity in the state (Kraft, 2003; Kraft, 2004; Kraft et al., 2008; Saad, 2008). A 2012 survey of Wisconsin municipal water-supply systems found that 47 systems have had raw water samples that exceeded the nitrate-N MCL, up from just 14 systems in 1999. 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 newly constructed wells and wells with pump work for nitrates. 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. The nitrate sampling was also strongly supported by the Private Water Advisory Council.

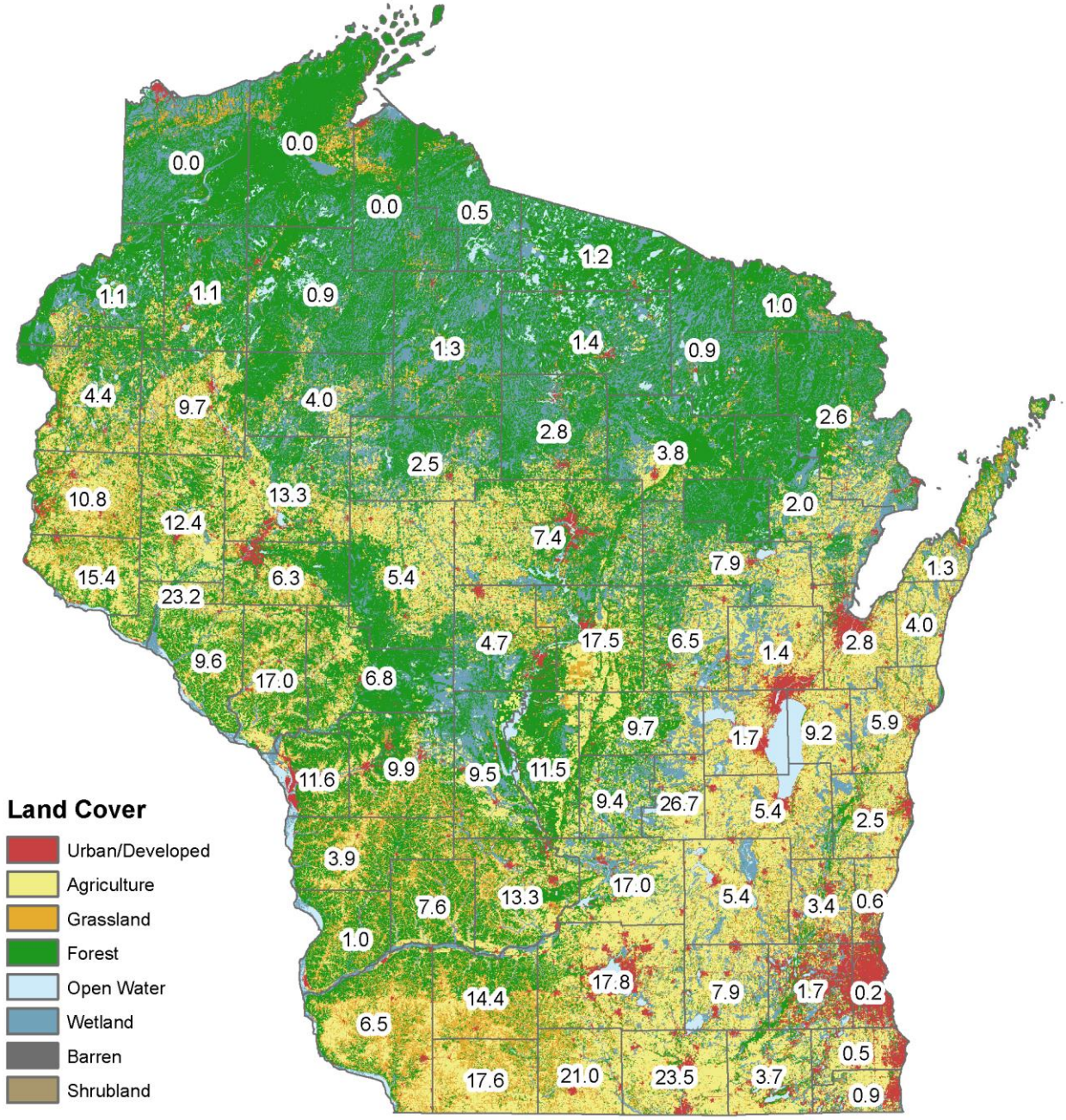
Since October of 2014 the department has received over 80,000 sample results. This last spring the department analyzed the data set. This is probably the least biased large data set available in Wisconsin. Overall 7% of sample results were greater than 10 ppm for nitrate. However, some counties have a much greater percentage of well testing above the 10 ppm standard. See map below for individual county results.

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).



Map of Estimated Percentage of Private Wells over Nitrate Standard by County.



Map of Estimated Percentage of Private Wells over Nitrate Standard by County with Land Cover.

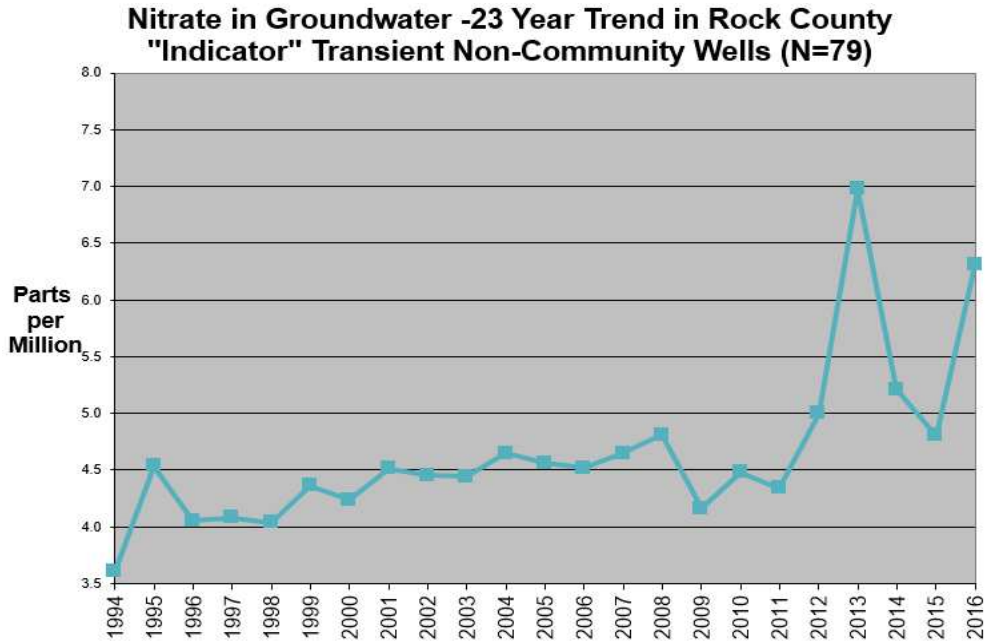
Groundwater nitrate trends

By analyzing a variety of data sources, evidence indicates that nitrate contamination of our groundwater resources has increased in more locations over time than have seen decreases. This is particularly true in areas vulnerable to nitrate contamination due to factors of intrinsic susceptibility (soils, geology, depth to water) and land use (higher percentage of surrounding land is cultivated).

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 dataset 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.

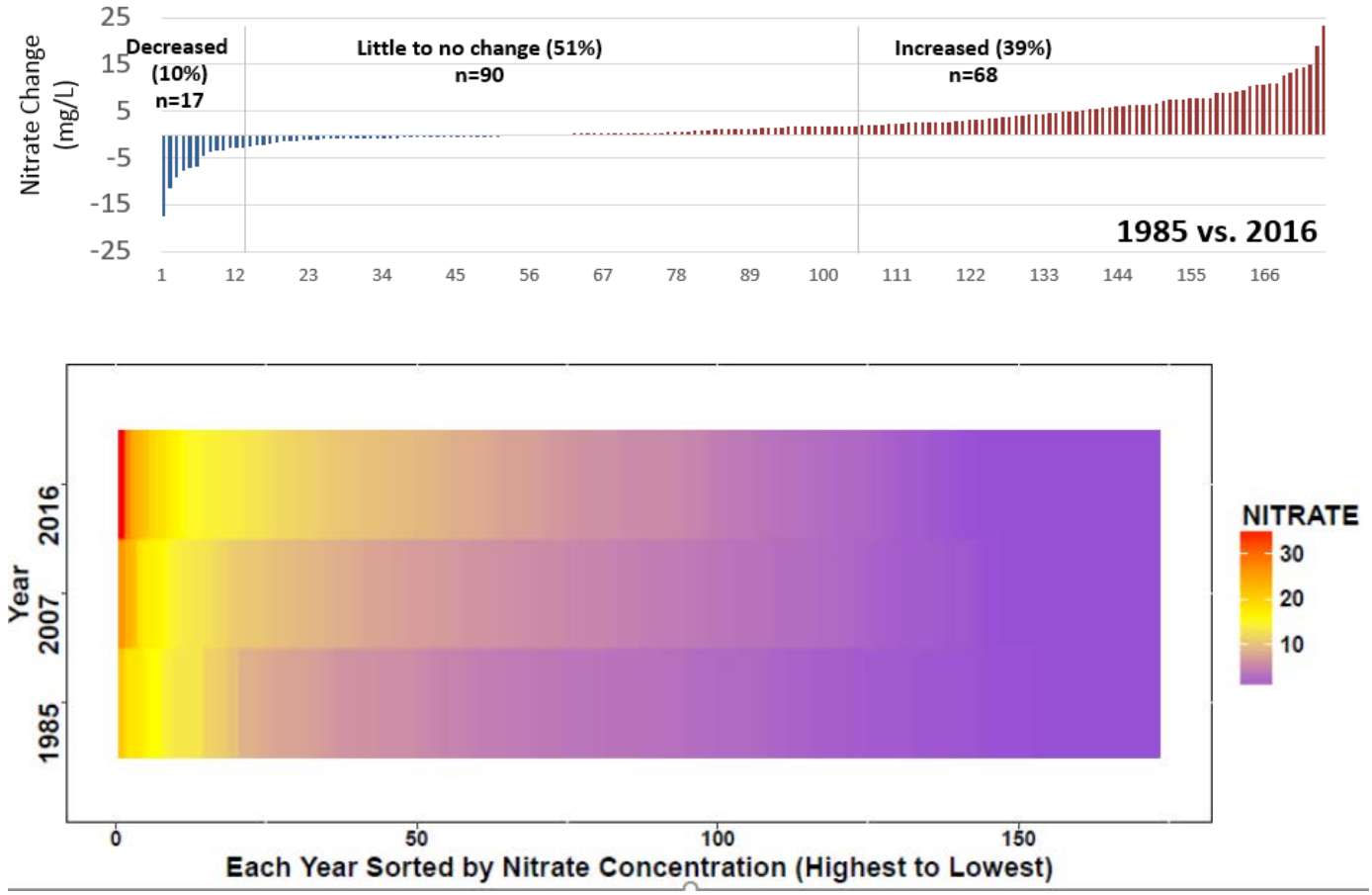
One data set available with a large number of wells distributed across the state is the compliance data set for non-community public wells (TN +NN). There are approximately 11,0000 wells of this type active at any given time, and they are required to submit nitrate sample results to DNR at least annually. In review of the historical record of public supply well data (since 1975), we find a relatively consistent number of wells exceed 5 mg/L and 10 mg/L nitrate thresholds in any decadal time period (about 18.3% of non-community water systems exceed 5 mg/L and about 6.5% exceed 10 mg/L). However, when looking at all the 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 database, approximately 21% of these wells exceeded 5 mg/L and approximately 8.3% exceeded 10 mg/L). A large number of the nitrate impacted wells dropped out of the data set over time.

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 dataset based on a consistent set of transient non-community public wells over approximately 25 years. In aggregate, this consistent group of 79 wells have shown an increasing nitrate average concentration trend since 1994, with a marked increase in the last decade (see figure below).



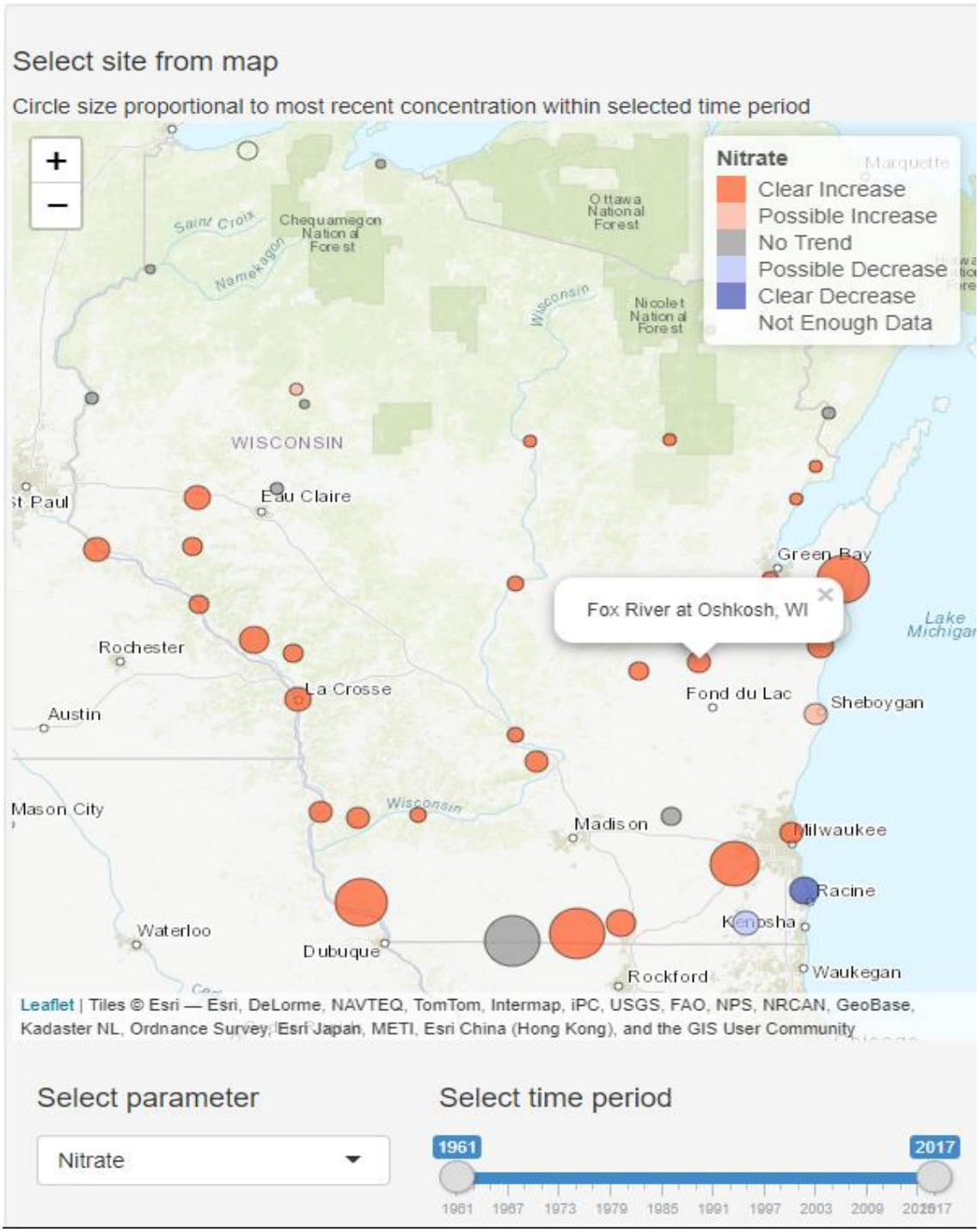
Source: Rock County Department of Public Health

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).

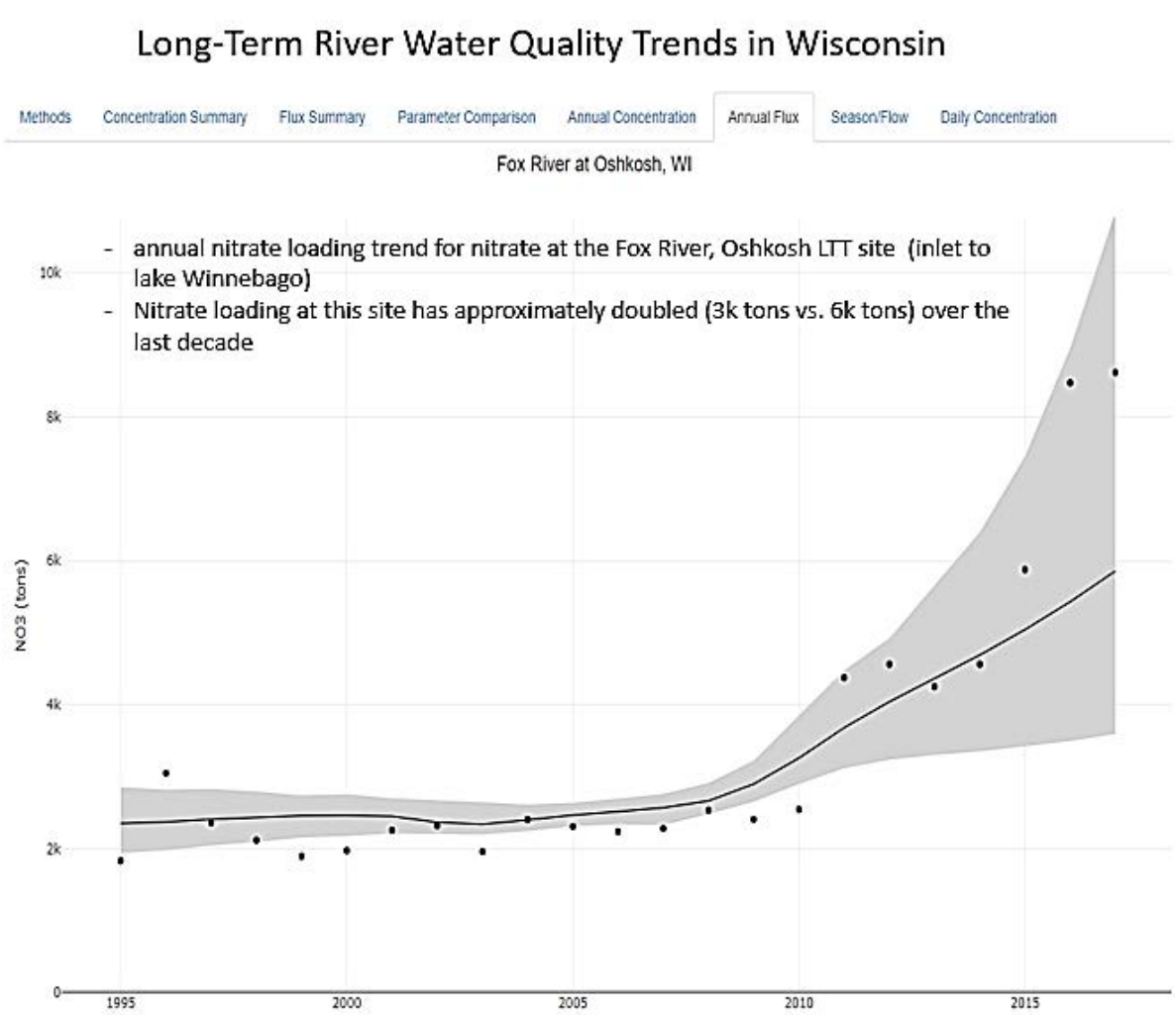


Source: Masarik et al., 2016 In preparation.

Another method to assess long term groundwater nitrate trends throughout the state is to evaluate data from 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 WDNR and USGS in these watersheds can provide information about the aggregate water quality yielded by these watersheds 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 address Nitrate

The data from new wells and pump work since 2014 was also 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 number of wells replaced for nitrate, when no reason was listed on the report. Using the same methodology, it is estimated that private well owners have spent more the 9 million dollars to replace wells elevated nitrate to date.

