Wisconsin Groundwater Coordinating Council

Report to the Legislature

Fiscal Year 2018

2018 GROUNDWATER COORDINATING COUNCIL MEMBERS

Department of Natural Resources – **Patrick Stevens – Jim Zellmer, Chair**
Department of Agriculture, Trade & Consumer Protection – **John Petty- Lori Bowman**
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**

SUBCOMMITTEES

Research & Monitoring

Geological and Natural History Survey - **Madeline Gotkowitz*** (Co-Chair) **and Dave Hart***
Department of Natural Resources – **Bill Phelps***(Co-Chair), **and Shaili Pfeiffer**
Department of Agriculture, Trade and Consumer Protection – **Stan Senger* and Rick Graham***
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University of Wisconsin System - **Paul McGinley*, Maureen Muldoon*, Tim Grundl* and Trina McMahon***
U. S. Geological Survey - **Mike Fienen*, Andy Leaf* and Cheryl Buchwald**
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)
Department of Natural Resources – **Bruce Rheineck** (Co-Chair)
University of Wisconsin System – **Moira Harrington**
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Department of Health Services – **Disa Patel and Sarah Yang**
Geological and Natural History Survey - **Dave Hart and Carol McCartney**
Department of Transportation - **Bob Pearson**
State Laboratory of Hygiene – **Moira Harrington**
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August 31, 2018

To: The Citizens of Wisconsin
The Honorable Governor Scott Walker
Senate Chief Clerk
Assembly Chief Clerk
Secretary Dave Ross - Department of Transportation
Secretary Laura Gutiérrez - Department of Safety and Professional Services
Secretary Sheila Harsdorf - Department of Agriculture, Trade & Consumer Protection
Secretary Linda Seemeyer - Department of Health Services
Secretary Daniel Meyer - 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 2018 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 FY18 (July 1, 2017 to June 30, 2018). 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 titled *Directions for Future Groundwater Protection.* 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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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 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 12 proposals, six new projects were selected for funding in FY18 - three by UWS and two by DNR and one by 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 18th 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 295 groundwater models have been given to schools and nature centers since 2001 and over 650 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 FY18 meetings:

- DNR Per and Polyfluoroalkyl substances (PFAs) occurrence in Wisconsin
- WGNHS, Demonstration of groundwater shoe-box and 3D karst models
- UW-Milwaukee, Anthropogenically driven changes to geochemistry and microbial community composition in a shallow groundwater system
- WGNHS, Distribution and variability of Wisconsin Precambrian bedrock and its impacts on groundwater quality and quantity
- USGS, Regional Variability of Nitrate Fluxes in the Unsaturated Zone and Groundwater in Wisconsin

More information on these topics and the coordinating efforts of the GCC can be found in the FY18 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 FY18. 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 284 public water supply systems (mostly systems like mobile home parks, restaurants and taverns) exceeded the nitrate drinking water standard of 10 mg/L in 2018 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 site specific.

Groundwater pumping issues have arisen in multiple regions of Wisconsin. Large scale drawdowns of the confined aquifer have been previously documented in the Lower Fox River Valley and southeastern Wisconsin. The connection between water withdrawals, surface water and groundwater and surface water has been well-documented in Dane County and areas within Wisconsin's Central Sands. Research continues to better understand site specific water resource vulnerability from groundwater withdrawals.

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 $17 million has been spent over 25 years by DNR, UWS, DATCP, and Commerce on more than 400 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
- Occurrence of radium in municipal wells
- 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

See the "Progress Portfolio" tab in the *on-line report* for more information on how agency collaboration and project results are used to improve management of the state's groundwater resources.

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

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.

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
- Developing soil type specific nitrogen nutrient land application rates and cropping best management practices that minimize nitrogen losses to groundwater
- Encouraging the use of soil type specific nitrogen nutrient land application rates and cropping best management practices, developed to minimize nitrogen losses to groundwater in identified sensitive areas of the state
- Developing educational materials for farmers and Nutrient Management Planners that identify specific alternate cropping and nutrient management practices that could be voluntarily implemented to minimize agricultural nitrogen losses to groundwater

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

Ongoing Recommendations

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 publically-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.

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

Industrial sand mining. Since 2010, unprecedented growth of industrial sand mining and processing has occurred in West-Central Wisconsin and is expected to continue growing for another decade. The potential impact of this industry on groundwater resources has not been comprehensively evaluated, which would be the first step to avoid problems and plan for restoration. Wisconsin should support data analysis and field investigations to understand how this industry might impact groundwater. Agencies should partner with industry and local governments to develop and adapt site analysis and best-management practices for this industry.

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.

Effects of extreme weather. More prolonged drought or heat waves can **i**ncrease groundwater demand at the same time as reducing supply. Groundwater quality may be affected by large fluctuations in water table elevation that can occur with extreme weather. 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. To understand and predict the impact of these changes on the state's groundwater, agencies should develop the data and provide analyses of likely scenarios for quantity and quality of 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.

DNR water supply specialists test a new water supply sampling method 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 from within the water system.

FY 2018 Highlights

- DG staff continue to draft revisions to chapter NR 812, Wis. Adm. Code, which will update well construction standards based on modern equipment and techniques, streamline approval procedures and reflect recent statutory changes. Public hearings on proposed NR 812 revisions are expected in late 2018.
- DNR DG transmitted a list of substances detected in groundwater to DHS for their review to possibly update existing or add new NR 140 health-based groundwater standards.
- DNR committed $120,000 in FY17 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 60 grants to low-income private well owners, providing over $114,000 to help replace contaminated wells or fill and seal unused wells.
- Completion of Springs inventory - WGNHS and Beloit College, in collaboration with DNR, completed a Joint Solicitation Project to update Wisconsin's Spring Inventory. The inventory investigated 1,377 features and provided detailed descriptions of 415 springs in 58 counties in Wisconsin. The project identified the location of springs throughout the state, building upon

historical datasets and current information gathered through stream and wetland surveys. Reference springs were identified as part of this project and will be continued to be monitored. For additional information go to: *https://wgnhs.uwex.edu/water-environment/springs*.

- *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 *http://dnr.wi.gov/topic/DrinkingWater* and *http://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 *http://dnr.wi.gov/topic/Brownfields* and *http://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 *http://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 *http://dnr.wi.gov/topic/Wastewater* and *http://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 *http://dnr.wi.gov/topic/Watersheds*, *http://dnr.wi.gov/topic/SurfaceWater* and *http://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.

Revisions to ch. NR 140 groundwater quality standards were last adopted by the Legislature in 2010. Following the required schedule, DNR has canvassed agencies for new substances that have been detected in or have a reasonable probability of entering groundwater to start the process of determining whether any new or revised standards are needed.

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 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 technical work group on Wisconsin-specific provisions to the NRCS conservation practice standard for agricultural nutrient management (*NRCS Code 590*). All states are

updating their provisions to be consistent with updated federal standards, including revisions related to nitrogen. Participants in federal and some state farm programs, as well as some state permit holders, must comply with the federal conservation practice standards.