	Estimated # of private wells	Estimated % of well over 10 ppm Nitrate Standard	Estimated # of private wells over Nitrate Standard	Estimated Replacement Cost (millions)
Adams County	9959	12.4%	1232	$10.82
Ashland County	2290	0.0%	0	$0.00
Barron County	9336	9.3%	872	$8.69
Bayfield County	5679	0.0%	0	$0.00
Brown County	14077	2.9%	414	$4.93
Buffalo County	3158	7.1%	224	$1.67
Burnett County	6689	1.2%	82	$0.41
Calumet County	3932	10.5%	413	$5.25
Chippewa County	13242	13.5%	1788	$15.99
Clark County	6581	5.4%	357	$1.80
Columbia County	8762	17.9%	1564	$19.22
Crawford County	2485	0.9%	24	$0.28
Dane County	23506	18.3%	4313	$65.61
Dodge County	11112	5.0%	553	$7.44
Door County	11797	1.3%	153	$2.04
Douglas County	5165	0.0%	0	$0.00
Dunn County	7501	12.1%	906	$6.65
Eau Claire County	9153	5.3%	483	$3.89
Florence County	2423	1.6%	39	$0.18
Fond du Lac County	12190	5.3%	649	$8.41
Forest County	4073	1.3%	54	$0.19
Grant County	5895	6.6%	389	$6.05
Green County	5474	20.2%	1106	$15.22
Green Lake County	4957	19.5%	968	$14.60
Iowa County	3511	12.5%	438	$7.13
Iron County	749	0.7%	6	$0.02
Jackson County	4688	6.7%	312	$1.63
Jefferson County	9491	8.3%	792	$8.16
Juneau County	5166	11.6%	600	$3.85
Kenosha County	15570	0.8%	132	$1.21
Kewaunee County	3741	3.3%	122	$0.90
La Crosse County	7216	13.4%	965	$8.99
Lafayette County	2628	15.3%	402	$5.74
Langlade County	6387	4.7%	298	$2.41
Lincoln County	7396	3.7%	277	$1.55
Manitowoc County	8693	6.2%	539	$6.87
Marathon County	22195	7.1%	1578	$11.36
Marinette County	10295	2.3%	239	$1.41
Marquette County	5951	9.4%	559	$5.90
Menominee County	1287	0.0%	0	$0.00

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

Because nitrate is both an acute and chronic health issue, Municipal and Other than Municipal Public water systems cannot serve water over the MCL and therefore must either replace the well or install approved treatment if they exceed this. Surveys of the cost to municipal systems have been conducted periodically in the past starting in the late 1990's. While complete information on the costs have not been confirmed, the current estimate is over 37 million dollars have been spent by public systems to deal with nitrate. The cost estimates do not include increased sampling or investigative cost. Examples of costs incurred by individual municipal systems range from a few hundred thousand dollars for a small system to replace a single well to many millions of dollars spent by some larger systems for new wells, blending water sources or treatment.

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.

GCC Agency Actions

Nitrate has always been a core concern for GCC agencies. Over 40 projects funded by the Wisconsin Groundwater Research and Monitoring Program (WGRMP), 10% of the total portfolio 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.

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 addition to regular well sampling surveys, one of the key ways that DATCP assists in addressing this problem is by supporting the development of nutrient management plans (NMPs). These plans specify the amount and timing of all 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). Not all farms are required to have a nutrient management plan, but DATCP provides free resources and training for farmers to encourage total coverage across the state.

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

A concerning pattern in many areas has been the continued increase of nitrate levels in groundwater and streams even after reduced regional use of nitrogen-based fertilizers. Several recent studies by WGRMP-funded researchers illuminate possible reasons for this. For one, long groundwater travel distances in some geologic settings mean that it can take decades for nitrate to travel to streams and wells situated deep in thick aquifers, so it will take at least that long to see a response from more recent management changes (Kraft et al., 2008). Until then, increases in nitrate levels due to historical agricultural practices are likely. More concerning is the numerous studies which indicate that NMPs are questionably 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. 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.

The DNR began a program in 2012 to work with stakeholders on the "Wisconsin Safer Drinking Water Nitrate Initiative". The Nitrate Initiative is an effort started by the WDNR Drinking Water and Groundwater Program to collaborate with multiple state agencies, researchers, and local communities to evaluate strategies to reduce impacts from non-point sources of nutrient pollution to sources of drinking water. Activities in pilot project areas include assessment of nitrogen inputs, groundwater nitrate levels, and determining nitrogen management practices that optimize groundwater conditions and agricultural production efficiency. Project areas are focused in locations where drinking water systems are approaching unsafe levels of nitrate contamination. DNR is currently working with stakeholders to determine optimal nitrogen management systems and strategies to stem rising nitrate trends in potable wells. Monitoring of nitrogen inputs, groundwater nitrate levels, and production costs will continue, and costs of nitrogen management will be compared to water treatment and well replacement costs.

To expand groundwater-focused Source Water Protection efforts beyond initial pilot project areas and foster partnerships with those who traditionally implement programs to reduce non-point source pollutant loads, the Drinking Water and Groundwater Program has partnered internally with our Clean Water Act implementing programs, and externally with the Wisconsin Land and Water Association to serve as a liaison to county conservation departments. WDNR and Wisconsin Land and Water provide county conservationists with technical assistance for drinking water source protection, including data on water supplies and nutrient impact occurrence and trends. Feedback and surveys of county conservation staff indicate increased awareness and interest on the part of local stakeholders in the protection of groundwater sources of drinking water.

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, including technical tools and the directing of incentives to promote efficient use of nitrogen and reduce losses to groundwater are another top priority. To protect our sources of drinking water, new tools are required to better understand and predict nitrogen loads to groundwater that may occur under differing agricultural nutrient management scenarios. Such tools would assist local resource managers with creating landowner and producer partnerships to implement groundwater protection plans focused in areas contributing recharge to potable wells that have been impacted. The WDNR has begun working with groundwater stakeholder partners to develop a suite of Groundwater and Nitrogen Decision Support tools (GW & Nitrogen DSTs) for use by community water supplies, conservation departments, agricultural leaders, and other stakeholders to achieve groundwater-focused water quality improvement. The partnership coalition, to include a broad range of state, federal, and local partners, will share "ownership" of the tools and the project will provide a framework for the continued development and improvement of the DST products as more research and data is incorporated over time. These decision support products would be used on a voluntary basis to guide development of

locally implemented source water protection action plans. A focus will be on agricultural nutrient management practices that would be sufficiently protective of groundwater quality within a "wellshed" or other groundwater management area.

When fully realized, these tools would allow for alternative land management and nutrient management scenario testing, 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 facilitate access to existing state and federal programs that incentivize land conservation practices. The DSTs could be used, for example, to meet requirements for inclusion into 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 plans, expanded to include drinking water source protection, will meet pre-requisites for agricultural practice cost share funding derived from existing non-point source pollution mitigation programs that have traditionally focused primarily on improving surface water quality.

The Groundwater DSTs (and the underlying spatial datasets) will have many applications beyond understanding nitrate transport from below the root zone and though the subsurface to a well or stream. But to address potable well impacts from 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 planning process.

The Groundwater and Nitrogen Decision Support Tool partnership incorporates multi-disciplinary technical contributions from researchers at the University of Wisconsin, and 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 and the Wisconsin Rural Water Association. Key federal partners include USGS, USDA-NRCS, and EPA. 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.

Further Reading

DNR overview on nitrate in drinking water [link]

DNR overview on nutrient management planning [link]

DATCP overview on nutrient management [link]

References

Brender, J.D. et al. 2013. Prenatal nitrate intake from drinking water and selected birth defects in offspring of participants in the National Birth Defects Prevention Study. Environmental Health Perspectives, 121(9):1083-1089. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3764078/

Brye K.R., J.M. Norman, L.G. Bundy, S.T. Gower. 2001. Nitrogen and carbon leaching in agroecosystems and their role in denitrification potential. Journal of Environmental Quality, 30(1):58–70.

Camargo J.A. and J.V. Ward. 1995. Nitrate toxicity to aquatic life: a proposal of safe concentrations for two species of near arctic freshwater invertebrates. Chemosphere, 31(5):3211-3216.

Camargo J.A., A. Alonso, A. Salamanca. 2005. Nitrate toxicity to aquatic animals: a review with new data for freshwater invertebrates. Chemosphere, 58:1255-1267.

Crunkilton, R.L. and T. Johnson. 2000. Acute and chronic toxicity of nitrate to brook trout (Salvelinus fontinalis). Wisconsin groundwater management practice monitoring project, DNR-140. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.CrunkiltonAcute

DATCP. 2015. Wisconsin Nutrient Management Update and Quality Assurance Team Review of 2015's Nutrient Management Plans. Wisconsin Department of Agriculture, Trade, and Consumer Protection. Available at https://datcp.wi.gov/Documents/NMUpdate2015.pdf

DATCP. 2017. Wisconsin Groundwater Quality, Agricultural Chemicals in Wisconsin Groundwater. Wisconsin Department of Agriculture, Trade, and Consumer Protection. Available at https://datcp.wi.gov/Documents/GroundwaterReport2017.pdf

Gebert, W.A., Walker, J.F., and Kennedy, J.L., 2011, Estimating 1970–99 average annual groundwater recharge in Wisconsin using streamflow data: U.S. Geological Survey Open-File Report 2009–1210

https://pubs.usgs.gov/of/2009/1210/

Knobeloch, L., B. Salna, A .Hogan, J. Postle, H. Anderson. 2000. Blue babies and nitrate contaminated well water. Environmental Health Perspectives, 108(7):675-678. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1638204/

Knobeloch, L., P. Gorski, M. Christenson, H. Anderson. 2013. Private drinking water quality in rural Wisconsin. Journal of Environmental Health, 75(7):16-20.

Kraft, G.J., B.A. Browne, W.D. DeVita, D.J. Mechenich. 2008. Agricultural pollutant penetration and steady-state in thick aquifers. Ground Water Journal, 46(1):41-50.

Kraft, G.J. and W. Stites. 2003. Nitrate impacts on groundwater from irrigated vegetable systems in a humid north-central US sand plain. Agriculture, Ecosystems & Environment, 100(1):63-74.

Kraft, G.J., B.A. Browne, W.M. DeVita, D.J. Mechenich. 2004. Nitrate and pesticide penetration into a Wisconsin central sand plain aquifer. Wisconsin groundwater management practice monitoring project, DNR-171. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.KraftNitrate

Marco A., C. Quilchano, A.R. Blaustein. 1999. Sensitivity to nitrate and nitrite in pond-breeding amphibians from the Pacific Northwest, USA. Environmental Toxicology and Chemistry, 18(12):2836-2839.

Masarik, K.C. 2003. Monitoring water drainage and nitrate leaching below different tillage practices and fertilization rates. University of Wisconsin-Madison Thesis. 110 pp.

McGurk M.D., F. Landry, A. Tang, C.C. Hanks. 2006. Acute and chronic toxicity of nitrate to early life stages of lake trout (Salvelinus namaycush) and lake whitefish (Coregonus clupeaformis). Environmental Toxicology and Chemistry, 25(8):2187-2196.

Moltchanova E., M. Rytkonen, A. Kousa, O. Taskinen, J. Tuomilehto, M. Karvonen. 2004. Zinc and nitrate in the ground water and the incidence of Type 1 diabetes in Finland. Diabetic Medicine, 21(3):256-261.

Norman, J.M. 2003. Agrochemical leaching from sub-optimal, optimal and excessive manure-N fertilization of corn agroecosystems. Wisconsin groundwater management practice monitoring project, WR99R001A.

Parslow, R.C., P.A. McKinney, G.R. Law, A. Staines, R. Williams, H.J. Bodansky. 1997. Incidence of childhood diabetes mellitus in Yorkshire, northern England, is associated with nitrate in drinking water: an ecological analysis. Diabetologia 40(5):550-556.

Saad, D.A. 2008. Agriculture-Related Trends in Groundwater Quality of the Glacial Deposits Aquifer, Central Wisconsin. Journal of Environmental Quality, 37(5-S):S209-S225.

Shaw B. 1994. Nitrogen Contamination Sources: A Look at Relative Contribution. Conference proceedings: Nitrate in Wisconsin's Groundwater – Strategies and Challenges. May 10, 1994. Central Wisconsin Groundwater Center, University of Wisconsin-Stevens Point, WI. Available at http://www.uwsp.edu/cnr-ap/watershed/Documents/nitrogen_conferenceproceedings.pdf

Schubert, C., L. Knobeloch, M.S. Kanarek, H.A. Anderson. 1999. Public response to elevated nitrate in drinking water wells in Wisconsin. Archives of Environmental Health, 54(4):242-247.

Schultz, A. and K.C. Malecki. 2015. Reducing human health risks from groundwater: private well testing behaviors and barriers among Wisconsin adults. Wisconsin groundwater management practice monitoring project, DNR-221.

Smith, G.R., K.G. Temple, D.A. Vaala, H.A. Dingfelder. 2005. Effects of nitrate on the tadpoles of two ranids (Rana catesbeiana and R. clamitans). Archives of Environmental Contamination and Toxicology, 49(4):559-562.

Stelzer, R.S. and B.L. Joachim. 2010. Effects of elevated nitrate concentration on mortality, growth, and egestion rates of Gammarus pseudolimnaeus amphipods. Archives of Environmental Contamination and Toxicology, 58(3): 694-699.

Mechenich, D. 2015. Interactive Well Water Quality Viewer 1.0. University of Wisconsin-Stevens Point, Center for Watershed Science and Education. Available at http://www.uwsp.edu/cnr-ap/watershed/Pages/WellWaterViewer.aspx

Ward, M.H., S.D. Mark, K.P. Cantor, D.D. Weisenburger, A. Correa-Villasenor, S.H. Zahm. 1996. Drinking water nitrate and the risk of non-Hodgkin's lymphoma. Epidemiology 7(5):465-471.

Weyer, P.J., J.R. Cerhan, B.C. Kross , G.R. Hallberb, J. Kantamneni, G. Breuer, M.P. Jones, W. Zheng, C.F. Lynch. 2001. Municipal drinking water nitrate level and cancer risk in older women: The Iowa Women's Health Study. Epidemiology, 11(3):327-338.

Xu, G., P. Song, P.I. Reed. 1992. The relationship between gastric mucosal changes and nitrate intake via

drinking water in a high-risk population for gastric cancer in Moping county, China. European Journal of Cancer Prevention, 1(6):437-443.

Yang, C.Y., M.F. Chen, S.S. Tsai, Y.L. Hsieh. 1998. Calcium, magnesium, and nitrate in drinking water and gastric cancer mortality. Japanese Journal of Cancer Research, 89(2):124-130.

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 health-based 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 micrograms per liter (ug/l) (WI NR 140.10, WI NR 809.11). Some people who drink water containing arsenic in excess of the MCL over many years could experience skin damage or problems with their circulatory 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 Silurian dolomite 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 rock, while arsenic bearing iron oxides can be in the end moraines of the various glacial advances.

In *western* 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.

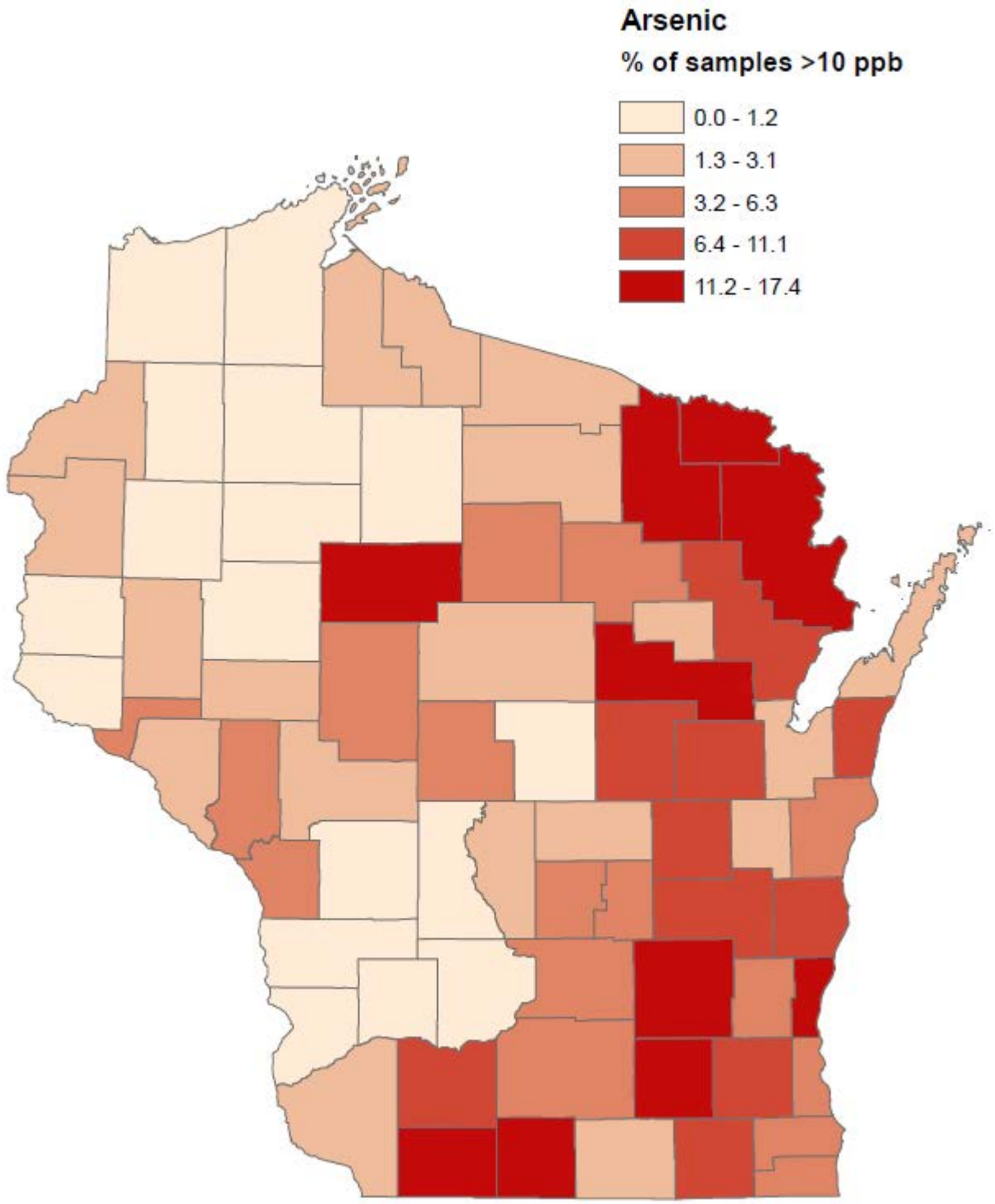
GCC Agency Actions

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), 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, provide low-cost testing of private wells, and gather 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 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; 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 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 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.

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.



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 4 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	% >50	% >100		County	% >10	% >50	% >100
Adams	1.6	0.5	0.3		Marathon	2.1	0.5	0.3
Ashland	2.2				Marinette	16.2	3.5	2.1
Barron	0.5	0.1			Marquette	4.6	0.8	0.4
Bayfield	1.1				Menominee	2.5		
Brown	1.9	0.4	0.1		Milwaukee	5.3		
Buffalo	1.6				Monroe	0.6		
Burnett	2.9				Oconto	11.1	2.1	1.3
Calumet	3.1				Oneida	2.2		
Chippewa	0.6				Outagamie	10.9	1.7	0.4
Clark	4.6	1.5	1.5		Ozaukee	17.4	2.7	1.0
Columbia	5.0	1.5	0.4		Pepin	3.8	0.6	
Crawford					Pierce			
Dane	4.6	1.1	0.4		Polk	1.9	0.2	
Dodge	12.5	4.9	3.6		Portage	1.2	0.2	0.2
Door	2.0	0.1	0.0		Price	1.0		
Douglas					Racine	4.8	0.1	
Dunn	2.5	0.4			Richland			
Eau Claire	1.4				Rock	1.8	0.4	0.2
Florence	12.6	2.0	1.2		Rusk	0.8		
Fond du Lac	10.1	4.5	2.3		Saint Croix	0.9		
Forest	15.5	1.4			Sauk	0.9		
Grant	3.1	0.4			Sawyer	0.5		
Green	12.7	3.9	1.6		Shawano	16.2	3.1	1.3
Green Lake	3.9	0.8	0.8		Sheboygan	9.6	0.2	0.1
Iowa	8.8	2.6	2.2		Taylor	13.4	1.5	
Iron	2.9				Trempealeau	3.9		
Jackson	1.7				Vernon			
Jefferson	12.6	3.7	1.1		Vilas	3.0		
Juneau	0.7				Walworth	6.8	1.1	0.5
Kenosha	4.0	0.5	0.2		Washburn	0.4		
Kewaunee	7.4	1.9			Washington	6.3	0.7	0.2
La Crosse	3.4	0.3			Waukesha	7.5	0.7	0.2
Lafayette	15.9	5.8	3.7		Waupaca	7.4	0.4	0.2
Langlade	6.2	2.5	1.2		Waushara	1.5		
Lincoln	3.4				Winnebago	7.3	1.0	
Manitowoc	3.8				Wood	4.0	0.4	0.4

Table 1. Percent of wells over 10 ppb, 50 ppb and 100 ppb arsenic by county.

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. DNR and some county governments are also working to both promote well sampling programs and explore impediments to private well sampling.

In the areas of the state that are 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 moving homes from private wells to public supplies has been effective in reducing exposure in towns like Algoma in Winnebago County.

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

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 (see attached) and the presence of heavy metals in geologic formations near La Crosse, among others (see attached).

Other Research on the Occurrence of Natural Contaminants in WI Groundwater

Radium in Southeastern Wisconsin

Another 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.

Chromium in Dane County

More recently 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.

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.

Further Reading

DNR overview of arsenic in drinking water wells [link]

DNR special well casing depth areas for arsenic [link]

DHS overview of arsenic health effects [link]

WGNHS report on arsenic release due to well disinfection [link]

WGNHS report on preliminary investigation near Lake Geneva, Wisconsin [link]

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

Wisconsin Natural Resource magazine article on arsenic in private wells [link]

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

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 [link]

Taylor, R.W. and G. Mursky. 1990. Mineralogical and geophysical monitoring of naturally occurring radioactive elements in selected Wisconsin aquifers. Wisconsin groundwater management practice monitoring project, DNR-051. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.TaylorMineral

References

Bahr, J.M., M.B. Gotkowitz, T.L. Root. 2004. Arsenic contamination in southeast Wisconsin: sources of arsenic and mechanisms of arsenic release. Wisconsin groundwater management practice monitoring project, DNR-174. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.BahrArsenic

Burkel, R.S. 1993. Arsenic as a naturally elevated parameter in water wells in Winnebago and Outagamie Counties, Wisconsin. Wisconsin groundwater management practice monitoring project, DNR-087. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.BurkelArsenic

Burkel, R.S. and R.C. Stoll. 1995. Naturally occurring arsenic in sandstone aquifer water supply wells of northeastern Wisconsin. Wisconsin groundwater management practice monitoring project, DNR-110. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.BurkelNaturally

Gotkowitz, M.B. 2002. Report on the preliminary investigation of arsenic in groundwater near Lake Geneva, Wisconsin. Final report to the Wisconsin Department of Natural Resources, DNR-163. Available at http://wgnhs.uwex.edu/pubs/wofr200002/

Gotkowitz, M.B., J.A. Simo, M. Schreiber. 2003. Geologic and geochemical controls on arsenic in groundwater in northeastern Wisconsin. Final report to the Wisconsin Department of Natural Resources, DNR-152. Available at https://wgnhs.uwex.edu/pubs/000831/

Gotkowitz, M., K. Ellickson, A. Clary, G. Bowman, J. Standridge and W. Sonzogni, 2008. Effect of well disinfection on arsenic in ground water, Ground Water Monitoring and Remediation, 28: 60-67.

Gotkowitz, M.B., P.I. McLaughlin, J.D. Grande. 2012. Sources of naturally occurring chromium in bedrock aquifers underlying Madison, Wisconsin. Wisconsin Geological and Natural History Survey, Open-File Report 2012-08. Available at http://wgnhs.uwex.edu/pubs/wofr201208/

Gorski, P. M. Shafer, J. Hurley. 2015. Hexavalent Chromium (Cr(VI)) in Wisconsin Groundwater: Identifying factors controlling the natural concentration and geochemical cycling in a diverse set of aquifers. Wisconsin groundwater management practice monitoring project, WR12R005.

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

Grundl, T.J., K.R. Bradbury, D. Feinstein, D.J. Hart. 2003. A combined hydrogeologic/geochemical investigation of groundwater conditions in the Waukesha County area, WI. Wisconsin groundwater management practice monitoring project, WR03R002. Available at https://www.wri.wisc.edu/wp-content/uploads/SummaryWR03R002.pdf

Knobeloch L. and H Anderson. 2002. Effect of arsenic-contaminated drinking water on skin cancer prevalence in Wisconsin's Fox River Valley. Proceedings of the 5th International Conference on Arsenic Exposure, San Diego CA.

Luczaj, J. and K. Masarik. 2015. Groundwater quantity and quality issues in a water-rich region: examples from Wisconsin, USA. Resources, 4(2):323-357. Available at http://www.mdpi.com/2079-9276/4/2/323

Luczaj, J.A., M.J. McIntire, and M.J. Olson Hunt. 2016. Geochemical characterization of trace MVT mineralization in Paleozoic sedimentary rocks of northeastern Wisconsin, USA. Geosciences, 6(2):29. Available at http://www.mdpi.com/2076-3263/6/2/29

Pelczar, J.S. 1996. Groundwater chemistry of wells exhibiting natural arsenic contamination in east-central Wisconsin. MS thesis. University of Wisconsin-Madison. Available at http://digital.library.wisc.edu/1793/53154

Simo, J.A., P.G. Freiberg, K.S. Freiberg. 1996. Geologic constraints on arsenic in groundwater with applications to groundwater modeling. Wisconsin groundwater management practice monitoring project, WR95R004.

Simo, J.A., P.G. Freiberg, M.E. Schreiber. 1997. Stratigraphic and geochemical controls on the mobilization and transport of naturally occurring arsenic in groundwater: Implications for water supply protection in northeastern Wisconsin. Wisconsin groundwater management practice monitoring project, DNR-129.

Sonzogni, W.C., A. Clary, G. Bowman, J. Standridge, D. Johnson, M. Gotkowitz. 2003. Importance of disinfection on arsenic release in wells. Wisconsin groundwater management practice monitoring project, DNR-172. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.SonzogniImport

Taylor, R.W. and G. Mursky. 1990. Mineralogical and geophysical monitoring of naturally occurring radioactive elements in selected Wisconsin aquifers. Wisconsin groundwater management practice

monitoring project, DNR-051. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.TaylorMineral

West, N., M. Schreiber, M. Gotkowitz. 2012. Arsenic release from chlorine-promoted alteration of a sulfide cement horizon: Evidence from batch studies on the St. Peter Sandstone, Wisconsin, USA. Applied Geochemistry, 27(11):2215-2224.

Zambito, J., Haas, L., Parsen, M., McLaughlin, P. 2019. Geochemistry and mineralogy of the Wonewoc–Tunnel City contact interval strata in western Wisconsin. Wisconsin groundwater management practice monitoring project, WR15R004. Available at https://wgnhs.wisc.edu/pubs/wofr201901/

Zierold K, Knobeloch L, and H Anderson. 2004. Prevalence of chronic disease in adults exposed to arsenic-contaminated drinking water. American Journal of Public Health, 94(11):1936-1937. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1448563/

Spatial Distribution and Source Identification of Dissolved Strontium in Eastern Wisconsin's Groundwater Aquifers

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Abstract

In northeastern Wisconsin over 75 groundwater samples have been collected and analyzed to better determine the hydrogeochemistry of the aquifers in the region. Dissolved strontium in parts of the Cambro-Ordovician aquifers of eastern Wisconsin exceeds the lifetime and short-term EPA Health Advisory Limit of 4 mg/L and 25 mg/L, respectively. These elevated strontium levels occur along the western rim of the ancestral Michigan Basin. Over 60% of the samples we collected in northeastern Wisconsin had strontium values over the lifetime Health Advisory Limit. For our study, the highest recorded strontium value was 28.6 mg/L. Earlier datasets collected show strontium as high 41.2 mg/L in the region with an exceedance rate similar to ours!

The high strontium concentrations are contained within the Cambrian and Ordovician aquifers (Sinnipee Group, St. Peter Sandstone, Prairie du Chien Group, and Cambrian Sandstones). Strontium bearing minerals are present in the region, including celestine ($SrSO_4$) and strontianite ($SrCO_3$), which are possible sources. There does not seem to be a strong correlation between the dissolved strontium concentrations and the position of the western edge of the Maquoketa Shale. Piper plots also reveal significant subregional variation in the general hydrochemistry, even within the same aquifer, suggesting the possibility of compartmentalization or distinct hydrochemical processes operating in different areas. Initial Sr-isotopic results for groundwater show $^{87}Sr/^{86}Sr$ ratios of 0.70992-0.71005, which indicates a radiogenetic source. This suggests that the original source of strontium was likely to be either the Precambrian crystalline rocks or sandstone aquifers.

Purpose of this Study

- Eastern Wisconsin has high dissolved Strontium (Sr) concentrations in Cambrian and Ordovician bedrock aquifers that exceed both lifetime, and in some cases, short-term EPA Health Advisory Levels.
- Objectives for this study include:
  - Determine the regional and stratigraphic distribution of dissolved strontium (Sr) in the groundwater of eastern Wisconsin with a focus on Brown, Calumet, and Outagamie counties.
  - Evaluate potential sources of Sr in eastern Wisconsin's bedrock.

Geologic Setting and Hydrostratigraphy

- The eastern Wisconsin region lies on the western flank of the ancestral Michigan basin and is bordered by the Wisconsin arch to the west, the Canadian shield to the north, and the Illinois basin to the south (figure 1).

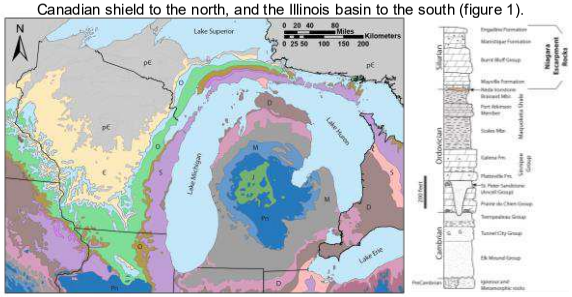

Figure 1 (left): Generalized bedrock geologic map showing eastern Wisconsin and the ancestral Michigan basin. Base map from Luczaj (in press). Figure 2 (right): Stratigraphic column of northeastern Wisconsin (Luczaj, in Press).

- In eastern Wisconsin, several hundred feet of Paleozoic sedimentary rocks and Pleistocene glacial sediments overlie Precambrian igneous and metamorphic basement rocks (Figure 2).
- The relatively thin sequence of Paleozoic rocks in northeastern Wisconsin dips gently to the east into the ancestral Michigan basin, where the thickness of the sedimentary section increases substantially to over 15,700 feet (4,800 m).
- West of the Niagara escarpment, the principal sources of groundwater for industry, agriculture, and domestic use are the Ordovician St. Peter Sandstone and the Cambrian sandstones (Figure 2).
- The Paleozoic rocks in eastern Wisconsin have been influenced by an ancient hydrothermal mineralization event, which was responsible for dolomitization, sulfide mineralization, and other minerals, such as celestine (Luczaj, 2006; Luczaj & McIntire, in prep).
- These hydrothermally deposited minerals are responsible for some of the region's groundwater problems, including arsenic and possibly strontium contamination.

Strontium Health Concerns

- A widely recognized adverse health effect from strontium ingestion appears to be strontium rickets, which is a musculoskeletal disease in which bones are thicker and shorter than normal and can be deformed (Özgür et al., 1996).
- Strontium in groundwater has also been strongly correlated with tooth enamel mottling in Wisconsin children (Curzon and Spector, 1977).
- The U.S. EPA has established health advisories for the ingestion of Strontium from drinking water. The lifetime Health Advisory limit is 4 mg/L, and is based on exposure of a 70-kg adult consuming 2 liters of water per day. For a 10 kg child, one-day and ten-day Health Advisory limits are 25 mg/L (U.S. EPA, 2011).

Methods

- Groundwater sample collection began during July 2012 and will continue through June 2013. To date, 100 samples have been analyzed for various geochemical parameters by Pace Analytical Services, Inc. (Green Bay, WI). By the end of this project an ~150 samples will be collected and analyzed. Hydrogen & Oxygen stable isotopes were analyzed by the KPESIL lab at the University of Kansas.
- Solid sample collection was obtained from existing cuttings and cores at the University of Wisconsin-Green Bay. Currently, these samples are being analyzed by ALS Chemex of Thunder Bay, Ontario, Canada.
- Geospatial mapping is done using ArcMap 10. All data are entered into a designated GIS database and manipulated using editor and spatial analysis tools to show distribution and trends in strontium concentrations.
- Source identification is being attempted using a variety of methods included calculation of saturation indices, Sr isotopes, known spatial trends, and whole rock analysis.
- Data analysis is being done using Microsoft Excel to organize data, Statistical Analysis System (SAS) to identify correlations amongst variables, and numerous graphical methods such as piper plots and stiff diagrams.

General Groundwater Chemistry of NE Wisconsin

- The groundwater chemistry of northeastern Wisconsin varies greatly. Even in a single county there can be a great amount of variation in the groundwater's major ion chemistry (Figure 3).

Blue = Zone 1
Red = Zone 2
Green = Zone 3

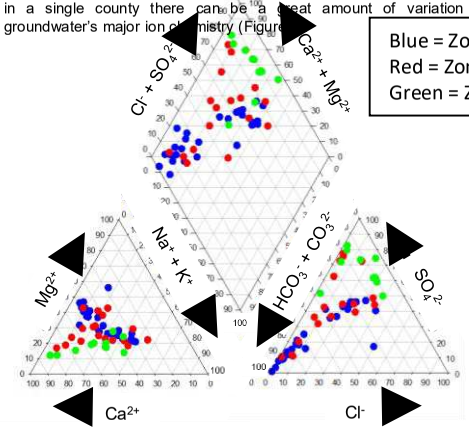

Figure 3: General chemistry of Brown County, WI. Data shown were collected by Joe Baeten and John Luczaj of the UW-Green Bay. Each zone represents a different area of Brown County that is separated by one ore more mapped faults in the region.

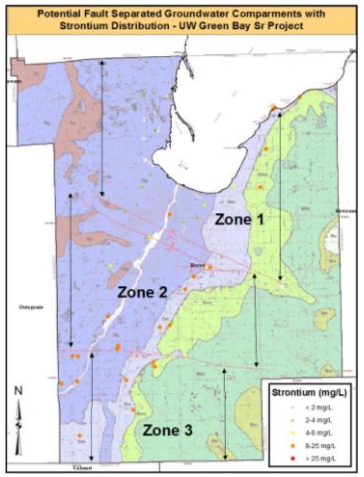

Figure 4: Geologic map of the buried bedrock surface in Brown County, Wisconsin (Luczaj, 2011). Dark blue and brown areas in western Brown County are the Sinnipee Group (Og and Op). Light blue (Om) represents the Maquoketa Shale. Green colors indicate Silurian dolostone units. Red lines indicate major faults along reactivated basement tectonic features that cut across the Paleozoic rocks in the region. These faults separate the Brown County Cambro-Ordovician deep aquifer system into three different zones.

- The magnesium percent decreases as you move from Zone 1 to Zone 3 where as the percent calcium has relatively the same range in all zones (Figure 4).
- Transects perpendicular to Zone boundaries (e.g., along the Niagara escarpment) show a significant increase in the dissolved Sr concentration between Zones 1 and 2.
- Zone 3 has a greater percent of sulfate compared to the other two zones. Each zone has high chloride levels; which occur east of the Maquoketa boundary.

Statewide Distribution of Sr in Wisconsin's Aquifers

As early as the 1930s, Wisconsin has been recognized as having some of the highest groundwater Sr concentrations in the United States (Nichols and McNall, 1957; Skougstad and Horr, 1963; WHO, 2011). Some areas have reported values as high as 41 mg/L (White et al., 1963). Recent datasets

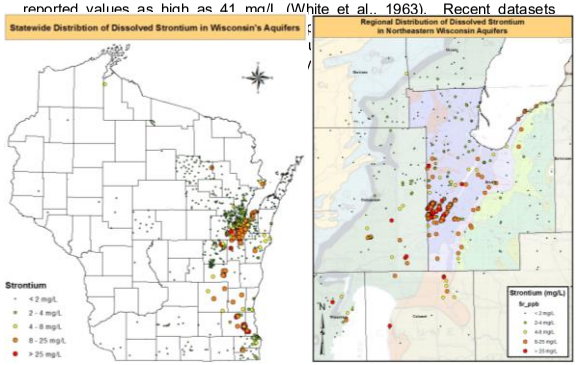

Figure 5a (left): statewide distribution of dissolved strontium in Wisconsin's aquifers. Data were compiled from various sources. Figure 5b (right): strontium distribution in northeastern Wisconsin showing subsurface bedrock.

Sr Spatial Distribution in NE WI – UWGB Sr Project

This project has confirmed the trend of elevated dissolved strontium in eastern Wisconsin that runs north to south along the western flank of the Michigan Basin and is typically found in the Cambrian-Ordovician aquifers. East of the Maquoketa boundary, the strontium concentration seems to be uniformly elevated throughout the region. However, significantly elevated levels of dissolved strontium are only found in certain areas west of the Maquoketa subcrop (Figure 6). We hypothesize that preferential flow due to faults and/or compartmentalization of the aquifers has caused this difference in strontium

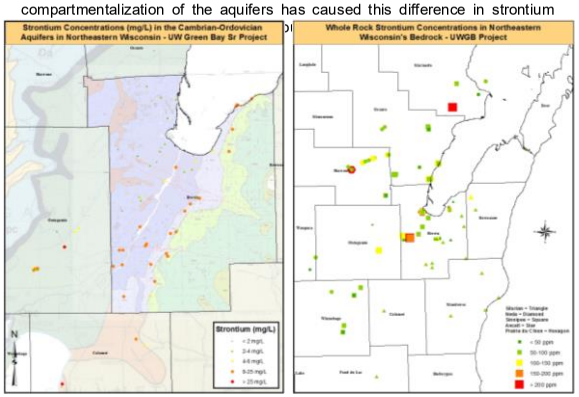

Figure 6 (left): Regional distribution of strontium concentration in northeastern Wisconsin from samples collected for the UWGB Sr Project. Figure 7 (right): Spatial distribution of whole rock samples collected by Luczaj and McIntire (in preparation) showing bedrock strontium concentrations. These samples represent both representative samples of the rock unit as well as biased samples taken from highly mineralized horizons. Silurian is represented by a triangle, Neda Formation is represented by a diamond, Sinnipee is represented by a square, Ancell (St. Peter) is represented by a star, and the Prairie du Chien is represented by a hexagon.

Whole rock data from northeastern Wisconsin show the highest Sr concentrations in the Sinnipee and Prairie du Chien dolomites (Figure 7), with the highest whole rock values (731 ppm) in the Lawrence Quarry in western Brown County. This is where some of the highest Sr values have been recorded in the groundwater.

Source Evaluation – Celestine Saturation

Potential bedrock strontium sources being evaluated include dissolution of Sr minerals such as Celestine and Strontianite, dissolution of calcite, crystalline bedrock, connate basinal brines, dedolo

The mineral Celestine has been reporte in the Ordovician St. Peter Sandstone i areas such as De Pere, Cedarburg, Tw Rivers, and Milwaukee (Tyler, 1936). Celestine and Strontianite occur in the Sinnipee Group of Brown and Outagamie Counties (Luczaj & McIntire, in prep.) (Figure 8).

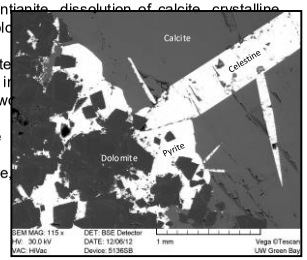

Figure 8 (right): SEM image showing bladed $SrSO_4$ (Celestine) from the Lawrence Quarry near De Pere, Wisconsin. Mineral sequence shows dolomite first, followed by celestine, pyrite, and late calcite.

In southern and eastern Brown County the saturation index (SI) for Celestine approaches zero, and in 3 wells located in the Wrightstown and Greenleaf area, SI is oversaturated with respect to Celestine (Figure 9). The saturation index calculations take into consideration the activity coefficients and ionic strength of the groundwater analyzed.

Sulfate and strontium concentrations show similar patterns indicating that both ions are important controls on the saturation index (Figure 10).
Strontium concentrations are highest in the southern half of Brown County. Sulfate increases to the southeast of this area, especially in Zone 3 of the aquifer.

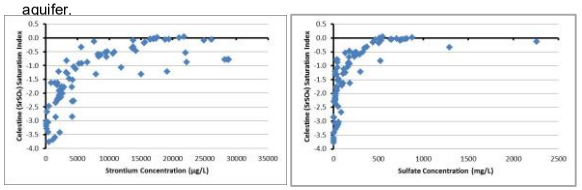

Figure 10: left, strontium concentration plotted against the saturation index of Celestine in the aquifers of northeastern Wisconsin. Right, sulfate concentration plotted against the saturation index of Celestine in the aquifers of northeastern Wisconsin.

Ongoing & Future Work

This project is designed to identify the spatial relationships of strontium and other major ions in the aquifers of northeastern Wisconsin. Ongoing work will focus on the regional and stratigraphic distributions as well as attempt to identify Sr sources through Sr-isotopic analysis. Graphing, mapping, and statistical methods will be used to identify spatial trends and potential sources. The final goals of this project include a completed Master's thesis and multiple publications.

Preliminary results for hydrogen and oxygen isotopes show heavier water in the central and northwestern parts of Brown County, possibly indicating preferential recharge along the Green Bay fault zone. Lightest waters occur in the southern and northeastern parts of the county, indicating a colder climate-derived origin (Fig. 11).

Fluoride is also an ion of concern for northeastern Wisconsin that has a similar spatial trend as strontium. This correlation has been identified in the past (Krohelski, 1986) and is being further explored by this project (Figure 12).

S r gr egion.
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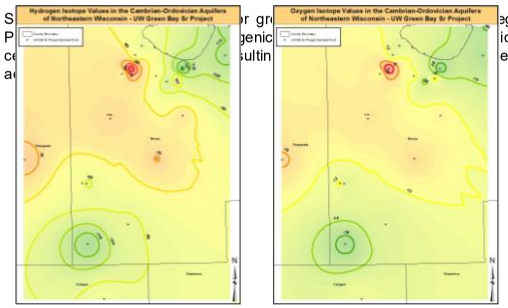

Figure 11: Isotopic analyses for ∂D (left) and $\partial^{18}O$ (right) for groundwater in the Cambrian-Ordovician aquifers in Brown, Calumet, and Outagamie counties. Data from UW Green Bay Sr Project.