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 the Wisconsin Attorney General issued a formal opinion (OAG-01-16) regarding the DNR's authority to consider environmental impacts when reviewing high capacity well applications. The Attorney General 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). The Attorney General 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 the Attorney General, 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 the Attorney General opinion as of June 2016.

- 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, the results of this challenge are pending.

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 (2018)

	Great Lakes Basin	Mississippi River Basin	**Total**
Groundwater	3,617	9,706	13,323
Surface Water	394	676	1,070
Total	4,011	10,382	14,393

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.

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.

Industrial Sand Mining

As noted in previous sections, DNR reviews high capacity wells including those associated with industrial sand mining (ISM) operations in accordance with existing Wisconsin statute and administrative code. Each facility is unique, and each may present potential impacts to proximal water resources. In an effort to better understand the impact of water use related to current and proposed ISM facilities, DNR is working with Chippewa County, the WGNHS and the USGS to model groundwater conditions.

While sand has been mined for industrial use in Wisconsin for over a hundred years, the recent boom in industrial sand mining for use in the energy sector has created regulatory challenges as new programs adjust to a new major industry. Concerns have been raised over potential for contamination from flocculants used during sand processing. DNR is working with Chippewa County as they evaluate potential risks associated with these chemicals. Exploratory boreholes have been found in proximity to ISM facilities that have not been properly filled and sealed, which can create a conduit for contaminants to reach groundwater. DNR is providing technical assistance on a project evaluating potential groundwater quality impacts associated with ISM facilities. The project is focused on elevated concentrations of metals and pH fluctuations in stormwater ponds and will be led by DNR's runoff management program.

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 is underway 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 reflect changes in other statutes and codes.

Advance notification to DNR is required for all new and replacement 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 to observe wells during construction, and reviewing well construction reports and associated sampling results. During the past year, staff conducted over 1000 compliance inspections, and 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. During FY18, DNR re-launched a historic program newsletter called "NewsBits" as a quarterly e-newsletter providing program updates, annual data and compliance reminders.

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. In FY18, DG and RR staff implemented standard procedures to provide temporary emergency water supplies to two private well owners affected by fecal contamination that was suspected to be due to livestock waste. 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 over 1300 individuals as well drillers, heat exchange drillers and/or pump installers each year under ch. NR 146, Wis. Adm. Code. License holders can attend training through multiple training providers. DNR evaluates and approves all continuing education credits to ensure that license holders are qualified to do their work in a way that meets standards and won't contaminate groundwater.

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 quantity, help well owners diagnose their aesthetic water quality problems and provide DNR water supply institutional knowledge. DG and Community Financial Assistance staff issued 60 grants to low-income private well owners across the state in FY18, providing over $114,000 in cost-sharing funds to help replace contaminated wells or to fill and seal unused wells. A 2017 statutory change to section 281.75(7)(a), Wis. Stats., increased the maximum amount of eligible costs for a well compensation or well abandonment grant to $16,000. The state's share is 75%, so this means that eligible grant applicants are now able to receive up to $12,000 in state assistance for each eligible project.

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. A new "*Well Driller Viewer*" tool was launched 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. Initial user satisfaction is high, and enhancements are planned to add data and functionality in FY19. A new Online Well Construction Report (WCR) system

The well driller viewer was launched in 2018.

was released to a pilot group of drillers in May 2018, allowing well drillers to electronically submit well construction reports, and is designed to reduce time and errors for both well drillers and DNR staff. Online WCR will be released more broadly in FY19.

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), 11 communities completed WHP plans this year (4 required and 7 voluntarily).

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, WRWA and other partners are developing and using groundwater monitoring, modelling and related tools in Spring Green, Fall Creek and Waupaca to demonstrate a voluntary community-based approach to rising nitrate levels. The village of Luck, WI 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. Unluckily, several contaminant plumes have the potential to affect the village's two municipal wells.

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 2014, 15% of Wisconsin public water systems were protected by implementation of a WHP plan. In FY14, approximately 20 communities submitted wellhead protection plans to the DNR. Over 400 communities now have a WHP plan for at least one of their wells.

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.

Six *new projects* were selected through the Joint Solicitation process for funding in FY19. Final reports and 2-page research summaries are available for many projects from the *Water Resources Institute website*.

In addition, DNR committed $120,000 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 FY18 WGNHS, with funding from the DNR, will continue 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.

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.

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 co-lead the Interagency Pharmaceutical Waste Working Group, with UW-Extension and diverse 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.

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

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

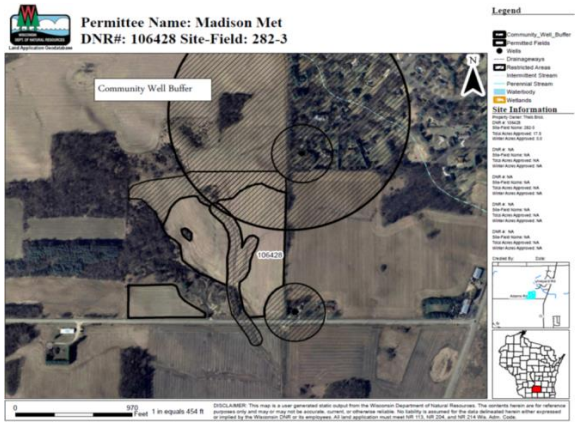
WQ implements the regulations in chapters NR 113, NR 204, and NR 214, Wis. Adm. Code. NR 113 relates to septage management and ch. NR 204 governs the treatment quality, use and disposition of municipal wastewater treatment plant sludge. Ch. NR 113 and ch. NR 204 incorporate federal septage and sludge 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.

Agricultural runoff and groundwater quality

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 ch. 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 Working Lands 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.

DNR promulgated a revised ch. NR 151 performance standard, which will require DATCP to amend ATCP 50 and 51, via rulemaking. Changes included in the ch. NR 151 revisions may impact nutrient management plan development and implementation. These changes include: TMDL's; soil erosion and pastures; tillage setback; phosphorus index; process-wastewater discharge prohibitions; nutrient management plan clarifications on municipal sludge, industrial waste or septage; and an explanation on how these sources may impact nutrient management plans. The DNR has also provided comments to DATCP to help make implementation of ch. NR 151 more consistent across the state.

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 2018 Highlights

- Awarded grants to 11 producer-led groups for FY 2017 funding and grants to 19 producer-led groups for FY 2018 funding through the Producer Led Watershed Protection Grant program.
- Published the results of the most recent statewide statistical sampling survey of pesticides and nitrates in private wells that included testing for 100 pesticide compounds.

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 is intended to protect both groundwater and surface water and lays out the process by which DATCP identifies the practices and procedures for implementing and enforcing compliance with the agricultural performance standards, including nutrient management. In 2005, DATCP adopted the USDA-NRCS 590 Nutrient Management Standard via administrative rule, ATCP 50, to meet DNR's nutrient management performance standard.

A Wisconsin nutrient management (NM) plan is an annually updated record that follows NRCS's 590 Nutrient Management Standard. A NM plan accounts for all nitrogen, phosphorus, or potassium (N-P-K) nutrients applied, and planned to be applied, to each field over the crop rotation, as well as all crop management practices utilized. Soils need to be tested by a DATCP certified laboratory every 4 years, with each field sampled every 5 acres. A NM plan manages nutrient applications to maximize farm profitability while minimizing degradation of both surface water and groundwater.

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 are either:

- 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.

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. Nutrients are managed according to:

- Soil nutrient reserves (soil test)

- Current crop and yield
- Previous crops and yields
- Soil types (e.g. sand, loam, clay)
- UW's recommendations for each crop and soil type
- Current and previous manure and fertilizer applications
- Location of potential surface or groundwater conduits
- Soil temperature
- Irrigation practices
- Draining/tiling practices
- Field slope
- Season (e.g., winter)
- The Phosphorus Index

The NRCS 590 Nutrient Management Standard was updated in 2015. This update was made mainly to address winter spreading risks, groundwater protection and improved management of nitrogen. Previously, the 2005 590 Standard focused on reducing the phosphorus losses to surface water systems but now addresses more loss pathways. A few of the new requirements that will further protect groundwater quality:

- Show adequate acreage and a winter spreading plan for all farms with mechanically applied manure or organic by-products.
- Account for N and P_2O_5 deposited by pastured or gleaning animals.
- Applications are prohibited on:
    - Concentrated flow channels; surface water; saturated soils; areas of active snow melt where water is flowing; land where vegetation is not removed.
    - Direct conduits to groundwater, a potable well, or within 8 feet of irrigation wells.
    - Areas near public water supplies within 1,000 feet of a community potable water well; or areas within 100 feet of a non-community potable water well (church, school, and restaurant) unless manure is treated to substantially eliminate pathogens.
    - Areas locally delineated by the Land Conservation Committee or in a conservation plan as areas contributing runoff to direct conduits to groundwater unless manure is substantially buried within 24 hours of application.
- Limits on surface applications in Surface Water Quality Management Areas and over subsurface drainage.
- Additional limits for manure applications on frozen or snow-covered soils:

  - No applications in areas where DNR Well Compensation funds provided replacement water supplies for wells contaminated with livestock manure or where Silurian dolomite is within 60 inches of the soils surface.
  - No applications of manure within 300 feet of direct conduits to groundwater.
- Fertilizer applications on N restricted soils that include high permeability soils (P), or rock soils with less than 20 inches to bedrock (R), or wet soils with less than 12 inches to apparent water table (W):
  - Or if the soil depth is less than 5 feet over bedrock or the area is within 1,000 feet of a community potable water well, no commercial N applications in late summer or fall (exclusions apply).
  - Spring applications of N cannot exceed the crop recommendations of all N sources and on highly permeable soils additional N strategies must be followed to slow the release (i.e., inhibitor, controlled release fertilizers) or minimize the amount spread at once (i.e., split applications).
- Manure sources of nitrogen need to minimize the amounts spread on P, R, and W soils in accordance with the soil types, the amount of dry matter in the manure, the date and the soil temperature in order to decrease losses.

The 2005 590 Standard did include a number of practices to protect groundwater from the impacts of nutrient applications and these provisions still need to be met under the new standard, such as:

- Nutrient and manure application setbacks from karst features and other conduits to groundwater.
- Nutrient applications must meet University of Wisconsin recommendations for crop production.
- Application prohibitions or restrictions in waterways, Surface Water Quality Management Areas (SWQMA's), slopes in winter, buffers, fields exceeding tolerable soil loss, and non-cropped fields.
- Irrigation management (inhibitors and split applications).

Like other agricultural performance standards, the nutrient management standard is "designed to achieve water quality standards by limiting nonpoint source water pollution" (Ch. 281.16 (3), Wis. Stats 'Nonpoint sources that are agricultural'). Requiring applications of nitrogen to meet University of Wisconsin recommendations for crop production, in conjunction with the other practices listed above, is meant to limit non-point pollution of groundwater. Currently, 36% of agricultural land in Wisconsin is covered by an approved nutrient management plan (Figure 1).

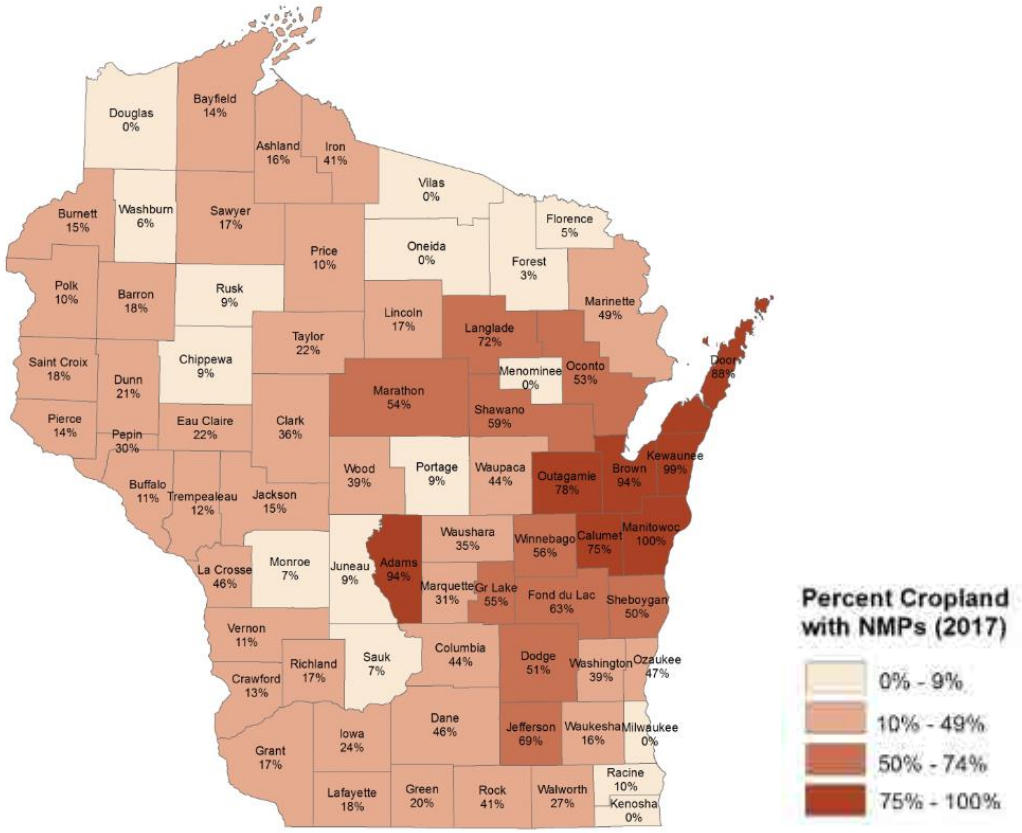


Figure 1. Percent of each county's cropland with a nutrient management plan in 2017 (calculated from county reported acres and 2012 National Agricultural Statistics Service of Wisconsin county cropland).

Increasing attention on the role of land use practices in achieving water quality goals was recognized in the 2008-2009 state budget. Funding for the land and water resource management program's cost-share allocation increased from $520,000 to $6.5 million in the second year of the 2008-2009 biennium, and although not maintained at those levels, cost-share funding has continued to remain in the $2-3 million range each of the subsequent biennium.