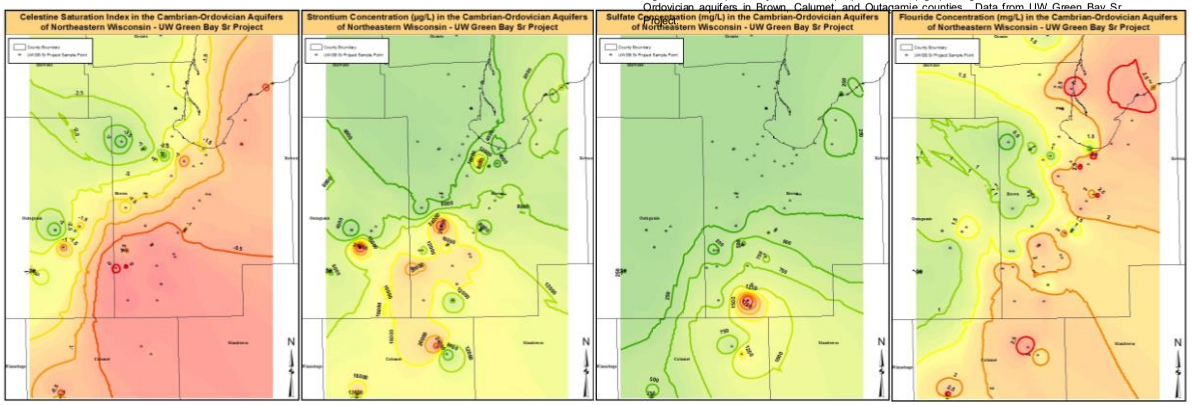

Figure 9: left, Celestine saturation index; middle, strontium concentration; and right, sulfate concentration in northeastern Wisconsin. Contours are based only on those samples collected for the UWGB Sr Project. The saturation index takes into consideration the activity coefficients and ionic strength of groundwater.

Figure 12: fluoride concentration in the Cambro-Ordovician aquifers of NE Wisconsin. Data from UWGB Sr Project.

Strontium Removal Effectiveness During Treatment

Three private homes and two municipal wells were tested for their effectiveness in removing strontium. Water softeners and R/O systems are relatively effective at removing strontium. Private home water softeners proved to be more effective than industrial sized water softeners. Water softening systems in private homes removed 97% or more of the strontium from the water. Municipal softening systems showed removal of 56-74% of strontium. In one test the final strontium concentration after softening was at 12,500 µg/L, still over three times the lifetime health advisory limit (Tables 1 & 2).

Reverse Osmosis system for the private systems always followed the water softening equipment and would remove the majority of remaining strontium. The final percentage of strontium left after the reverse osmosis was only 0.02-0.13 percent of the initial (Tables 1).

Table 1

Sr Removal By Private Treatement Equipment			
WUWN	Percent Remaining After Softner	Percent Remaining After R/O	Percent Remaining After Iron Filter
KO402	3.1	0.13	-
OD234	1.1	0.02	-
FP788	0.2	0.02	99.1

Table 2

Sr Removal By Municipal Treatment Equipment		
WUWN	Percent Remaining After Iron Filter	Percent Remaining After Softner
TU539	97.1	26.3
TU107	-	43.4

Sr Removal By Private Treatement Equipment			
WUWN	Raw	After Softner	After R/O
KO402	16900	531	21.8
OD234	17100	187	2.7
FP788	22200	45.1	4.8

Sr Removal By Municipal Treatment Equipment		
WUWN	Raw	After Softner
TU539	4410	1160
TU107	28800	12500

Conclusions

- Early results show elevated dissolved strontium is contained within the Cambro-Ordovician aquifers, apparently related to the dissolution of strontium minerals such as celestine ($SrSO_4$).
- Compartmentalization of these aquifers likely due to regional zones of faulting and is reflected in the major ion geochemistry of the groundwater.
- Dissolved strontium in groundwater of northeastern Wisconsin also shows a radiogenic signature consistent with an original source derived from Michigan basin hydrothermal fluids.
- From a public health perspective, household water softeners should provide an adequate method of removing strontium. Although less effective, municipal systems that treat for radium also resulted in significant reductions of dissolved Strontium.

Acknowledgements

We would like to thank the home owners, businesses, and municipalities that allowed access to water samples, without which this project would not have been possible. Funding for this project and for Luczaj & McIntire (in prep) was made available by the University of Wisconsin Water Resources Institute (Project numbers WR12R004 and WR07R0004). Dave Johnson (Wisconsin Department of Natural Resources) provided the original idea for this project. Funding for data collected by Dennis Rohr and his students was made possible by a 2007 Toyota TAPESTRY Grants for Science Teachers – Large Grant titled "Seymour/Oneida Community Groundwater Testing Project".

References Cited

Bartholomay, R.C., Carter, J.M., Qi, S.L., Squillace, P.J., and Rowe, G.L., 2007, Summary of selected U.S Geological Survey data on domestic well water quality for the Centers for Disease Control's National Environmental Public Health Tracking Program: U.S. Geological Survey Scientific Investigations Report 2007-5213, 57 p.

Curzon, M.E.J. and Spector, P.C., 1977, Enamel mottling in a high strontium area of the U.S.A. Community Dentistry and Oral Epidemiology, V. 5, p. 243-247.

Krohelski, J. T., 1986, Hydrogeology and Ground-Water Use and Quality, Brown County, Wisconsin. Prepared by United States Department of the interior Geological Survey, In cooperation with the University of Wisconsin-Extension & Geologic and Natural History Survey. Information Circular Number 57. 42 pages.

Luczaj, J. A., 2006, Evidence against the Dorag (Mixing-Zone) model for dolomitization along the Wisconsin arch – A case for hydrothermal diagenesis. AAPG Bulletin, v. 90, p. 1719-1738.

Luczaj, J.A., 2011, Preliminary Geologic Map of the Buried Bedrock Surface, Brown County, Wisconsin. WGNHS Open File Report 2011-2. http://wisconsingeologicalsurvey.org/wofrs/WORF2011-02.pdf

Luczaj, J.A., (2013; in press), Geology of the Niagara Escarpment in Wisconsin. Geoscience Wisconsin.

Luczaj, J.A. and McIntire, M.J., in preparation, Geochemical characterization of MVT mineralization in eastern Wisconsin Paleozoic sedimentary rocks: Implications for Groundwater Quality.

Nichols, M.S. and McNall, D.R., 1957, Strontium Content of Wisconsin Municipal Waters. Journal of the American Water Works Association v. 49, p. 1493-1498.

Özgür, S., Sümer, H, and Koçoğlu, 1996, Rickets and soil strontium. Archives of Disease in Childhood, v. 75, p. 524-526.

Skougstad, M.W. and Horr, C.A., 1963, Occurrence and Distribution of Strontium in Natural Water. U.S. Geological Survey Water-Supply Paper, 1496-D, p. 55-97.

Tyler, S. A. (1936). Heavy Minerals of the St. Peter Sandstone in Wisconsin. Journal of Sedimentary Petrology, v. 6, No. 2, pp. 55-84.

U.S. EPA, 2011, 2011 Edition of the Drinking Water Standards and Health Advisories. EPA 820-R-11-002, Office of Water U.S. Environmental Protection Agency Washington, DC, 12 pages.

White, D. E., Hem, J.D., and Waring, G. A., 1963, Data of Geochemistry: Chapter F. Chemical Composition of Subsurface Water. Sixth Edition. Geological Survey Professional Paper 440-F.

World Health Organization (WHO), 2010, Strontium and Strontium Compounds, Concise International Chemical Assessment Document 77, 63 pages.

Wonewoc Formation and Tunnel City Group Rock

Wisconsin Geological and

Poster continues on next page.

Abstract:

Wisconsin faces a variety of groundwater quality issues that include both natural contaminants, such as arsenic from sulfide minerals, and human-induced contaminants, such as nitrate from agricultural land-use practices. Although some Cambrian-age sandstone-dominated rock units have been suggested to be potential natural sources of groundwater contaminants, little detailed rock geochemical data exists for these units. At the WGNHS, we are midway through a project to characterize the elemental composition of rocks of the Cambrian Wonewoc Formation and Tunnel City Group across western and south-central Wisconsin. Geochemical data has been collected using a handheld x-ray fluorescence (XRF) analyzer from drill cores, outcrops, and well cuttings. This dataset indicates that the elemental composition of rocks from the Wonewoc Formation and Tunnel City Group include a variety of elements for which groundwater quality standards and advisory levels exist, including aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, vanadium, and zinc. Furthermore, the presence and abundance of these elements varies spatially across the state, through stratigraphic successions, and even within individual rock beds at the centimeter-scale. Our preliminary data confirms that a regional geochemical and mineralogical dataset for the Wonewoc-Tunnel City interval is critical for determining the potential for these rock units to serve as natural source of groundwater contaminants.

Methods:

We used a portable x-ray fluorescence (pXRF) analyzer to determine the elemental abundances of major and minor rock constituents present in hand samples, rock core, and well cuttings from the lower Tunnel City and upper Wonewoc rock units. The pXRF analyzer operates by bombarding a sample with x-rays which results in the sample reacting at the sub-atomic level and releasing energy; this energy is detected by the pXRF analyzer which applies an algorithm to interpret this energy as elemental abundances because the energy wavelengths are element specific.

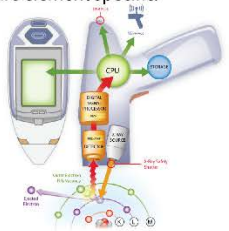

Figure 1 (left): Schematic of the x-ray fluorescence process.

Figure 2 (right): Image of pXRF analyzer fixed to a stand support. A slabbed core sample is set above the x-ray window ready to be analyzed.

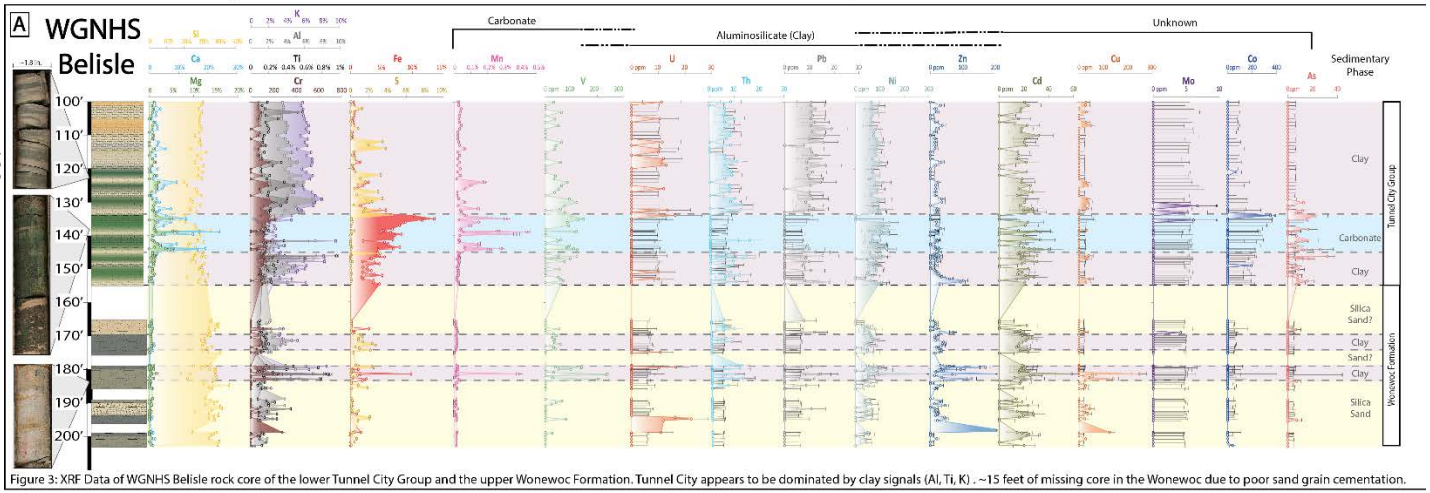

Figure 3: XRF Data of WGNHS Belisle rock core of the lower Tunnel City Group and the upper Wonewoc Formation. Tunnel City appears to be dominated by clay signals (Al, Ti, K) . ~15 feet of missing core in the Wonewoc due to poor sand grain cementation.

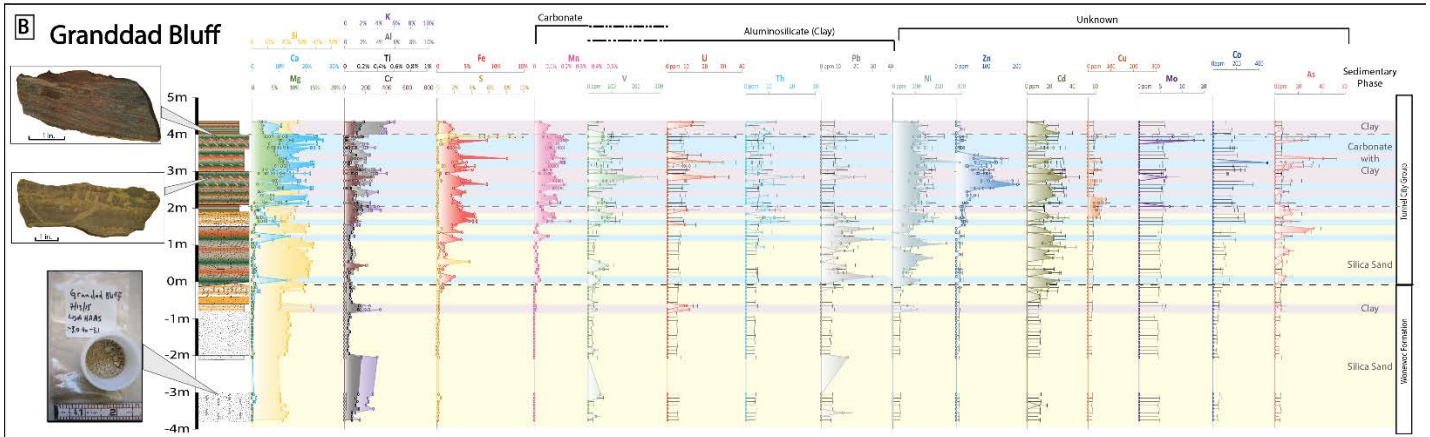

Figure 4: XRF Data of hand samples collected at Granddad Bluff in La Crosse, WI. Samples were collected 5 meters above and 4 meters below the Tunnel City-Wonewoc contact in 10 cm increments. Tunnel City hosts both calcareous (Ca, Mg) and sandy (Si) Rocks.

s: Potential Natural Sources of Groundwater Contaminants in Wisconsin?

Lisa Haas, Jay Zambito, Mike Parsen
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DEPARTMENT of GEOSCIENCE
University of Wisconsin-Madison

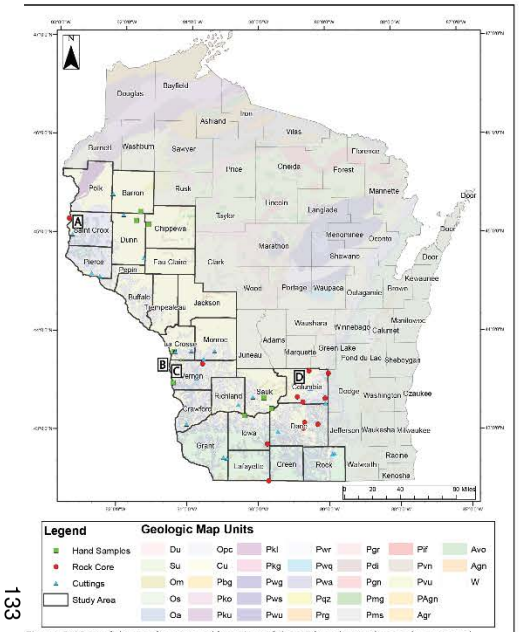


Figure 5: Map of the study area and location of the 45 hand samples, rock cores and cuttings sets studied. **A**) WGNHS Belisle rock core, XRF data displayed left, **B**) Granddad Bluff hand samples, XRF data displayed bottom left, **C**) Arbor Hills cuttings set, XRF data displayed upper right, **D**) WGNHS Triemstra rock core, XRF data displayed right.

Municipality	Tomah	Bangor	Coon Valley	Stoddard	La Crosse	La Crosse	
WUWN	ST009	UN859	OH527	CQ196	RV223	GC657	**Advisory Level**
pH	4.6	6.97	4.7	4.5*	4.08	6.85	
Sulfate	1478.5	-	-	-	-	-	250 mg/L
Aluminum	22630	3220	23900	67300	23200	2320	200 ug/L
Arsenic	ND	ND	129	92	38	ND	10 ug/L
Cadmium	ND	2	1	5	5	ND	5 ug/L
Chromium	2.5	ND	77	220	56	1	100 ug/L
Cobalt	244.2	306	501	909	501	23	40 ug/L
Copper	307.5	1610	324	1290	511	16	1300 ug/L
Iron	39.19	53.6	218	672	376	24.3	0.3 mg/L
Lead	-	ND	109	80	47	ND	15 ug/L
Manganese	222.8	142	921	2980	897	56	50 ug/L
Molybdenum	ND	-	20	-	ND	ND	40 ug/L
Nickel	1232	419	771	1750	832	41	100 ug/L
Strontium	843.1	70	144	217	219	54	4000 ug/L
Vanadium	ND	5	69	239	56	1	30 ug/L
Zinc	574.6	385	52	4460	706	56	2000 ug/L

Figure 6: Concentrations of elements that are known health risks and pH measurements from private wells near La Crosse, WI. Water quality data provided by D. Johnson (WDNR) and the WI State Lab. of Hygiene.

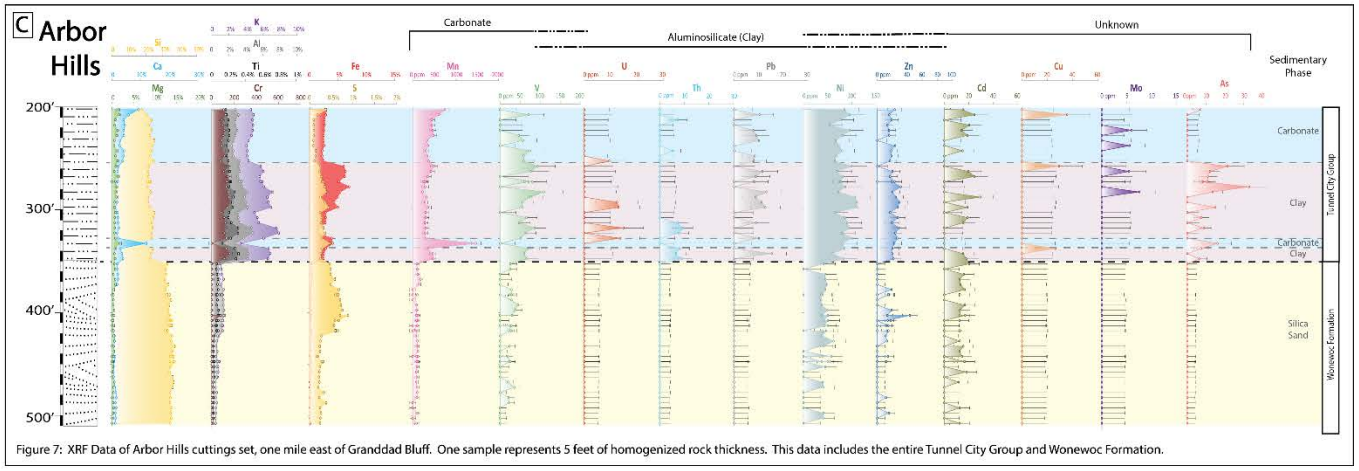


Figure 7: XRF Data of Arbor Hills cuttings set, one mile east of Granddad Bluff. One sample represents 5 feet of homogenized rock thickness. This data includes the entire Tunnel City Group and Wonewoc Formation.

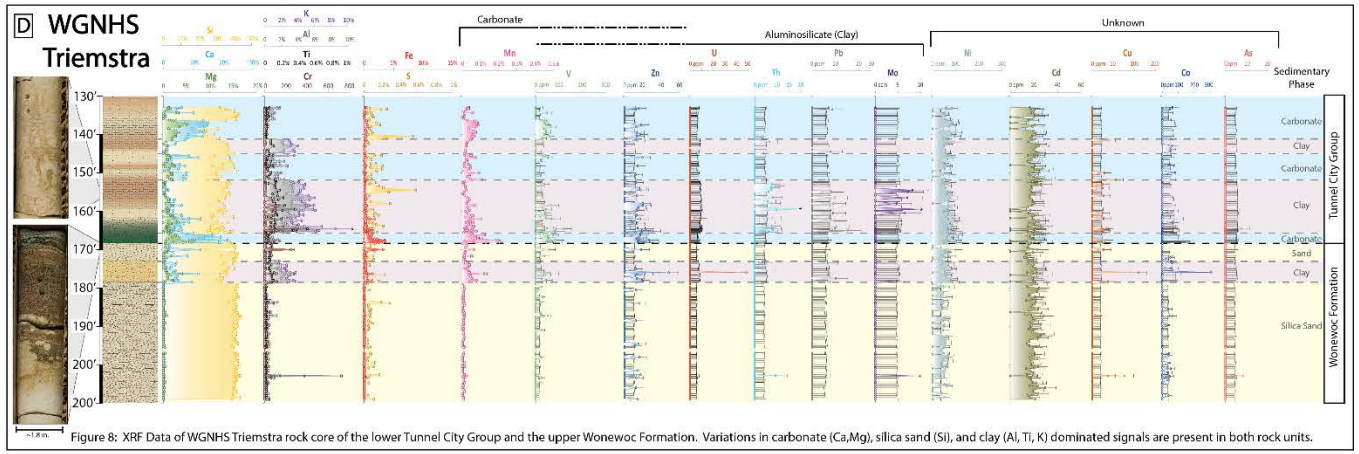


Figure 8: XRF Data of WGNHS Triemstra rock core of the lower Tunnel City Group and the upper Wonewoc Formation. Variations in carbonate (Ca,Mg), silica sand (Si), and clay (Al, Ti, K) dominated signals are present in both rock units.