The allocation of DATCP's annual appropriation in the 2015-17 budget of $2.5 million in SEG funds "for cost-sharing grants and contracts under the soil and water resource management program under s 92.14", providing $1,735,000 to counties for landowner cost-sharing, $175,000 to fund grants for farmer training (Nutrient Management Farmer Education grant program), and $604,000 awarded to supporting partners, including UWEX/CALS, which includes SnapPlus software support in addition to outreach and education support.

DATCP's annual appropriation in the 2015-17 budget of $3,027,200 in GPR funds and $5,711,900 in SEG funds "for support of local land conservation personnel under the soil and water resource management program." DATCP has no underspending from prior years that might be added to the funds appropriated for this allocation. 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. DATCP's 2017 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 2017.

Funding Category	Total Requests	Unmet Requests	Final Allocations
County Staff/Support	$16,316,881	$7,577,781	$8,739,100
County LWRM Cost-Share (Bond)	$7,806,000	$4,491,000	$3,315,000
Bond Cost-Share Reserve (Bond)	$350,000	$0	$350,000
LWRM Cost-Share (SEG)	$2,560,940	$825,005	$1,735,935
Project Contracts (SEG)	$854,281	$249,295	$604,986
NMFE Training Grants (SEG)	$175,814	$0	$175,814
Total	**$28,063,916**	**$13,143,081**	**$14,920,835**

The majority of SEG grant funding directly benefits farmers by providing either cost-sharing or training. By dedicating a small portion of the SEG funds for support of projects focusing on training, outreach, and other DATCP priorities, DATCP is enhancing the statewide infrastructure fundamental to implementing state conservation activities, most importantly nutrient management planning.

In 2016, total requests from counties for SEG funds exceeded available funds by $990,000 and in 2017 it was $825,000. The lack of sufficient funds has practical implications for our capacity to implement state and local priorities, including newly added farm runoff standards, and may impact conservation compliance efforts for farmers' participation in the Farmland Preservation Program.

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. The 2008-2009 state budget first allocated funds to DATCP for the creation of a Manure Management Advisory System (MMAS). This system is currently focused on helping 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. In order to accomplish this goal, web-accessible tools have been developed, 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. Developed with inter-agency collaboration, the RRAF model was validated against both edge-of-field observed runoff as well as small USGS gauged basin response. The model is updated three times daily and is hosted on the DATCP website. The encouraging results from this first-generation tool are aiding State of Wisconsin officials in increasing awareness of risky spreading conditions to help minimize contaminated agriculture runoff from entering the State's water bodies.

The 590 Restriction maps have been 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. This tool allows plans to be written and updated faster and more accurately using better information that is updated at least annually and also provides a better user experience by making data management easier.

Through these combined efforts, the total number of acres covered by over 7,700 nutrient management plans statewide in the 2017 crop year rose to over 3.3 million acres, see Figure 2.

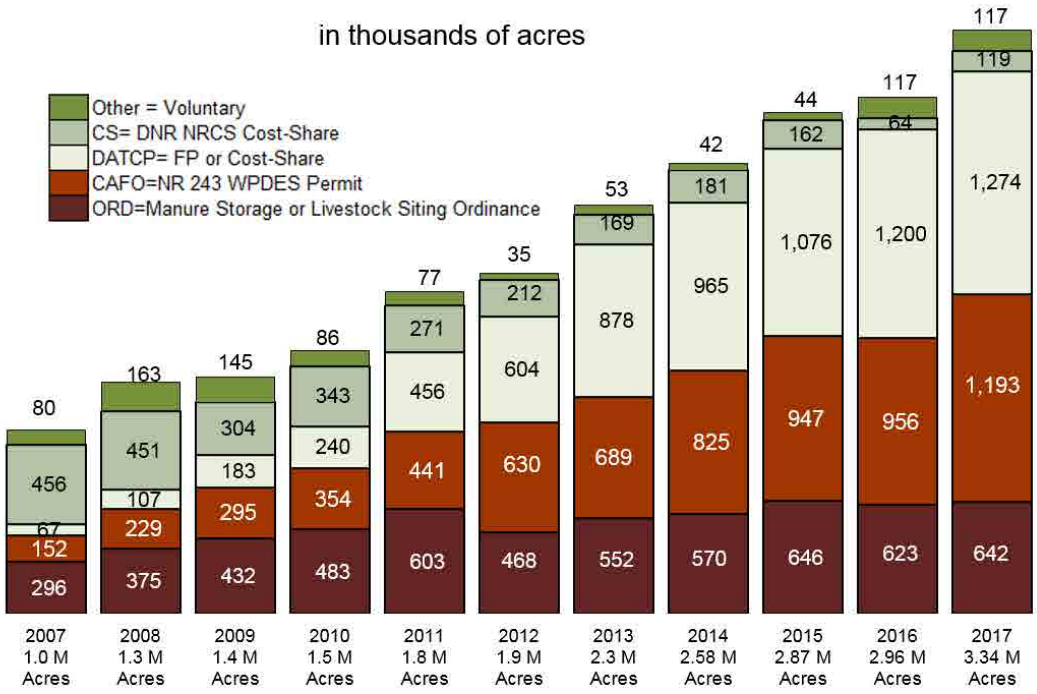


Figure 2. Acreage trends in nutrient management as reported to DATCP. Taken from DATCP's annual nutrient management report: *https://datcp.wi.gov/Documents/NMUpdate2017.pdf*

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 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. Seventeen groups were awarded the full $250,000 for 2018 funding. Due to overwhelming interest for the 2018 grants, the legislature increased program funding for the 17-19 biennium by $500,000 for a total of $750,000 (see Figure 3). Because of this, DATCP was able to instead award 19 groups $558,246 for 2018 grants. This financial incentive, combined with the requirement of working closely with neighbors and local conservation groups, will allow those most intimately involved with the local soil and water issues to tailor the best possible solutions to their unique, local challenges in a way that statewide requirements cannot.

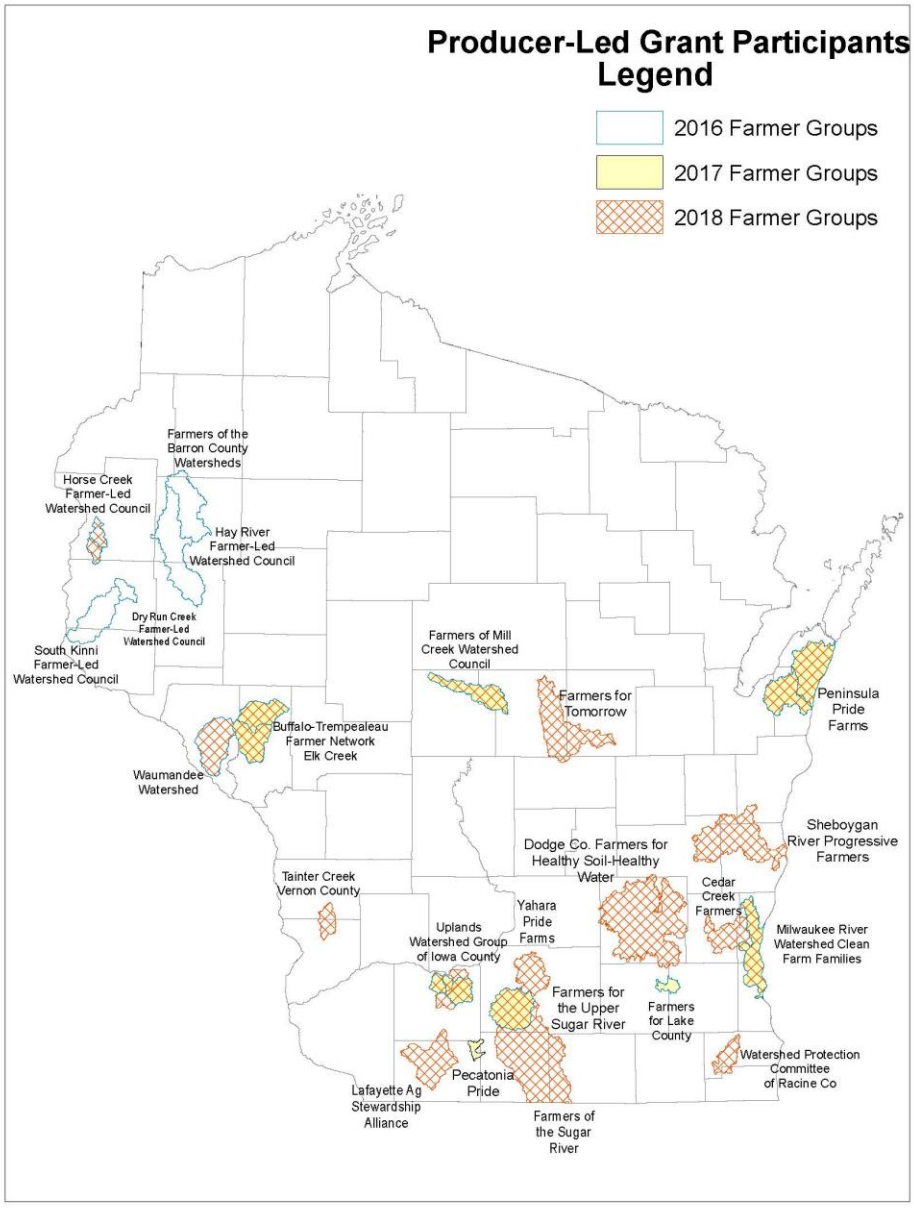


Figure 3. The location of the 2016-2018 producer-led watershed initiatives that were awarded a DATCP grant.

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 2017, 92 grants were issued: 27 for agricultural waste, 33 for household hazardous waste and 32 for the collection of unwanted prescription drugs. There were 864 farmers and 7 agricultural businesses that brought in nearly 141,000 pounds of agricultural waste, 17% more than 2016. Farm participation can vary greatly depending on the weather or the frequency of collections within a county. Some counties may not hold a farm collection each year, preferring to do it every other year or every few years. Farm participation seems to be holding steady overall, ranging between 100,000 and 150,000 pounds in recent years. However, many counties have been reporting declining collections as more farmers are using custom application and products are becoming more concentrated. Much of the old stockpiled pesticides from years ago 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 continues to increase. More than 2.2 million pounds were collected in 2017 from just over 65,000 residents. Lead and oil-based paints are the most common waste collected from households. In 2017, slightly more than 811,000 pounds were taken in for disposal. The next category is solvents and thinners with nearly 317,000 pounds. Pesticides are the third-most collected waste with nearly 309,000 pounds. Drug collections netted almost 40,000 pounds of unwanted pharmaceuticals, a decline of about 5,000 pounds. This could be attributed to a few grant recipients electing not to claim their reimbursement because their costs were lower than anticipated so no collection amounts were reported. Another group of grant recipients purchased drug drop boxes so no collection amount was reported. Prescription drugs were collected through collection events or through permanent drug drop boxes located in police stations throughout Wisconsin. Despite the decline in the amount of unwanted prescription drugs collected through Clean Sweep supported projects, Wisconsin overall collected and disposed of nearly 127,000 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 has conducted a number of annual surveys to investigate the occurrence of pesticides in groundwater resulting from nonpoint sources. In 2016, the agency conducted a statistically random sampling survey of private wells statewide. The results of the survey were published in early 2017, providing a comparison of pesticide and nitrate results to earlier statewide random surveys, the last of which was published in 2008. Publications of these surveys are available on DATCP's web site at: *https://datcp.wi.gov/Pages/Programs_Services/GroundwaterReports.aspx* .

Research Funding

Due to budget constraints, DATCP did not have funding for new pesticide research projects in FY 2017, but intends to fund a research project in 2018 that will evaluate lawn care pesticides in groundwater in the Milwaukee metropolitan area. DATCP currently funds fertilizer research at approximately $200,000 per year.

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 that allows the user to search the database and plot maps that show data located within a user-defined geographic area. The database was placed on-line in early 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:
Visit the following web site (http://www.datcp.state.wi.us/)
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2811 Agriculture Drive, PO Box 8911
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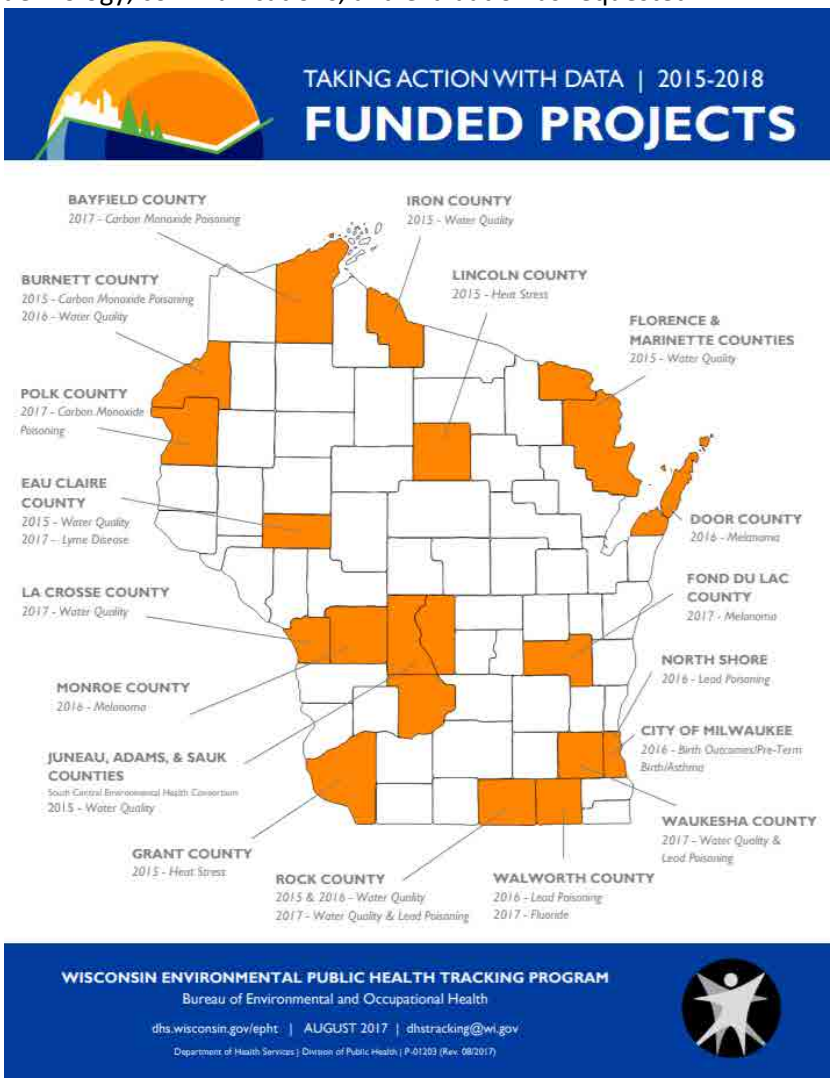
DEPARTMENT OF HEALTH SERVICES (DHS)