Discussion:

The XRF data collected to date reflects a consistent reginal geochemical pattern, yet demonstrates a complex mineralogy within the Tunnel City Group and the Wonewoc Formation. In the western portion of the state, as seen with the WGNHS Belsile core, Granddad Bluff hand samples and Arbor Hills cuttings set reflect a glauconitic, carbonate and clay dominated lowest Tunnel City, known as the Birkmose Member. In the south-central portion of the state, seen in the WGNHS Triemstra core, a thin Birkmose equivalent unit is observed, but most of the Tunnel City Group is represented by the quartz-dominated Mazomanie Formation. The Wonewoc formation is undifferentiated throughout the state as friable quartz sandstone, however, just below the contact the Wonewoc has minor amounts of carbonate cemented in each of the areas studied except for WGNHS Belsile where no core was preserved.

On a finer scale, the XRF data reveals heterogeneity in the composition of both the Tunnel City and the Wonewoc. This is most evident in the core and hand samples in which we could identify centimeter-scale lithologic and mineral variability; in contrast, the cuttings samples represent homogenized compositions that underestimate the abundance of trace metals. Aluminosilicate clay layers occur in both the Tunnel City and the Wonewoc, and are consistent with peaks in abundance of Uranium, Thorium, and Lead. Sulfide minerals have also been observed in both the Tunnel City and the Wonewoc, and appear as small nodules in the Tunnel City or as fine, disseminated grains in the Wonewoc that sometimes fill burrows. Elements such as arsenic, cadmium, cobalt, copper, nickel, and zinc that were observed in high concentrations in groundwater in western Wisconsin are relatively abundant in the Tunnel City as well as parts of the Wonewoc. These elements are not strictly associated with the clay, carbonate, nor quartz sandstone minerals, suggesting association with either sulfides or yet-to-be identified mineral phases.

Future work:

- To analyze 22 more samples of core and cuttings and add them to our current dataset of 23 samples that have already been analyzed.
- Apply x-ray powder diffraction (XRD) and inductively coupled plasma mass spectrometry (ICP-MS) analyses on specific samples to determine the mineralogical phases that host high elemental concentrations, as well as confirm those high elemental concentrations.
- Compile the data set and submit it as an open file report for the public, consultants, policy makers, and regulators.

Acknowledgments:

UW Water Resources Institute and the WGNHS provided funding for this project.

Dave Johnson of the WDNR suggested this project to us, and has provided critical insight as the project has developed.

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 groundwater quality 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 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 Dept. 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 a list of substances, designated "Cycle 10", that included pesticides and pesticide metabolites was sent to DHS for review. Pesticides and metabolites included on the Cycle 10 list were 8 herbicides and herbicide metabolites: Isoxaflutole, Isoxaflutole DKN, Isoxaflutole BA, Glyphosate, Glyphosate AMPA, Thiencarbazone-methyl, Sulfentrazone and Dacthal TPA & MTP degradates, and 3 neonicotinoid insecticides: Thiamethoxam, Imidacloprid and Clothianidin. The DNR received recommendations from DHS on June 21, 2019 for 21 new or revised groundwater quality standards, including recommendations for 10 new pesticide/pesticide metabolite standards. The DNR is now in the process of beginning rulemaking to potentially adopt the DHS recommended groundwater standards in ch. NR 140.

Commonly detected pesticides which have established groundwater quality or drinking water standards

in Wisconsin include atrazine, alachlor and metolachlor, and their metabolites.

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. 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. 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).

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 ES and public drinking water MCL for alachlor are 2 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, potatoes and some others. Both the parent and metabolite forms (metolachlor, metolachlor-ESA and metolachlor-OXA) are routinely detected in groundwater and have health-based groundwater quality standards established. 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 southcentral, 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. 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 eventually pesticide metabolites as well (Postle and Brey, 1988). DATCP also developed rules to restrict aldicarb use in areas vulnerable to groundwater contamination.

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 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.

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

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, most believe it is not more difficult to control weeds with other alternatives, and 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. Most recent 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. Sample results from 2016 also show that there has been an increase in the number of monitoring wells that contain one or more detections of the neonicotinoid insecticides clothianidin, imidacloprid and thiamethoxam. A review of groundwater and surface water data collected by DATCP through 2016 showed that in addition to detections in monitoring wells, there is a significant occurrence of neonicotinoid insecticide detections in private wells and irrigation wells tested, with most detections occurring in sandy irrigated vegetable growing areas like those found in the Central Sands region and on terraces of the Wisconsin River Valley. DATCP has shared its neonicotinoid data with U.S. EPA and is writing a paper detailing the findings from its review of groundwater and surface water data collected through 2016 as EPA further evaluates the role that these compounds may have in declining pollinator populations nationwide.

Monitoring well near an agricultural field. Photo: DATCP.

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).

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 5-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.

On April 10, 2019 the DNR transmitted a list of substances, designated "Cycle 11", to DHS. The DNR has requested that DHS review available toxicologic information and, if appropriate, provide recommendations for state NR 140 groundwater quality standards for substances on the list. The Cycle 11 list includes 6 pesticides, including 4 herbicides: Flumetsulam, Fomesafen, Hexazinone and Saflufenacil, 1 insecticide, Chlorantraniliprole, and 1 fungicide: Metalaxyl.

Further Reading

DHS resources for contaminants in drinking water [link]

DNR overview of pesticides in drinking water wells [link]

DATCP water quality reports [link]

References

Agopian, A. J. et al. 2012. Maternal residential atrazine exposure and risk for choanal atresia and stenosis in offspring. Journal of Pediatrics, 162(3):581-586. Available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4105141/

Agopian, A. J. et al. 2013. Case-control study of maternal residential atrazine exposure and male genital malformations. American Journal of Pediatrics, 161(5):977-982.

ATSDR. 2003. Toxicological Profile for Atrazine. U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. Available at http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?id=EcoNatRes.ChestersSources

Chesters, G., G. V. Simsiman, R. N. Fathulla, B. J. Alhajjar, R. F. Harris, J. M. Harkin, J. Levy. 1990. Degradation of atrazine, alachlor, metolachlor in soils and aquifer materials. Wisconsin groundwater management practice monitoring project, DNR-047. Available at http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?id=EcoNatRes.ChestersDegradation

Chesters, G., J. Levy, D. P. Gustafson, H. W. Read, G. V. Simsiman, D. C. Liposcak, Y. Xiang. Sources and extent of atrazine contamination of groundwater at Grade A dairy farms in Dane County, WI. Wisconsin groundwater management practice monitoring project, DNR-065. Available at http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?id=EcoNatRes.ChestersSources

Cowell, S. E. and LeMasters G. S. 1992. Follow up to the grade A dairy farm well water quality survey.

Wisconsin groundwater management practice monitoring project, DNR-070. Available at http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?id=EcoNatRes.CowellFollow

Cragin, L. A. et al. 2011. Menstrual cycle characteristics and reproductive hormone levels in women exposed to atrazine in drinking water. Environmental Research, 111(8):1293-301.

Daniel, T. and R. Wietersen. 1989. Effect of soil type on atrazine and alachlor movement through the unsaturated zone. Wisconsin groundwater management practice monitoring project, DNR-062. Available at http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?id=EcoNatRes.DanielEffect

DATCP, 2008. Groundwater Quality: Agricultural Chemicals in Wisconsin Groundwater. Wisconsin Department of Agriculture, Trade and Consumer Protection, Water Quality Section, ARM Pub 180. 22 pp. Available via email request at datcppublicrecords@wi.gov or at https://datcp.wi.gov/Pages/Programs_Services/GroundwaterReports.aspx

DATCP, 2010. Fifteen years of the DATCP exceedance well survey. Wisconsin Department of Agriculture, Trade and Consumer Protection. Available via email request at datcppublicrecords@wi.gov

DATCP. 2011a. Final report on the 2010 Survey of Weed Management Practices in Wisconsin's Atrazine Prohibition Areas. Wisconsin Department of Agriculture, Trade and Consumer Protection, ARM Pub 215. Available via email request at datcppublicrecords@wi.gov

DATCP, 2017. Wisconsin Groundwater Quality: Agricultural Chemicals in Wisconsin Groundwater. Wisconsin Department of Agriculture, Trade and Consumer Protection, Water Quality Section, ARM Pub 264. 26 pp. Available via email request at datcppublicrecords@wi.gov or at https://datcp.wi.gov/Pages/Programs_Services/GroundwaterReports.aspx

EPA, 1995. Reregistration Eligibility Decision (RED) Metolachlor. EPA 738-R-95-006. April 1995. Available at https://archive.epa.gov/pesticides/reregistration/web/pdf/0001.pdf

EPA, 2006. Acetochlor. Revised HED Chapter of the Tolerance Reassessment Eligibility Decision (TRED) Document. March 2006.

Hayes, T., K. Hason, M. Tsui, A. Hoang, C. Haeffele, A. Vonk. 2002. Feminization of male frogs in the wild. Nature, 419:895-896.

Hayes, T., K. Hason, M. Tsui, A. Hoang, C. Haeffele, A. Vonk. 2003. Atrazine-induced hermaphroditism at 0.1 PPB in American Leopard Frogs (Rana pipiens): laboratory and field evidence. Environmental Health Perspectives, 111:568-575. Available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1241446/

Hayes, T. B., et al. 2006. Pesticide mixtures, endocrine disruption, and amphibian declines: are we underestimating the impact? Environmental Health Perspectives, 114(suppl 1):40-50. Available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1874187/

Hayes, T. B., et al. 2011. Demasculinization and feminization of male gonads by atrazine: Consistent effects across vertebrate classes. The Journal of Steroid Biochemistry and Molecular Biology, 127(1-2):64-73. Available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4303243/

Kraft, G. 1990. Fate of aldicarb residues in a groundwater basin near Plover, Wisconsin. Ph.D. dissertation, Department of Soil Science, UW-Madison.

LeMasters, G. S. and D. J. Doyle. 1989. Grade A dairy farm well water quality survey. Wisconsin groundwater management practice monitoring project, DNR-052. Available at http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?id=EcoNatRes.LeMastersGrade

Levy, J. and G. Chesters. 1995. Simulation of atrazine and metabolite transport and fate in a sandy-till aquifer. Journal of Contaminant Hydrology 20(1-2):67-88.

Levy, J., G. Chesters, D. P. Gustafson, H. W. Read. 1998. Assessing aquifer susceptibility to and severity of atrazine contamination at a field site in south-central Wisconsin, USA. Hydrogeology Journal, 6(4):483-499.

Lowery, B. and K. McSweeney. 1992. Effect of soil type, selected best management practices, and tillage on atrazine and alachlor movement through the unsaturated zone. Wisconsin groundwater management practice monitoring project, DNR-066. Available at http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?id=EcoNatRes.LoweryEffect

NASS. 2015. Wisconsin Agricultural Chemical Use, Corn and Potatoes, Fall 2014. United States Department of Agriculture, National Agricultural Statistics Service. Available at

NASS. 2016. Wisconsin Agricultural Chemical Use, Soybeans, Fall 2015. United States Department of Agriculture, National Agricultural Statistics Service.

Porter, W.P., et al. 1999. Endocrine, immune and behavioral effects of aldicarb (carbamate), atrazine (triazine) and nitrate (fertilizer) mixtures at groundwater concentrations. Toxicology and Industrial Health 15(1-2): 133-150.

Postle, J. K. and Brey K. M. 1988. Results of the WDATCP groundwater monitoring for pesticides. Wisconsin groundwater management practice monitoring project, DNR-002. Available at http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?id=EcoNatRes.PostleResults

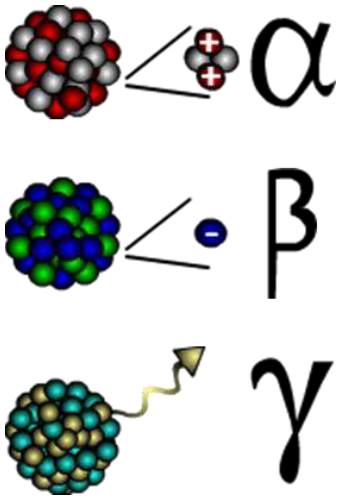
Rothschild, E. R., R. J. Manser, M. P. Anderson. 1982. Investigation of aldicarb in ground water in selected areas of the Central Sand Plain of Wisconsin. Ground Water 20(4):437-445.

WASS. 2006. Wisconsin Pesticide Use. Wisconsin Department of Agriculture, Trade and Consumer Protection. United States Department of Agriculture, National Agricultural Statistics Service.

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 groundwater standards for radionuclides in Wisconsin, but drinking water at public water systems is monitored for general indicators of radioactivity (alpha, beta, gamma activity) as well as for specific radionuclides (uranium, radium). The maximum contaminant levels (MCLs) in drinking water are 15 pCi/L for alpha activity, 4mrem/yr for beta or gamma activity, 5pCi/L for total radium, and 30 ug/L for uranium (WI NR 809.50-809.51). Some people who drink water containing alpha, beta or photon emitters, radium, or uranium in excess of the MCL 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 drinking water standard for radon, although the US EPA has proposed that radon levels be no higher than 4,000 pCi/L (where indoor air programs for radon exist) or 300 pCi/L (where indoor air programs do not exist).

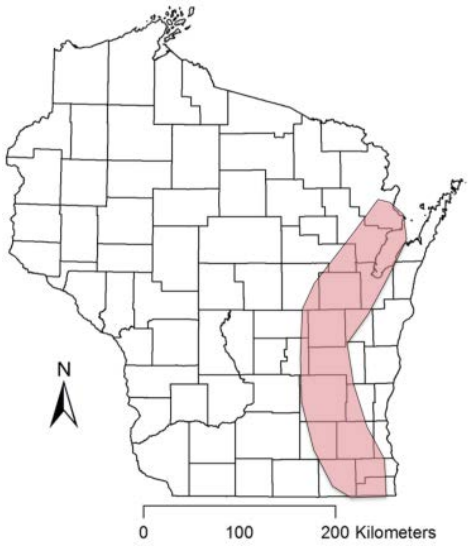
Occurrence in Wisconsin

Since radionuclides occur naturally in rock formations, every well in Wisconsin contains some level of dissolved radionuclides. In many 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 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 due to the confined conditions and geochemical differences.

About 80 public water systems have exceeded a radionuclide drinking water standard at some point in time. The DNR has been working with these systems since 2003 to ensure that they develop a



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 intersects the Maquoketa shale. *Figure*: *Luczaj and Masarik, 2015*.

compliance strategy and take corrective action, so currently less than 10 remain that are providing water in exceedance of the standards.

GCC Agency Actions

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).

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 a diversion of Lake Michigan water with return flow.

Further Reading

DHS resources for contaminants in drinking water [link]

DNR overview of radium in drinking water wells [link]

DNR overview of radon in drinking water wells [link]

WGNHS report on distribution of radionuclides in groundwater [link]

WGNHS report on radon in private wells in SE Wisconsin [link]

References

Arndt, M. F. 2010. Evaluation of gross alpha and uranium measurements for MCL compliance. Water Research Foundation. Project 3028. Available at http://www.waterrf.org/PublicReportLibrary/3028.pdf

Arndt, M. F., and L. West. 2004. A Study of the factors affecting the gross alpha measurement, and a radiochemical analysis of some groundwater samples from the state of Wisconsin exhibiting an elevated gross alpha activity. Wisconsin groundwater management practice monitoring project, DNR-176. Available at http://www.slh.wisc.edu/wp-content/uploads/2013/10/dnrfinal.pdf

Grundl, T. and M. Cape. 2006. Geochemical factors controlling radium activity in a sandstone aquifer. Ground Water 44(4):518-527.

Grundl, T., K. Bradbury, D. Feinstein, S. Friers, D. Hart. 2006. A Combined Hydrologic/Geochemical Investigation of Groundwater Conditions in the Waukesha County Area, WI. Wisconsin groundwater management practice monitoring project, WR03R002. Available at http://www.wri.wisc.edu/Downloads/PartnerProjects/FinalReports/Final_WR03R002.pdf

Luczaj, J. and K. Masarik. 2015. Groundwater quantity and quality issues in a water-rich region: examples from Wisconsin, USA. Resources, 4(2):323-357. Available at: http://www.mdpi.com/2079-9276/4/2/323

Mudrey, M. G. and K. R. Bradbury. 1993. Distribution of radionuclides in Wisconsin groundwater. Wisconsin Geological and Natural History Survey, Open-File Report 1993-09. 19 p. Available at http://wgnhs.uwex.edu/pubs/wofr199309/

Sonzogni, W. C., D. M. Schleis, L. E. West. 1995. Factors affecting the determination of radon in groundwater. Wisconsin groundwater management practice monitoring project, DNR-111. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.SonzogniFactors

Taylor, R. W. and G. Mursky. 1990. Mineralogical and geophysical monitoring of naturally occurring radioactive elements in selected Wisconsin aquifers. Wisconsin groundwater management practice monitoring project, DNR-051. Available at http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?id=EcoNatRes.TaylorMineral

Weaver, T. R. and J. M. Bahr. 1991. Geochemical evolution in the Cambrian-Ordovician sandstone aquifer, eastern Wisconsin: 1. Major ion and radionuclide distribution. Ground Water 29(3):350-356.

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

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

industrial and commercial areas. However, exceedances of groundwater standards for VOCs have been reported in every county in the state.

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.

Further Reading

DHS resources for contaminants in drinking water [link]

DNR overview of VOCs in private drinking water wells [link]

DNR map of open and closed contaminated sites [link]

DNR database of contaminated soil and groundwater [link]

DHS overview of vapor intrusion [link]

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

References

Friedman, M.A. 1988. Volatile Organic Compounds in Groundwater and Leachate at Wisconsin Landfills. Wisconsin groundwater management practice monitoring project, DNR-004. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.FriedmanVolatile

Battista, J.R. and J.P. Connelly. 1989. VOC Contamination at Selected Wisconsin Landfills – Sampling Results and Policy Implications. Wisconsin groundwater management practice monitoring project, DNR-005. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.BattistaVOC

Battista, J.R. and J.P. Connelly. 1994. VOCs at Wisconsin landfills: recent findings. In: Proceedings of the 17th International Madison Waste Conference, Madison, WI, pp. 67–86

U. S. Department of Human and Health Services. 2006. Private Well Impacts from Wisconsin's Old Landfills. Public Health Report. Available at http://www.atsdr.cdc.gov/HAC/pha/Wisconsin's%20Old%20Landfill/WellImpacts-WisconsinOldLandfills021306.pdf

Emerging Contaminants

What are they?

An emerging contaminant is a substance that has not historically been considered a contaminant, but for which there is increasing evidence that it is present in the environment and may cause adverse human and environmental health effects. Some emerging contaminants have been present in the environment for a long time but could not be detected until the development of new testing methods. Others are of concern due to recent changes in synthesis, use or disposal practices. 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.

Pharmaceuticals, including antibiotics, birth control pills and other prescription medicines are one class of contaminants of emerging concern. *Photo: US Department of Defense*

Emerging contaminants often enter groundwater from wastewater from municipal, industrial or agricultural sources, although some come from naturally occurring sources. Pharmaceuticals, such as antibiotics, birth control pills or other prescription medicines are a large group of emerging contaminants from human-generated waste streams. Another is personal care products (PCPs), which include shampoos, detergents and “over-the-counter” non-prescription medicines. Other broad classes of emerging contaminants include viruses and agricultural pesticides and their metabolites.

Health effects of emerging contaminants vary and are not always well understood. Some emerging contaminants, including some pesticides, pharmaceuticals and PCPs, 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 these compounds may cause developmental, reproductive, neurologic and immune problems, as well as cancer (NIH, 2010), but more research is needed on many of them.

A relatively new group of emerging groundwater contaminants are the perfluoroalkyl and polyfluoroalkyl substances (PFAS). PFAS compounds 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.

Per- and Poly-fluorinated Alkyl Substances (PFAS)

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 certain types of industrial and aviation fire-fighting foams. These chemicals do not easily break down in the environment and have been known to accumulate in the environment and humans. In a nationwide study, low levels of PFAS were determined to be present in the blood of most Americans. The acronym PFC has been used to describe PFAS in the past. This acronym is no longer used to describe per- and poly- fluoroalkyl substances (PFAS) because it is used to describe perfluorocarbons (i.e., refrigerants), which are a different family of chemicals.

Although PFAS have been used extensively since the mid-20th century, experts are just recently understanding their potential impacts to human health. This understanding continues to evolve based on ongoing research. The specific PFAS perfluorooctane sulfonate (PFOS), perfluorooctanoate (PFOA), perfluorohexane sulfonate (PFHxS), and perfluorononanoic acid (PFNA) are the most studied 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.