FY2018 Highlights

- 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 2017, one local public health agency (LPHA) completed a project related to nitrate in drinking water with a mini-grant from the. Along with providing funding, Tracking staff offered the mini-grantee connection to subject matter experts and provided technical assistance related to epidemiology, communications, and evaluation as requested.



- In FY2018, multiple DHS programs have provided health education and information dissemination related to several groundwater contamination sites in Wisconsin, including one in which perfluorinated compounds (PFCs) have been found in private wells in Marinette County. DHS toxicologists and public health educators have characterized health risks from the PFCs, participated in technical discussions, and shared these findings in public meetings to help address health concerns regarding the contamination.

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 Department of Natural Resources (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, and the contaminants 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 Wisconsin Department of Natural Resources (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 26 substances. DHS is reviewing available scientific information regarding the health effects of these substances to use in the development of the standards.

New Substances

- Chromium, Hexavalent
- Strontium
- Thiamethoxam
- Imidacloprid
- Clothianidin
- Isoxaflutole
- Isoxaflutole DKN degradate
- Isoxaflutole BA degradate
- Dacthal TPA & MTP degradates
- Glyphosate

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
- Cobalt
- Barium
- 1,4-Dioxane

- Glyphosate AMPA degradate
- Sulfentrazone
- Bacteria, *Escherichia coli* (*E. coli*)
- Perfluorooctanoic Acid (PFOA)
- Perfluorooctane Sulfonate (PFOS)
- Bacteria, Total Coliform

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. Such incidents often generate public interest, especially with respect to the immediate local public health response.

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 and/or accidents. One example of this effort is a project that DHS is working on with the DNR and Marinette County Public Health Department assessing health risks from PFC groundwater contamination in the Town of Peshtigo.

Increasing the Availability and Accessibility of Data and Information on Private Well Water Quality
As a state partner in the Centers for Disease Control and Prevention's (CDC) Tracking network, DHS continually seeks to expand the availability and accessibility of data on environmental exposures and environmentally related diseases. To this end, the Tracking program has worked with the University of Wisconsin–Stevens Point (UWSP) and the Wisconsin Association of Local Health Departments and Boards (WALHDAB) to support expansion of UWSP's Private Well Water Viewer to summarize and visualize data from LPHA water testing laboratories. Partnership with UWSP and WALHDAB has resulted in the addition of data from the Eau Claire City-County Health Department on the UWSP data portal. It is anticipated that other local laboratories will make their data available on this platform to support well testing and community health assessment.

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 projects related to contaminants in groundwater that are described 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 concludes on July 31, 2018, they will offer 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 CDC, works to enhance statewide capacity to prepare for and respond to the public health impacts of extreme weather events, 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 profoundly 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 the CHP Wisconsin Climate and Health Adaptation Plan, WEM's Wisconsin Hazard Mitigation plan, and LPHA and local emergency management planning processes.

CHP is currently working on three flood-related vulnerability intervention 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:

- The Flood Resilience Map (FRM), currently in the second phase of development, provides an online user-friendly interface for assessing a community's risk and vulnerability during a flooding event. This tool, once completed, will help local emergency management, local emergency preparedness, and LPHAs plan for and prepare for flooding events, as well as inform future educational dissemination projects designed for private well owners in vulnerable areas.
- 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.

In addition to these activities, CHP continues to investigate climate and extreme weather impacts on groundwater resources, including changes to groundwater quality and quantity, climate indicators related to water supplies, and climate-related health impacts on residents who rely on groundwater resources for drinking water.

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 decommissioned 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.

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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.

We are partnering with The Nature Conservancy to collect the data that is critical for building a groundwater model of a priority wetland near Lulu Lake in the Mukwonago basin. *Photo: David Hart, WGNHS*.

FY 2018 Highlights (see *http://wgnhs.uwex.edu/2017-year-in-review/*)

- Completing an inventory of the springs of Wisconsin
- Studying the potential impacts to groundwater resources from industrial sand mining and irrigated agriculture in Chippewa County
- Completed a hydrogeologic characterization for the Town of Lincoln, Kewaunee County
- Investigated changes in nitrate concentrations in groundwater beneath agricultural fields
- Conducted new geologic mapping in Dodge, Trempealeau, Sauk, and Waushara Counties
- Investigations of groundwater-surface water relationships in Wisconsin streams, lakes, and wetlands
- Completed a study of geologic sources of radium in groundwater in south-central Wisconsin

Details of Ongoing Activities

Groundwater-Level Monitoring Network

The Wisconsin groundwater-level monitoring network has been operated jointly by the WGNHS and the U.S. Geological Survey (USGS) since 1946. The network provides a consistent, long-term

record of fluctuations in water levels in shallow and deep aquifers. 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 routinely used in the development of regional groundwater flow models.

In spring 2017, a "Core Network Plan", developed by the DNR with input by the USGS and WGNHS, clarified priorities and responsibilities, and assures ongoing funding for continued operation, maintenance and management of the network. The DNR and USGS now lead the operation, maintenance and management of the groundwater-level monitoring network, with the WGNHS contributing in-kind support.

During FY 2018, the WGNHS took the lead in a number of areas to enhance and improve the network. In fall 2017, the WGNHS published Open-File Report 2017-04 documenting repairs made to seven network wells as part of a National Ground Water Monitoring Network–funded grant through the USGS.

In November 2017, the WGNHS submitted an application to the USGS for a 2-year grant for funds to repair 17 additional wells, abandon and replace three wells, and install one new well; if approved, work would begin in FY 2019.

The WGNHS continues to support the evaluation and maintenance of the monitoring network, aids in data collection, interpretation, and provides information to public and private clients. Visit the website at: *http://wgnhs.uwex.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 2017 in eight counties. Many of these studies will generate or have generated *water-table maps* or depth-to-bedrock maps.