The highest exposure to PFAS are to workers involved in making or processing PFAS and PFAS-containing materials. Workers may be exposed to PFAS by inhaling them, and swallowing them, but inhaling them is the most likely route for exposure. The general population may be exposed to PFAS in several ways including: drinking municipal or private well water contaminated by PFAS, eating fish caught from water contaminated by PFAS, accidentally swallowing soil or dust contaminated by PFAS, eating food that was packaged in material that contains PFAS, and using consumer products that contain PFAS.

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. Under the Safe Drinking Water Act's third Unregulated Contaminants Monitoring Rule (UCMR-3), select municipal water systems were asked to test for six PFAS (PFOA, PFOS PFNA, PFHxS, PFHpA and PFBS), between 2013 and 2015. Levels 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, and PFAS has also been found in groundwater near the Johnson Controls International/Tyco facility (Marinette), former Mirro plants (Manitowoc and Chilton) and Department of Defense sites (i.e. Wisconsin Air National Guard facilities at Truax Field and Volk Field) in Wisconsin. PFAS are present in some consumer products, industrial processes, and types of firefighting foams. Therefore, PFAS are potentially present at municipal fire departments, industrial facilities, and in waste streams entering municipal landfills and treatment works. PFAS have been identified in municipal wastewater treatment facilities' influent, effluent and biosolids due to the diverse

waste streams accepted (i.e. industrial and municipal parties). There is some concern that these biosolids cause groundwater contamination when beneficially reused via agricultural landspreading.

Wastewater effluent. 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 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 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 were found in seven of ten monitoring wells and two domestic wells; human enteric virus indicators were found in three monitoring wells; and pathogenic bacteria indicators were found in one monitoring well (Bradbury et al., 2015). Other studies also suggest human enteric viruses from wastewater may be present in private and public drinking water wells across the state (Borchardt et al., 2003a, 2003b, 2004, 2007; Bradbury et al. 2013). . PFAS have been identified in municipal wastewater treatment facilities' influent, effluent and biosolids due to the diverse waste streams accepted (i.e. industrial and municipal parties).

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*.

Agricultural sources. Due to the expense of testing and the limited analytical methods available, only a fraction of the pesticides applied to agricultural fields and their metabolites have been tested for in groundwater. However, DATCP's most recent statewide statistical survey of agricultural chemicals in groundwater found that approximately 42% of private wells in Wisconsin contained at least one of the 101 pesticides and pesticide metabolites analyzed (DATCP, 2017). The most commonly detected compounds do have health-based groundwater standards, but the potential health effects of others are less understood. Hormones from livestock operations were detected in runoff and tile drain water from one agricultural field in a study funded by the Wisconsin Groundwater Research and Monitoring Program (WGRMP), but they were not found in nearby groundwater monitoring wells (Hemming et al., 2013). A different study evaluated "shallow" water supply wells in karst bedrock areas in northeastern Wisconsin that were suspected of being impacted by agricultural activities due to nearby land use and contamination with bacteria and/or nitrate (Bauer-Dantoin, 2013). In this study, researchers identified estrogenic activity in some well samples, suggesting that agricultural activity may be a source of EDCs in groundwater in karst areas.

Industrial sources. Municipal and industrial landfills and hazardous waste clean-up sites are always sources of concern for both known and emerging contaminants. One example of emerging contaminants suspected to originate at these sites are PFAS compounds, organic molecules that have a number of industrial applications including use in firefighting foams and as a carpet, upholstery and fabric protector. These compounds were detected in three public water supply wells during monitoring for unregulated contaminants required by the US EPA from 2013-2015. Since the EPA unregulated contaminant sampling effort, testing for a more comprehensive list of PFAS compounds has been conducted in Wisconsin, and the chemicals have been detected in private water supply wells, and at a number of municipal water supply systems. PFAS groundwater sampling is also being conducted at Department of Defense sites in Wisconsin. It is suspected that the compounds may be present in groundwater at other locations near firefighting training sites and facilities that manufacture products containing PFAS.

Natural geologic formations. The susceptibility of groundwater to contamination by natural trace elements depends on the geochemical environment, which can be highly variable spatially and temporally and is not always well described. Strontium is emerging as a trace element of concern in eastern Wisconsin, particularly in the Brown and Outagamie county areas. A study detected strontium above the US EPA's health advisory limit in about 63% of well samples from this area (Luczaj et al., 2013), but the full extent of groundwater with high strontium levels is not well documented, nor are the potential health effects.

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.

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

Ongoing 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 good 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 that facilitates regular review of groundwater monitoring data and identification of 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 representative sample of small (serving < 10,000 people), public water systems. The Third UCMR (UCMR3) monitoring period was completed in 2015 and monitoring for the Fourth UCMR (UCMR4) is occurring from 2018 - 2020. Data collected at Wisconsin public water supply systems during UCMR monitoring supplements data from other GCC-supported monitoring and occurrence studies.

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. To address this regulatory gap, the DNR formally requested that DHS provide recommendations for groundwater quality standards for two PFAS, PFOA and PFOS, in accordance with State law. In June of 2019, based on a review of thousands of peer-reviewed studies, the DHS recommended a groundwater enforcement standard of 20 parts per trillion (ppt) for combined levels of PFOA and PFOS. Upon receiving recommendations, the DNR has begun the formal rulemaking process to promulgate amendments to NR 140 groundwater quality standards. The rulemaking process may take up to 30 months to complete.

The DNR is formulating a strategy address PFAS in the State. This will include a request for voluntary sampling of influent and effluent by WPDES permitted municipal wastewater treatment plants. PFAS may be present in municipal wastewater treatment facilities' biosolids that have been regularly applied to agricultural lands throughout the state. The DNR intends to investigate the fate and transport of PFAS in biosolids. Additional statewide PFAS biosolids and sludge testing may be requested in the coming years. To effectively protect human health and the environment from potential risks associated with the land application of PFAS containing biosolids, a PFAS GIS screening tool to prioritize sites for potential sampling based on the likelihood of those substances being used and the susceptibility of nearby receptors (e.g., drinking water wells, wildlife, etc.). Wisconsin will be drawing on the examples and experiences of other states to guide future PFAS efforts at State agencies that protect groundwater resources within the State.

Further Reading

DNR overview of pharmaceuticals and PCPs in the environment [link]

DNR web page on per- and polyfluoroalkyl substance (PFAS) contamination [link]

Wisconsin Remediation and Redevelopment Database (WRRD) [link]

DATCP Groundwater Quality Reports [link]

NIH factsheet on endocrine disruptors [link]

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

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

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

References

Bauer-Dantoin, A., S. Wingert, K. Fermanich, M. Zorn. 2013. Well Water in Karst Regions of Northeastern Wisconsin Contains Estrogenic Factors, Nitrate, and Bacteria. Water Environment Research, 85(4):318-326. (Wisconsin groundwater management practice monitoring project, WR08R004).

Borchardt, M. A., P. D. Bertz, S. K. Spencer, D. A. Battigelli. 2003a. Incidence of enteric viruses in groundwater from household wells in Wisconsin. Applied and Environmental Microbiology, 69(2):1172-1180.

Borchardt, M. A., P. H. Chyou, E. O. DeVries, E. A. Belongia. 2003b. Septic system density and infectious diarrhea in a defined population of children. Environmental Health Perspectives, 111(5):742-748. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1241485/

Borchardt, M.A., N. L. Haas, R. J. Hunt. 2004. Vulnerability of municipal wells in La Crosse, Wisconsin, to enteric virus contamination from surface water contributions. Applied and Environmental Microbiology, 70(10): 5937-5946. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC522136/

Borchardt, M.A., K. R. Bradbury, M. B. Gotkowitz, J. A. Cherry, B. L. Parker. 2007. Human enteric viruses in groundwater from a confined bedrock aquifer. Environmental Science & Technology 41(18):6606-6612.

Bradbury, K.R. and J. Bahr. 2005. Monitoring and predictive modeling of subdivision impacts on groundwater in Wisconsin. Wisconsin groundwater management practice monitoring project, DNR-178. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.BradburyMonitor

Bradbury, K.R., M. A. Borchardt, M. B. Gotkowitz, S. K. Spencer, J. Zhu, R. J. Hunt. 2013. Source and transport of human enteric viruses in deep municipal water supply wells. Environmental Science & Technology, 47(9):4096-4103.

Bradbury, K.R., T.W. Rayne, and J.J. Krause. 2015. Impacts of a rural subdivision on groundwater: results of a decade of monitoring. Wisconsin groundwater management practice monitoring project, DNR-217.

DATCP, 2017. Groundwater Quality: Agricultural Chemicals in Wisconsin Groundwater. Wisconsin Department of Agriculture, Trade and Consumer Protection, Water Quality Section, ARM Pub 264. 26 pp. Available via email request at datcppublicrecords@wi.gov or online at https://datcp.wi.gov/Pages/Programs_Services/GroundwaterReports.aspx

Gao, J. and J.A. Pedersen. 2005. Adsorption of sulfonamide antimicrobial agents to clay minerals. Environmental Science & Technology, 39:9509-9516.

Gao, J. and J.A. Pedersen. 2010. Sorption of sulfonamides to humic acid–clay complexes. Journal of Environmental Quality, 39:228–235.

Gu, C., K.G. Karthikeyan. 2005a. Interaction of tetracycline with aluminum and iron hydrous oxides. Environmental Science & Technology, 39:2660-2667.

Gu, C. and K.G. Karthikeyan. 2005b. Sorption of the antimicrobial ciprofloxacin to aluminum and iron hydrous oxides. Environmental Science & Technology, 39(23):9166-9173

Gu, C, K.G. Karthikeyan, S. D. Sibley, and J.A. Pedersen. 2007. Complexation of the antibiotic tetracycline with humic acid. Chemosphere, 66:1494–1501.

Gu, C. and K.G. Karthikeyan. 2008. Sorption of tetracycline to humic-mineral complexes. Journal of Environmental Quality, 37:704–711.

Hemming, J., M. Mieritz, C. Hedman, S. Havens and M. Shafer. 2013. Potential of hormones from livestock operations to contaminate groundwater. Wisconsin groundwater management practice monitoring project, DNR-203. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.HemmingHormones

Karthikeyan, K.G. and W.F. Bleam. 2003, Occurrence of antibiotics in wastewater effluents and their mobility in soils: A case study for Wisconsin. Wisconsin groundwater management practice monitoring project, DNR-169. Available at http://digital.library.wisc.edu/1711.dl/EcoNatRes.KarthikeyanOccurr

Luczaj, J.A., M. Zorn, J. Baeten. 2013. An evaluation of the distribution and sources of dissolved strontium in the groundwater of eastern Wisconsin, with a focus on Brown and Outagamie counties. Wisconsin groundwater management practice monitoring project, WR12R004.

McMahon, K. 2006. Evaluation of on-site wastewater treatment as a source of antibiotic resistance genes in groundwater. Wisconsin groundwater management practice monitoring project, WR05R006.

NIH. 2010. Endocrine Disruptors. National Institute of Environmental Health Services. Available at https://www.niehs.nih.gov/health/topics/agents/endocrine/index.cfm

Pedersen, J. A., and K.G. Karthikeyan. 2005. Fate of representative fluoroquinolone, macrolide, sulfonamide and tetracycline antibiotics in subsurface environments. Wisconsin groundwater management practice monitoring project, WR03R008.

Pedersen, J.A., K.G. Karthikeyan, and H.M Bialk. 2009. Sorption of human and veterinary antibiotics to

soils. Natural Organic Matter and its Significance in the Environment. Wu, F.; Xing, B. (eds). Science Press: Beijing, China, pp. 276-299.

Sibley, S. D., and J.A. Pedersen. 2008. Interaction of the macrolide antimicrobial clarithromycin with dissolved humic acid. Environmental Science & Technology, 42:422–428

Sonzogni, E.C., J.D.C. Hemming, M.A.E. Barman, and S. Geis. 2006. Occurrence of estrogenic endocrine disruptors in groundwater. Wisconsin groundwater management practice monitoring project, WR04R004.

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 2017 water use reporting showed that the largest category of groundwater withdrawals was municipal public water supplies, accounting for 92 billion gallons in 2017, down from 93 billion in 2016 (DNR 2019). The second largest category of groundwater withdrawal in the state was agricultural irrigation, totaling 64.5 billion gallons, remaining steady with another wet growing season.

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/topic/WaterUse/WithdrawalSummary.html

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 department is taking the necessary steps to identify the components of the water budget driving the fluctuation in each of the three named lakes. The study will move us forward in developing methodologies for determining "how much is too much?" for a lake. 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 (http://dnr.wi.gov/topic/groundwater/documents/GCC/GwQuantity/RegionalDrawdowns.pdf), 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.

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.

References:

Clancy, K., G.J. Kraft, and D.J. Mechenich. 2009. Knowledge development for groundwater withdrawal around the Little Plover River, Portage County, Wisconsin. Center for Watershed Science and Education, University of Wisconsin – Stevens Point. 47 pp.

Kraft, G.J., D.J. Mechenich, K. Clancy, and J. Haucke. 2012. Irrigation effects in the northern lake states – Wisconsin central sands revisited. Ground Water Journal. V. 50: 308-318.

Kraft, G.J. and D.J. Mechenich. 2010. Groundwater Pumping Effects on Groundwater Levels, Lake Levels, and Streamflows in the Wisconsin Central Sands. Report to the Wisconsin Department of Natural Resources in Completion of Project NMI00000247 Center for Watershed Science and Education, University of Wisconsin – Stevens Point / Extension. https://www.uwsp.edu/cnr-ap/watershed/Documents/gwpumpcentralsands2010.pdf

Krohelski, J.T., Bradbury, K.R., Hunt, R.J., and Swanson, S.K., 2000, Numerical model of groundwater flow in Dane County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 98, 31 p.

Macholl, J.A. 2007. Inventory of Wisconsin's springs. Wisconsin Geological and Natural History Survey Open-File Report 2007-003. Available at http://wgnhs.uwex.edu/pubs/wofr200703/

Swanson, S. et al. 2017. An updated Springs Inventory for the State of Wisconsin. Project ID 15-HDG-01. Available at https://www.wri.wisc.edu/wp-content/uploads/FinalDNR224.pdf

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 around Green Bay have risen. These changes at one well can be seen in Figure 1.

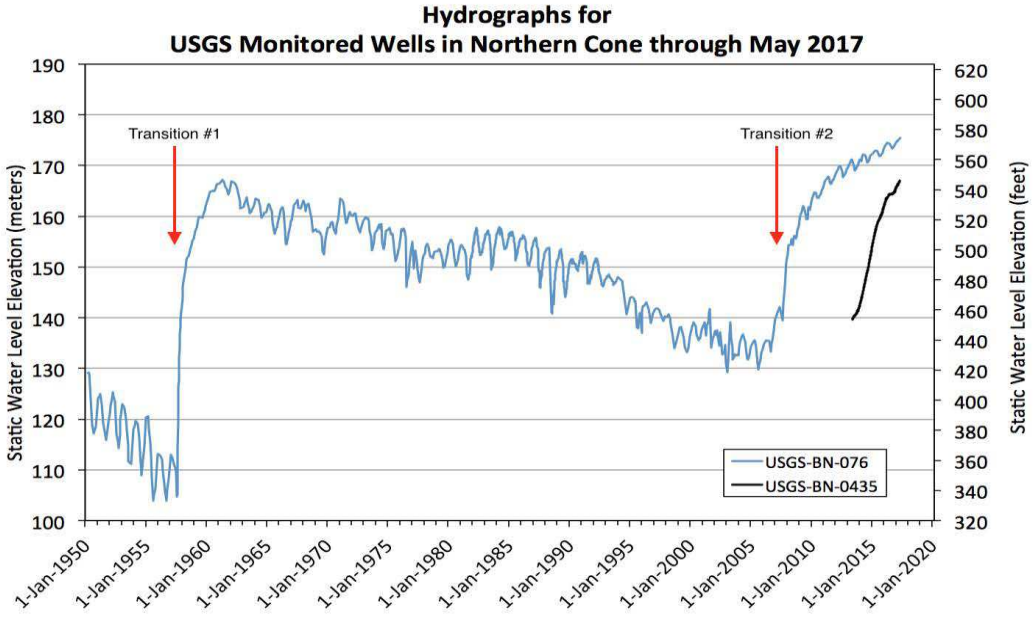


Figure 1: Changes in groundwater levels in a groundwater level monitoring well in Green Bay, Wisconsin. Transition 1 is City of Green Bay Switch to surface water. Transition 2 is Green Bay suburbs switch to surface water (Luczaj).

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.

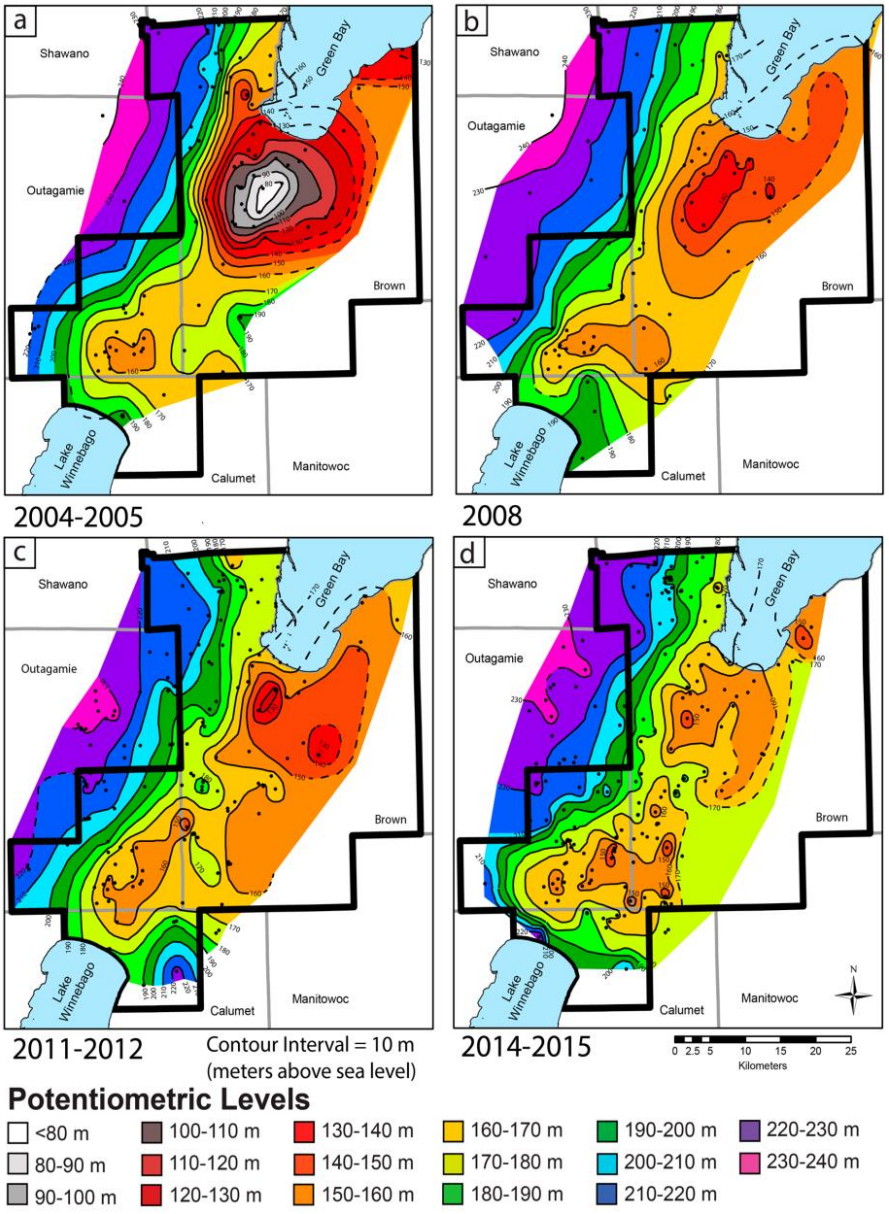


Figure 2: Water table elevations in Brown County (WGNHS).

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, a recently added well

in Waukesha County to the groundwater observation network shows 2013 water levels to be approximately 100 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.

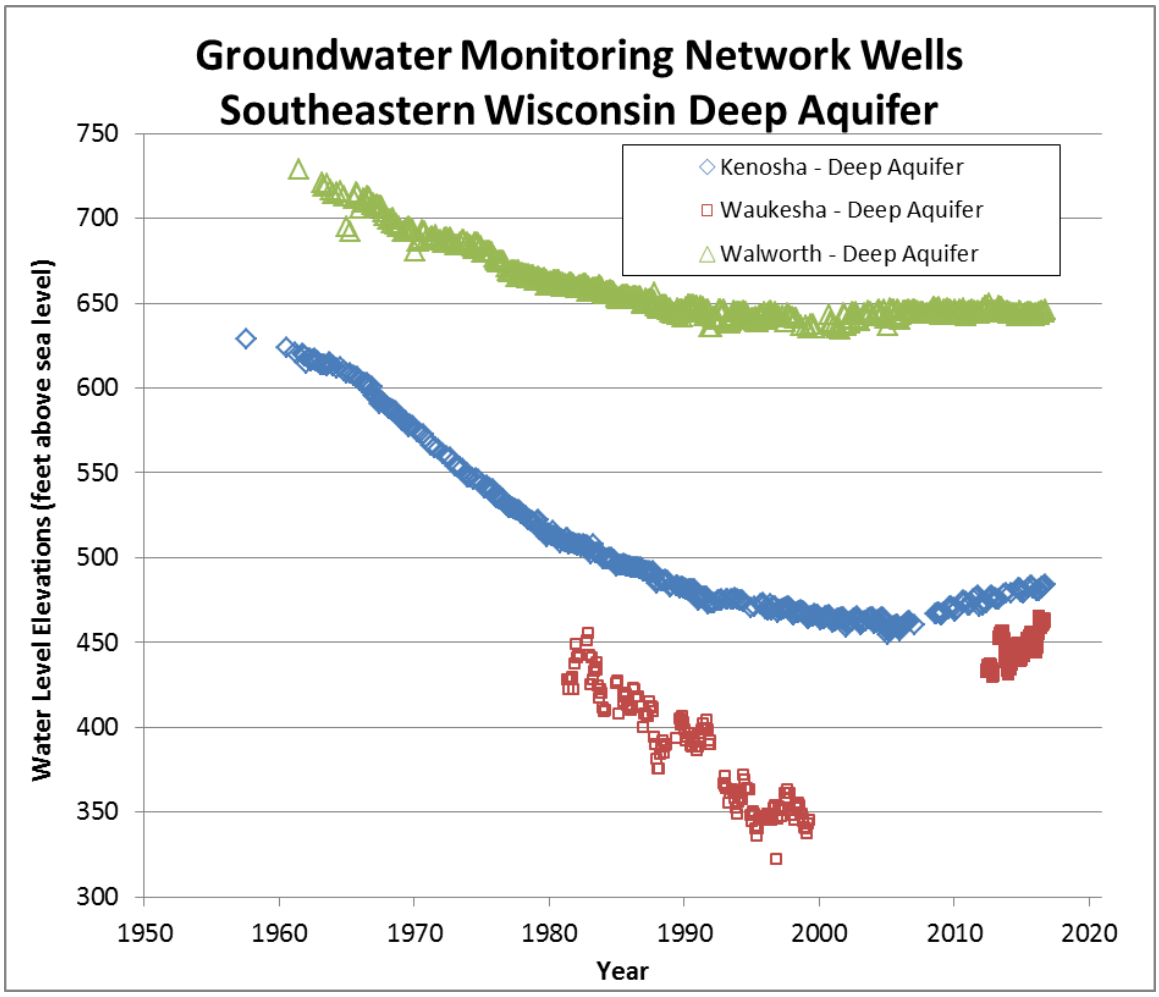


Figure 3: Water levels in a groundwater level monitoring wells in Waukesha, Kenosha and Walworth counties (DNR).

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 existing Dane County model, developed in the mid-1990s (Krohelski, 2000), 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%).

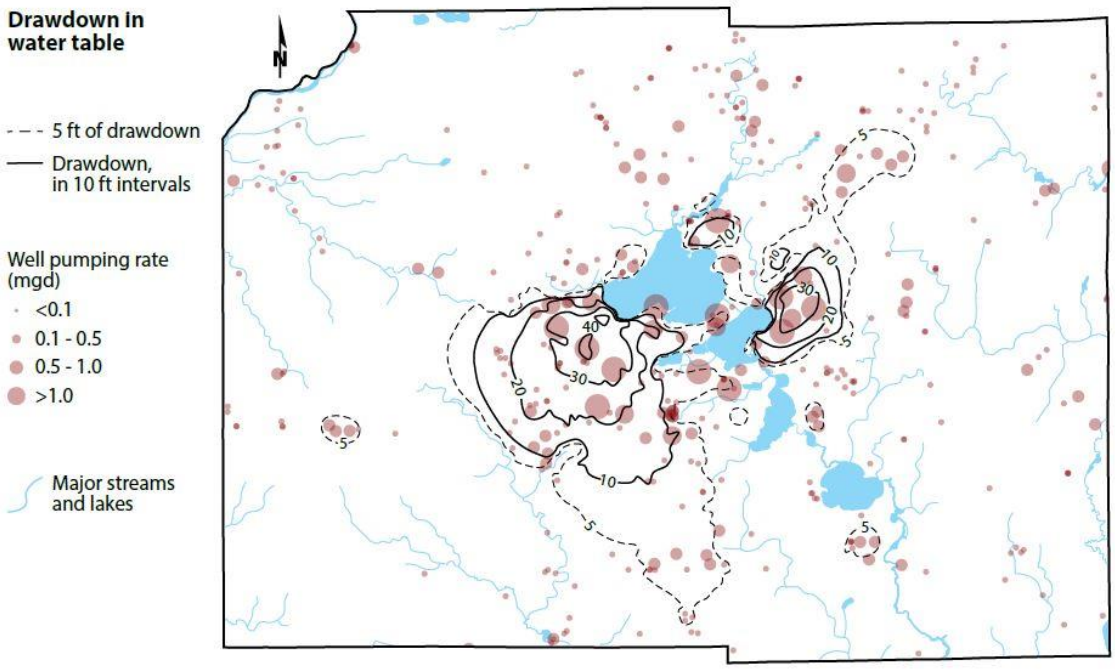


Figure 4 - Simulated drawdown (feet) in the Mount Simon Sandstone; predevelopment to 2010. The Mount Simon Sandstone, located several hundred feet below land surface and up to 800 feet thick, is the lowermost aquifer unit within Dane County. This porous sandstone is a highly productive aquifer which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

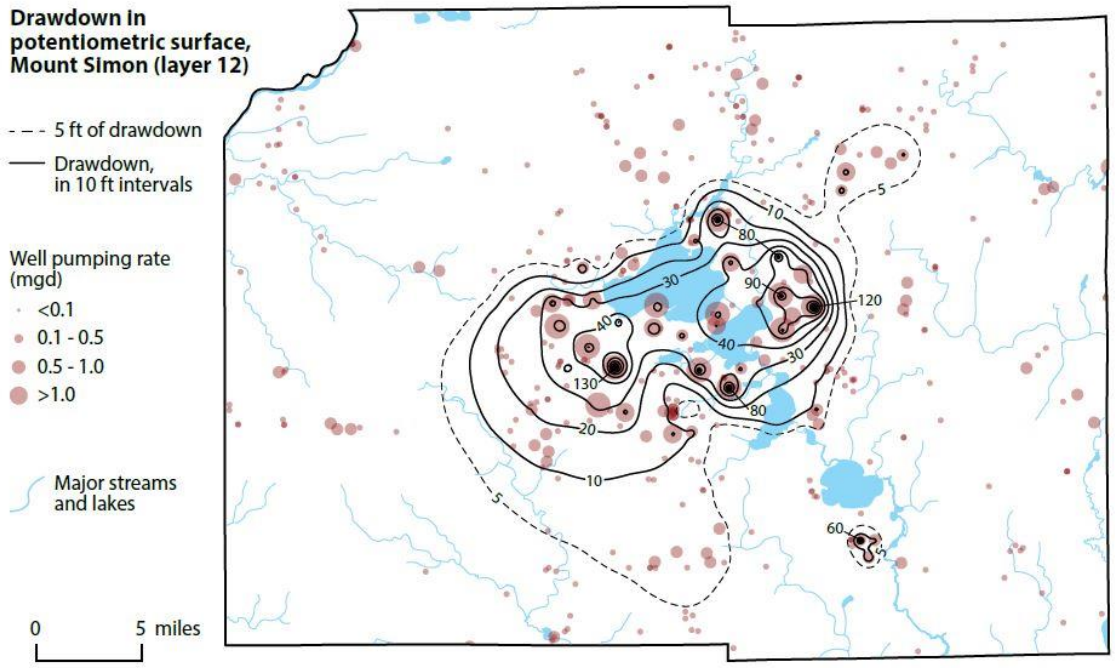


Figure 5 - Simulated drawdown (feet) at the water table; predevelopment to 2010. Drawdowns from the lower Mount Simon aquifer system propagate upwards to the shallow sand and gravel and upper bedrock aquifer systems to create drawdowns at the water table (WGNHS).

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 will evaluate and model 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 includes 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 involves data collection and compilation across the region. As required by Act 10, field studies will also evaluate the impact of groundwater withdrawals on lakes.

The department will determine if there is the potential for significant impacts to the lake's average seasonal levels as a result of groundwater withdrawals. If the department determines that the potential for significant impacts exists, several steps will be taken including a public hearing, economic impact analysis and providing recommendations to the Legislature for special measures to mitigate those impacts.

References:

Bradbury, K.R., M.N. Fienen, M.L. Kniffin, J.J. Krause, S.M. Westenbroek, A.T. Leaf, and P.M. Barlow. 2017. A groundwater flow model for the Little Plover River in Wisconsin's Central Sands. Bulletin 111. Wisconsin Geological and Natural History Survey, 82 p. Available at http://wgnhs.uwex.edu/pubs/B111/

Feinstein, D.T., D.J. Hart, T.T. Eaton, J.T. Krohelski, and K.R. Bradbury. Simulation of regional groundwater flow in southeastern Wisconsin. 2004.

Krohelski, J.T., Bradbury, K.R., Hunt, R.J., and Swanson, S.K., 2000, Numerical model of Groundwater flow in Dane County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 98, 31 p.

Luczaj, J.A. and Hart, D.J., 2009, Drawdown in the Northeast Groundwater Management Area (Brown, Outagamie, and Calumet Counties, WI). Final Project Report submitted to the Wisconsin Department of Natural Resources on July 3, 2009; 59 pages. https://wgnhs.uwex.edu/pubs/wofr200904/

Luczaj, J., J. Maas, D. Hart, and J. Odekirk. 2017. Aquifer Drawdown and Recovery in the Northeast Groundwater Management Area, Wisconsin, USA: A Century of Groundwater Use. Geosciences 7(1). Available at: http://www.mdpi.com/2076-3263/7/1/11

Parsen, M.J., Bradbury, K.R., Hunt, R.J., and Feinstein, D.T., 2016, The 2016 groundwater flow model for Dane County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 110, 56 p.

Pfeiffer, S.M. personal communication, 2013.

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 2018, this network consists of 92 long-term monitoring wells, two spring gaging stations and project-specific, limited-term monitoring wells. The long-term 92 permanent wells and two spring gaging stations, or "Core Network" are located in 45 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 2019, DNR committed $100,000 to the Core Network and provided additional funding of $65,000 to USGS to install monitoring equipment on 21 short-term project wells in support of the Central Sands Lakes Study.

In FY 2019 WGNHS received a 2-year grant from the USGS National Ground-Water Monitoring Network (NGWMN) program in the amount of $198,089. This grant, which continues through July 2020, seeks to repair 16 monitoring wells, replace three damaged wells, and install a new well in Langlade County. Improvement efforts also include compilation of historical well records, well borehole evaluations, and well integrity testing as needed to complement existing information for each well.

Central Sands Lakes Study

Under 2017 Wisconsin Act 10, the department will evaluate and model 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.

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Chippewa county Groundwater Model

Chippewa County worked with WGNHS and USGS to conduct a 5-year study of groundwater resources in western Chippewa County. The goal of the study was to answer two questions, how does pumping of high-capacity wells affect water levels in nearby wells and flows in streams today and how might changes in pumping rates, placement of new high-capacity wells and changes to the landscape affect wells and streams in the future? The new model incorporates additional geological and water level data. Chippewa County now has a new tool to understand current groundwater conditions and to test hypothetical future scenarios. The final report was published in May 2019 and is available on the Wisconsin Geological and Natural History Survey website.

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.

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.

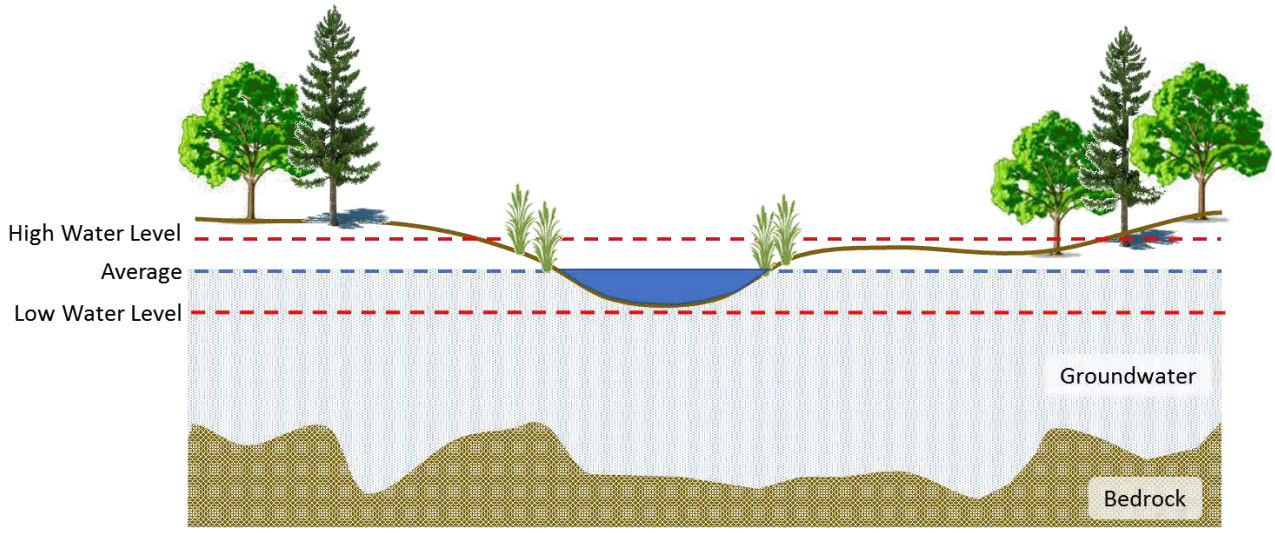
Groundwater level monitoring

The DNR and its partners at the United States Geological Survey (USGS) [exit DNR] and the Wisconsin 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 91 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

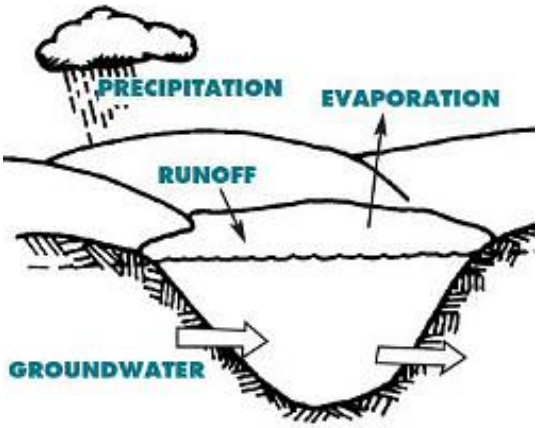
The upper surface of groundwater, referred to as the water table, can fluctuate in response to precipitation events and water withdrawals. During times of drought, local water tables can decline due to decreased recharge and increased water use (e.g. watering lawns, irrigating farm fields, municipal 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.



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

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.

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. As of June 2019, the charts below indicate that most of the state has received well above average precipitation in recent years and groundwater data reflects this trend. Groundwater levels are at or near historic highs throughout the state, which is consistent with groundwater flooding reports received by the department in recent years.

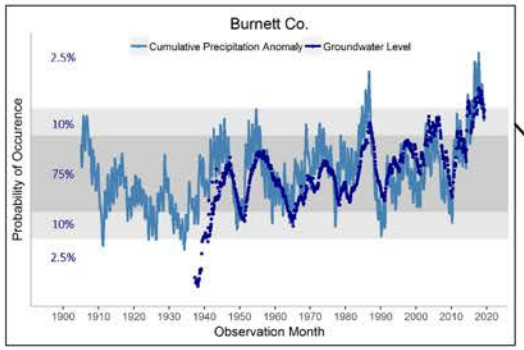
View the regional charts to see the status of water levels as compared to the long-term average, as well as the relationship between precipitation and groundwater below.

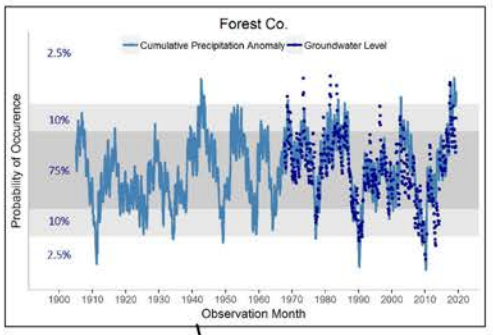
Flooding resources

Recommendations for private wells inundated by flooding

Coping with flooding

Flood insurance


Burnett Co.
Cumulative Precipitation Anomaly
Groundwater Level
Probability of Occurence
2.5%
10%
75%
10%
2.5%
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
Observation Month


Forest Co.
Cumulative Precipitation Anomaly
Groundwater Level
Probability of Occurence
2.5%
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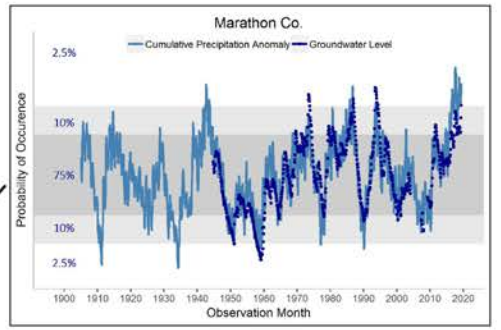
Observation Month


Marathon Co.
Cumulative Precipitation Anomaly
Groundwater Level
Probability of Occurence
2.5%
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10%
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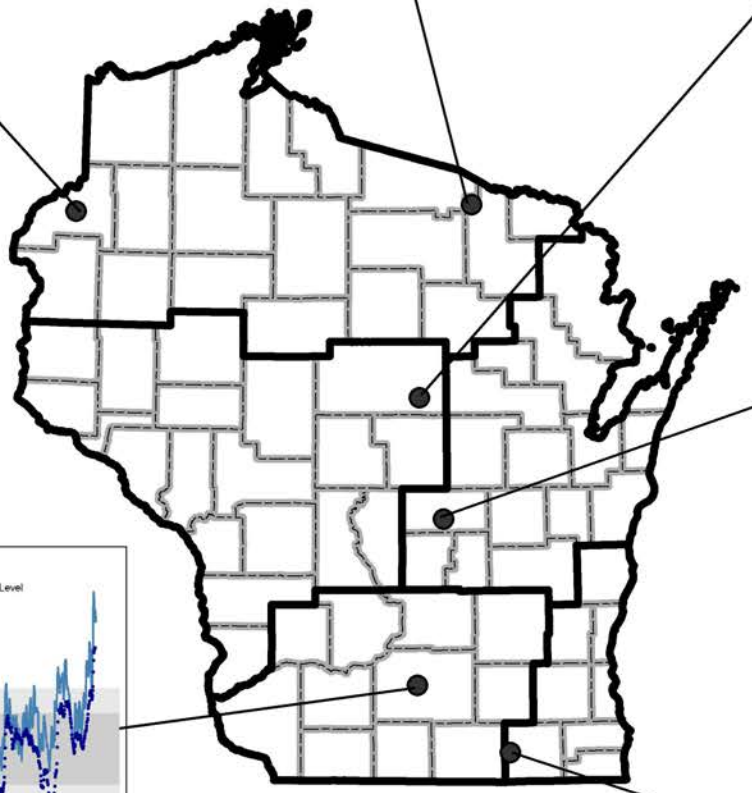
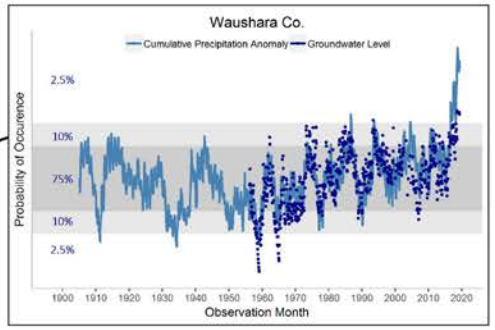
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
Observation Month




Waushara Co.
Cumulative Precipitation Anomaly
Groundwater Level
Probability of Occurence
2.5%
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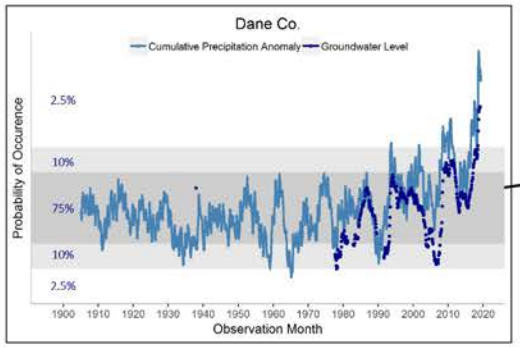
Observation Month


Dane Co.
Cumulative Precipitation Anomaly
Groundwater Level
Probability of Occurence
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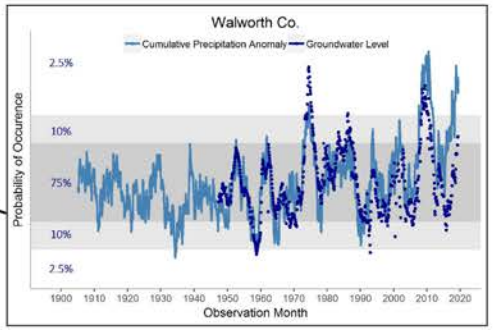
Observation Month