- ***Bayfield County water-table map and water well database.*** 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 early 2019, and staff have compiled interim products here: *http://wgnhs.uwex.edu/pubs/wofr201702/*.
- ***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 effort is anticipated to be released in late 2018. (Early on in the project we developed a *4-page fact sheet* describing the study's goals and timeline.)
- ***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 will determine 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.
- ***Hydrogeologic characterization of the Town of Lincoln, Kewaunee County*.** This two-year study was funded by the Town of Lincoln (Kewaunee County) and resulted in the publication of a series of hydrogeologic maps including depth to bedrock, depth to water table, water-table elevation, groundwater recharge, groundwater contaminant susceptibility, and catchments and closed depressions (*WGNHS Open-File Report 2017-05*). We supported this work through educational opportunities such as Farm Tech Days in Kewaunee County in July 2017 as well as a number of outreach events to the Town of Lincoln, Kewaunee County officials and the DNR. The WGNHS continues to advise stakeholders about this study and ongoing groundwater issues in Kewaunee County.
- ***Establishment of a groundwater-level monitoring network in central Trempealeau County***. In cooperation with the University of Wisconsin–Eau Claire, this project was funded by Trempealeau County and led to the deployment of four Wellntel monitoring units in the vicinity of the Town of Lincoln (Trempealeau County), near the cities of Blair, Whitehall and Independence. The network was in place by the summer of 2017 and the WGNHS provided educational programming and continued support to help the county assume the ongoing operation, maintenance and management of the network.

- ***Bedrock geology of Trempealeau County.*** With cooperative funding from the USGS STATEMAP program, the WGNHS completed a new map of the bedrock geology of Trempealeau County.
- ***Bedrock geology of Dodge County.*** With cooperative funding from the USGS STATEMAP program, the WGNHS is conducting new mapping of the bedrock geology of Dodge County. This work is scheduled for completion in FY2019.
- ***Bedrock geology of Fond du Lac County.*** The WGNHS is completing new mapping of the bedrock geology and depth to bedrock of Fond du Lac County. These maps are in the final stages of publication and should be released during 2018.

Regional Groundwater Studies

Regional groundwater studies usually span multiple counties. During 2017 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 is scheduled for publication in 2018.

Chequamegon-Nicolet National Forest. *Photo: Ken Bradbury*

- ***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 2017 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.
- ***Groundwater/surface water interactions in the Marengo watershed in the Chequamegon National Forest.*** Water temperature is important to the health and

habitat of a stream. 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. That 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.

- ***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.

Groundwater Data Management and Support

In 2017 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 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.
- ***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.
- ***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.

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. WGNHS produces and serves as a distributor of many groundwater educational publications from our sales counter at our office and from our *website*. 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 Farm Technology Days, at the Wisconsin State Fair, at various museums and schools, and at UW-Madison outreach events (such as at Science Expeditions and at the Science Festival).

In 2017, 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 provided groundwater education at several public meetings in Kewaunee County in 2017, and provided seminars in karst geology and groundwater quality in Iowa and Lafayette 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.

Multiple WGNHS staff members gave presentations at the Wisconsin Society of Science Teachers conference helping to increase our efforts to reach teachers in 2018. Additionally, our 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.uwex.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 69 rest area and seasonal waysides. Other DOT groundwater related activities or assistance include: hazardous material investigation or remediation; wetland compensation; storm water management; and groundwater level monitoring points for the Wisconsin Groundwater-Level Monitoring Network at several locations.

FY 2018 Highlights

- Equipped county trucks that work on the state highway system with AVL/GPS equipment to better track salt usage across the state.
- Provided customized forecasts using an advanced Road Weather Information System based on pavement and weather sensors for 68 sites across the state.

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 that 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 1,210 salt storage site locations listed in the database with a total of over 2,600 buildings, 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 68 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

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, two counties benefited from the efficiencies of route optimization where trucks are strategically routed based on the location of the shop, the salt supply and fuel locations. Currently there are 27 more counties set to attempt route changes for next winter based on a uniquely designed map for each of those counties. The newest DOT initiative in winter maintenance is called "Liquid Only Routes" (LOR). Two counties tested LORs this past winter where they rarely put rock salt on the road. Instead they used brine or brine mixtures behind the plow to keep the snow from sticking to the road between plow cycles. These pilot LORs indicate that about 50% less salt can often be used and still achieve the "time to bare/wet" goals. Next winter more Liquid Only Routes will be tested on more state highway routes. DOT winter response performance measures can be found at this webpage link:

http://wisconsindot.gov/Pages/about-wisdot/performance/mapss/goalmobility.aspx.

For more information

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

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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. On average, four projects through the Institute are funded 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 University of Wisconsin-Extension's Central Wisconsin Groundwater Center*, the *University of Wisconsin Environmental Resources Center*, *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 2018 Highlights

One of the research projects supported by this program is exploring groundwater and nutrients in a fen ecosystem. Photo: Sara Stathas.

- Provided UWS funding to six research projects focused on groundwater microbiology and geochemistry, groundwater-surface water interactions, new monitoring techniques, and various groundwater contaminants, including radium, and supported students at UW-Milwaukee, UW-Madison, UW-Extension, and UW-Platteville.
- Coordinated the Request for Proposals and the review process for the FY19 Joint Solicitation for the Wisconsin Groundwater Research and Monitoring Program.
- Supported a full-time state Water Resources Science-Policy fellowship in partnership with the Wisconsin Department of Natural Resources and placed a postdoctoral fellow at the agency.
- 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, Wisconsin Department of Natural Resources,

Wisconsin Geological and Natural History Survey, and the U.S. Geological Survey's Wisconsin Water Science Center—to stage the 2018 event that attracted about 200 people, including resource managers, researchers, 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.
- Revised the 10-years-old outdated *WRI website* using a modern platform to better serve our audiences.
- 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. There were about 17,000 online visitors to the newsletter in the last year. Plans are in place to increase subscribers. These include signing up more people at events, using contests as an incentive, and stepped up solicitation through the website.

The Wisconsin Water Library's Senior Special Librarian Anne Moser shares a baby lake sturgeon with young children as part of a yearlong engagement with this Shorewood class to explore watersheds. In-person events like this, many geared toward K-12 students, reached nearly 1,600 people in the last year.

- Supported the production of 29 final project reports, 14 theses, and 62 peer-reviewed publications over the past five years.
- Conceptualized and carried out three public events exploring the intersection of water science, fish and the arts—two in Fond du Lac and one in Madison. The events attracted about 50 people.
- 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. In this reporting period, more than 250 students were exposed to the kits and their teaching.

Research

The WRI research portfolio 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 FY18 included research focused on groundwater microbiology and geochemistry, groundwater-surface water interactions, new monitoring techniques, and various groundwater contaminants, including radium.

The Groundwater Coordinating Council's research efforts touch all corners of the state. Here, University of Wisconsin-Madison Ph.D. student Dom Ciruzzi is charting the effect of trees on water levels in the Central Sands area. With the region's numerous high-capacity wells pulling the water from aquifers researchers also want to know what other factors are affecting the dropping amount of water. Photo: Sara Stathas.