Walworth Co.
Cumulative Precipitation Anomaly
Groundwater Level
Probability of Occurence
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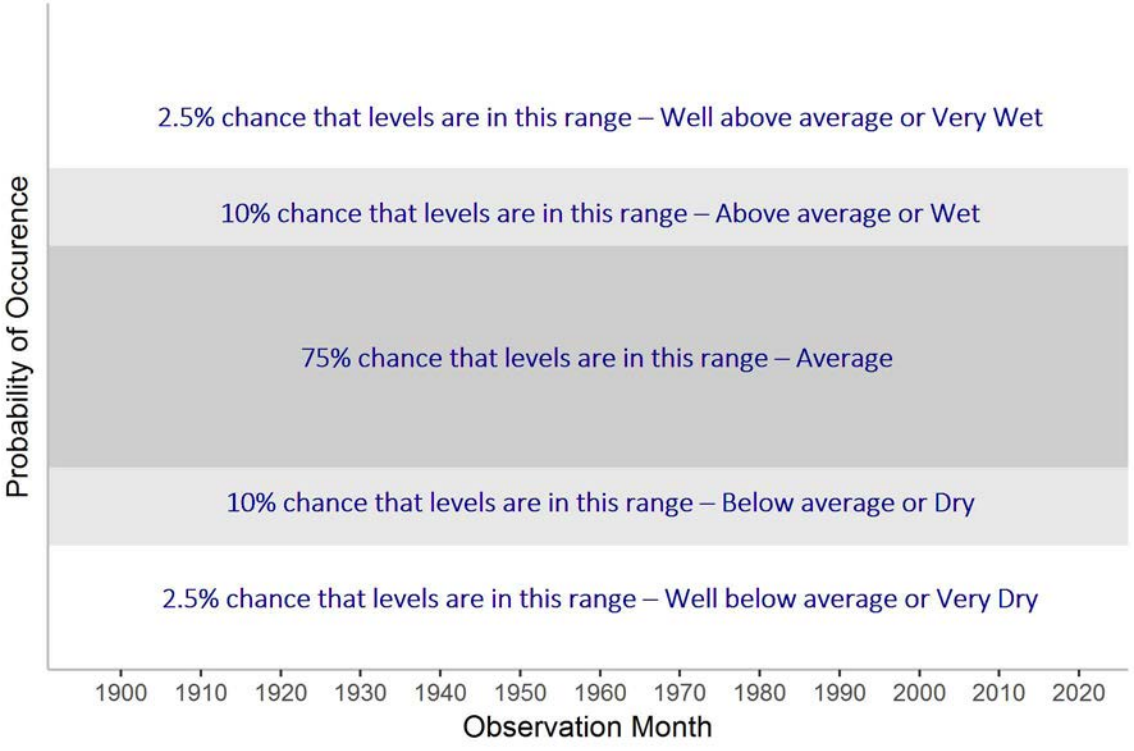
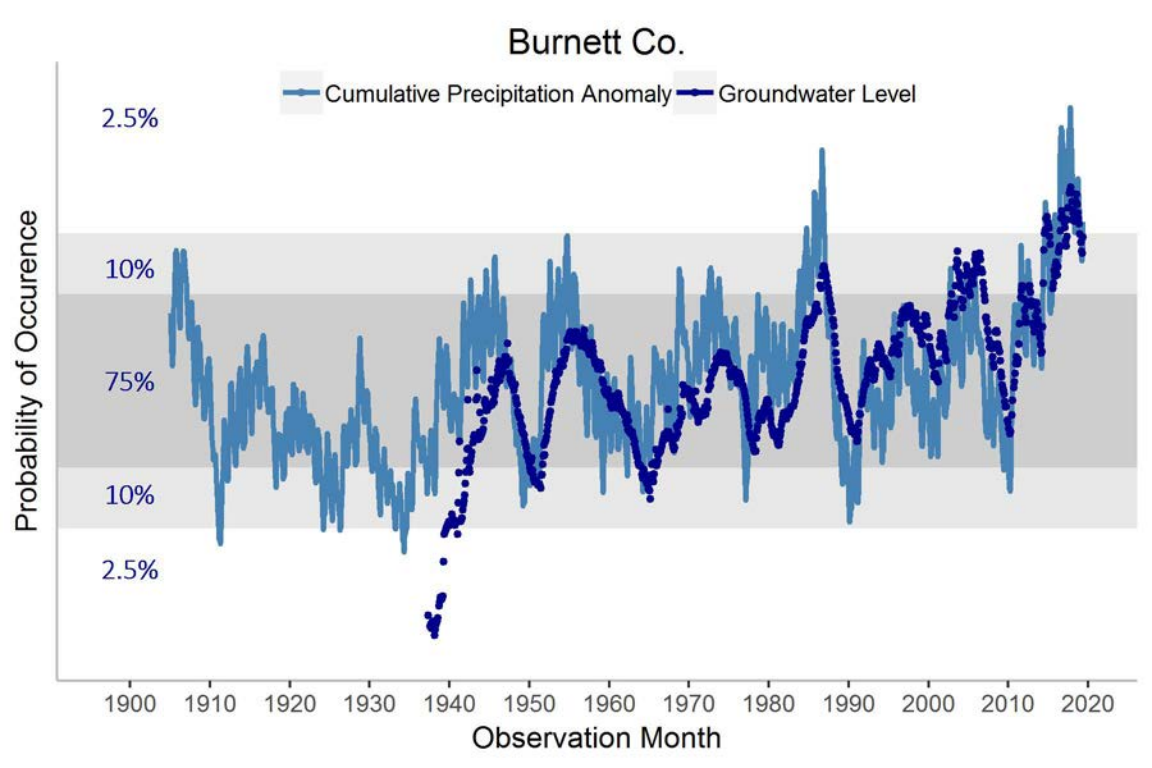
Observation Month


2.5% chance that levels are in this range – Well above average or Very Wet
10% chance that levels are in this range – Above average or Wet
75% chance that levels are in this range – Average
10% chance that levels are in this range – Below average or Dry
2.5% chance that levels are in this range – Well below average or Very Dry
Probability of Occurence
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
Observation Month


Burnett Co.
Cumulative Precipitation Anomaly
Groundwater Level
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Probability of Occurence
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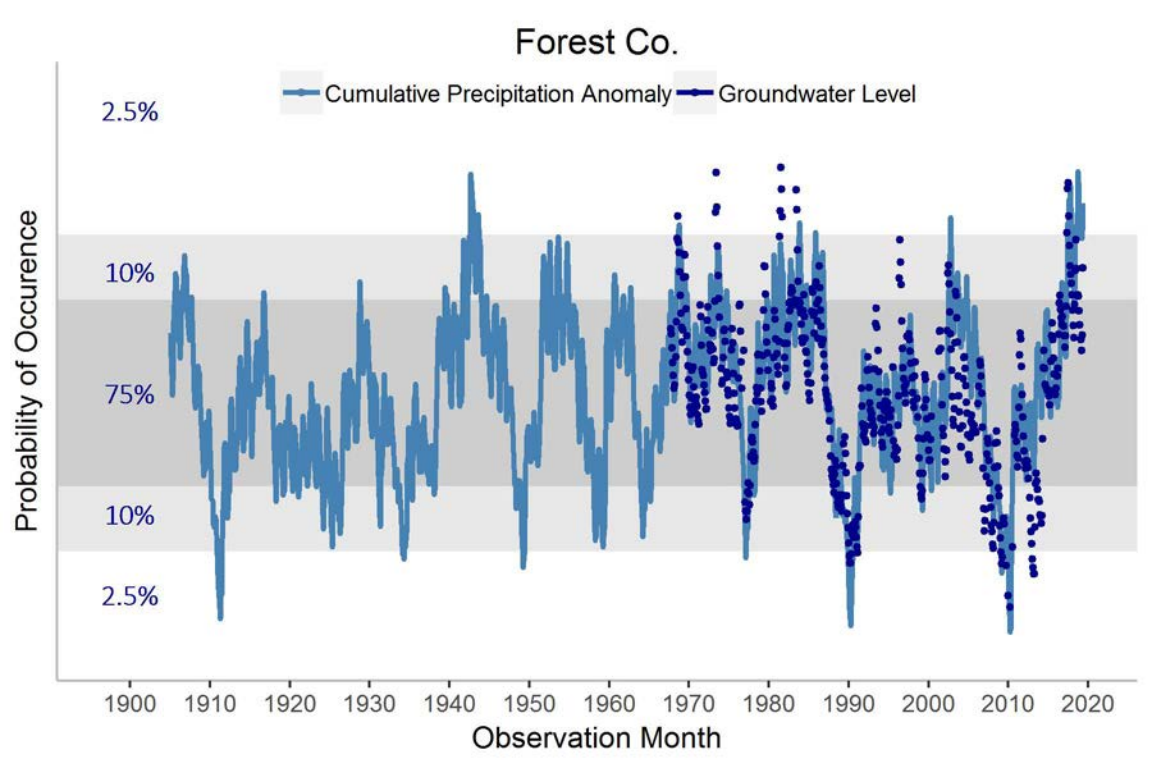
Observation Month


Forest Co.
Cumulative Precipitation Anomaly
Groundwater Level
2.5%
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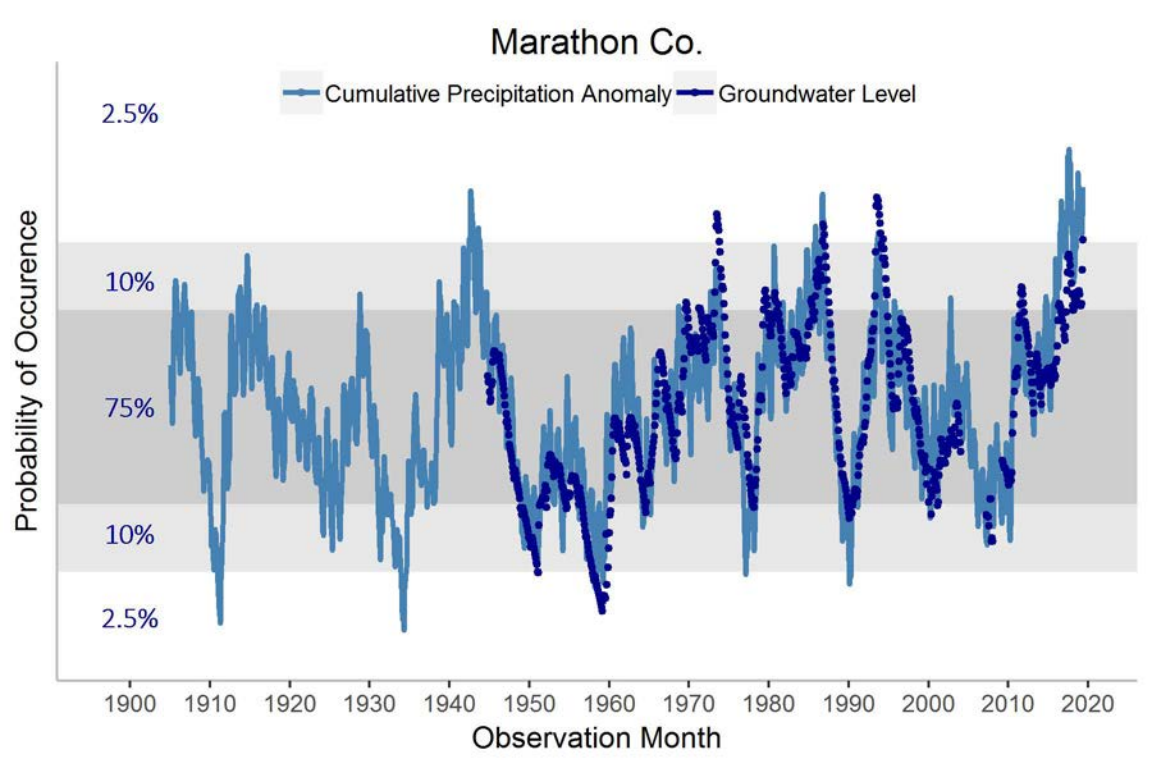
Marathon Co.
Cumulative Precipitation Anomaly
Groundwater Level
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Probability of Occurence
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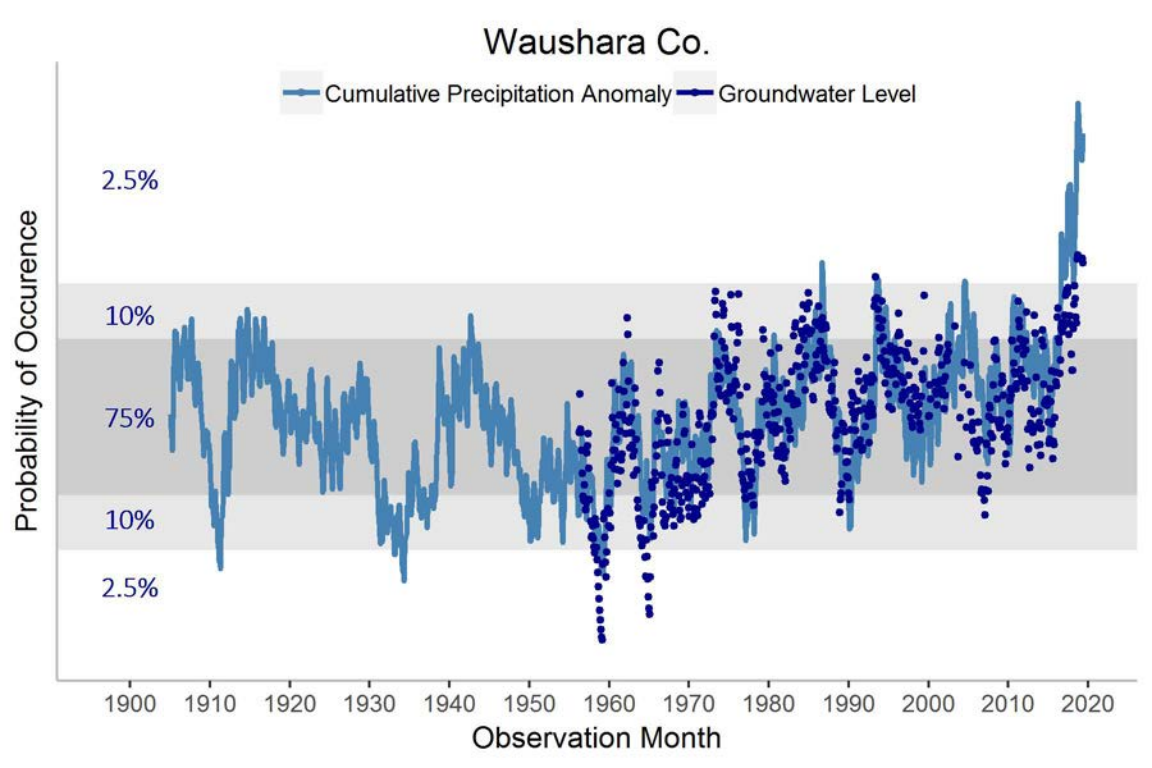
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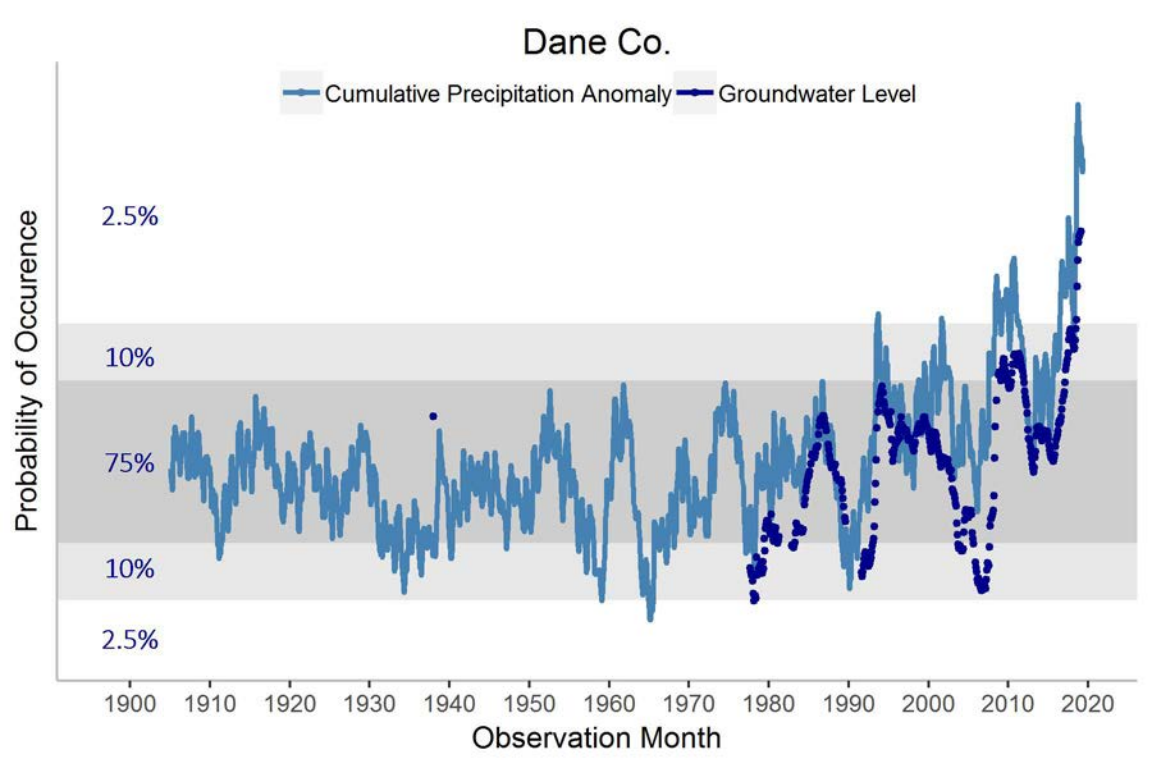
Observation Month


Dane Co.
Cumulative Precipitation Anomaly
Groundwater Level
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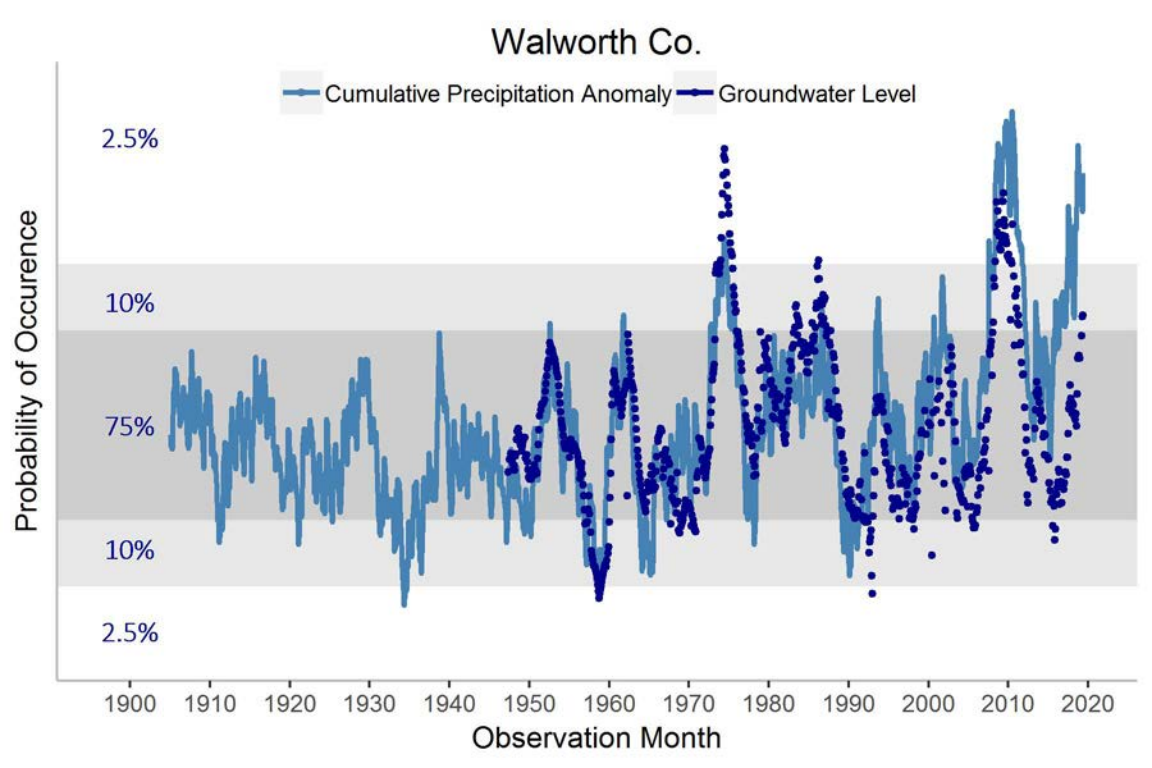
Observation Month


Walworth Co.
Cumulative Precipitation Anomaly
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Probability of Occurence
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Observation Month