During FY18, the WRI directed a wide-ranging program of priority groundwater research consisting of four new projects and two 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, UW-Extension, and UW-Platteville. Groundwater issues investigated during the past year included:

- Linking groundwater and nutrients to monitor fen ecosystems using airborne imaging spectroscopy. Eric Booth, Steven Loheide, UW-Madison. (new)
- Historic changes in groundwater use by trees in Wisconsin due to high-capacity groundwater pumping and climate variability. Steven Loheide, UW-Madison. (new)
- Mapping the base of the Cambrian aquifer through geophysical modeling of Precambrian topography, southern Wisconsin. Esther Stewart, Madeline Gotkowitz, UW-Extension. (new)
- New proxy-based hydrological reconstructions over the past five centuries in southwest Wisconsin. Christopher Underwood, Evan Larson, UW-Platteville. (new)
- Anthropogenically driven changes to the metagenome of a shallow groundwater and its effect on aquifer reactivity. Tim Grundl, Ryan Newton, UW-Milwaukee. (continued)
- Geologic sources of radium to municipal wells in Wisconsin. Matthew Ginder–Vogel, Madeline Gotkowitz, UW-Madison and UW-Extension. (continued)
- Engaging stakeholders to improve the use of groundwater flow models for decision making. Kenneth Genskow, Kenneth Bradbury. UW-Madison and UW-Extension. (continued)

For FY19 (July 1, 2018-June 30, 2019), the UWS selected three new groundwater research projects from proposals submitted in response to the Joint Solicitation and will continue three projects selected from the previous years' solicitations. The projects are based at UW-Madison and UW-Milwaukee and include:

- The impact of dissolved organic matter composition on the formation of disinfection by-products in groundwater. Christy Remucal, UW-Madison. (new)
- Improving water and nitrogen use efficiency under changing weather variability in the Central Sands. Christopher Kucharik, UW-Madison. (new)
- Dynamics of arsenic concentration and speciation in Wisconsin private drinking water wells. Shangping Xu, UW-Milwaukee. (new)
- Linking groundwater and nutrients to monitor fen ecosystems using airborne imaging spectroscopy. Eric Booth, Steven Loheide, David Bart, Philip Townsend, 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)

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 FY18, this allocation was matched 50:50 by the Wisconsin Department of Natural Resources Water Quality Bureau and used to fund a Wisconsin Water Resources Science-Policy postdoctoral fellow developing consistent monitoring approaches and assessment endpoints for suspended solids in streams. In addition, in FY18, this allocation supported the WICCI Water Resources Working Group and 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

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.

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 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 also 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 proposals submitted to the state of Wisconsin Joint Solicitation for Groundwater Research and Monitoring (WGRMP). A website called *iPROPOSE* was developed by WRI staff members in FY07-09. 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 *iPROPOSE* 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. In FY19, we will be moving to a new system called *eDrop* that provides similar services and security.

Information and Outreach Activities

The *University of Wisconsin Water Resources Institute website* is a portal to information about WRI 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 data base, funding opportunities, and conference information sections. The site is also integrated with the UW Aquatic Sciences Center's online reporting system, a tool that allows principal investigators to report on the progress of their projects. All of these areas are updated on a regular basis to ensure currency of information transfer. In this reporting period, the WRI website received an estimated 83,000 visitors. Additionally, WRI has a presence on Twitter, Facebook, Tumblr, 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 more than 11,000 views, which is a large number for a scientific topic. This year, two new videos were produced—one longer form and one shorter—both on a WRI project exploring the presence of naturally occurring radium in groundwater and a potential method to avoid its ability to contaminate local water supplies.

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. In the last year, the combined number of visitors to the podcasts' pages was more than 72,000.

During this reporting period, WRI staff were integral to the content-population of *http://www.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, and staff and faculty can search for colleagues working on topics complementary to their own to facilitate greater interdisciplinary collaboration and exploration. The site had an estimated 16,000 visitors in this reporting period.

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

Student mentoring is a critical aspect of the annual American Water Resources Conference, Wisconsin chapter, to augment lab experiences on campuses, such as this one at UW-Milwaukee. Photo: Sara Stathas.

The WRI was once again integral to the planning and staging of the American Water Resources Association-Wisconsin Section's annual conference. The theme of the 42nd conference was Working Together for Wisconsin's Water: Balancing Industry, the Environment and Public Health. 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 the American Water Resources Association-Wisconsin Section, the meeting was supported by academic and governmental partners, including the Center for Watershed Science and Education, UW-Stevens Point Wisconsin; Department of Natural Resources; Wisconsin Water Science Center, U.S. Geological Survey; and Wisconsin Geological and Natural History Survey.

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 Water Resources Institute 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 1,300 Wisconsin youth through 34 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 20,000 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 500 likes. The library's Twitter tool has been in use since June of 2009 and now has more than 1,900 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.

Feriancikova, L., and S. Xu. 2013. Transport of manure-derived, tetracycline resistant *Escherichia coli* in unsaturated soul. Final report, Water Resources Institute, University of Wisconsin-Madison. WR10R007.

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.

Hart, D. 2012. Preferential flow paths in heterogeneous glacially-deposited aquitards. Project Number WR11R005.

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.

Li., Z. 2013. Influence of adsorbed antibiotics on water quality and soil microbes. Final report, Water Resources Institute, University of Wisconsin-Madison. WR10R006.

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.

Luczaj, J.A., M. Zorn, and 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. Final report, Water Resources Institute, University of Wisconsin-Madison. WR12R004.

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.

Stelzer, R., T. Scott, and L. Bartsch. 2013. The effects of particulate organic carbon quantity and quality on denitrification of groundwater nitrate. Final report, Water Resources Institute, University of Wisconsin-Madison. WRI11R006.

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.

Thompson, A., K.G. Karthikeyan, and R. Jackson. 2013. Groundwater recharge characteristics and subsurface nutrient dynamics under alternate biofuel cropping systems in Wisconsin. Final report, Water Resources Institute, University of Wisconsin-Madison. WR10R003.

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

Baeten, Joseph. 2013. Spatial distribution and source identification of dissolved strontium in eastern Wisconsin's aquifers. University of Wisconsin-Green Bay.

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. 2015. Assessing the effects of riverbank inducement on a shallow aquifer in southeastern Wisconsin. M.S. Thesis. School of Freshwater Sciences, University of Wisconsin-Milwaukee.

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

Louison, Michael. 2013. Use of first-order tributaries by brown trout (*Salmo trutta*) as nursery habitat in a central Wisconsin coldwater stream network. M.S. Thesis. Department of Biology & Microbiology, University of Wisconsin-Oshkosh.

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

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.

Sourbeer, John. 2013. Long term soil moisture monitoring and assessing theoretical data interpretation techniques using heated distributed temperature sensing. M.S. Thesis, Civil and Environmental Engineering, 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.

Stenjem, Ryan S. 2013. Subsurface water and nutrient dynamics of cellulosic biofuel cropping systems. M.S. Thesis. Biological Systems Engineering, University of Wisconsin-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.

Arrington, K.E., S.J. Ventura, and J.M. Norman. 2013. Predicting saturated hydraulic conductivity for estimating maximum soil infiltration rates. Soil Science of America Journal 77:748-758. doi: 10.2136/sssaj2012.0288.

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.

Bauer, A.C., S. Wingert, K.J. Fermanich, and M.E. Zorn. 2013. Well water in karst regions of northeastern Wisconsin contains estrogenic factors, nitrate, and bacteria. Water Environment Research 85:318-326. *https://doi.org/10.2175/106143012X13373575831358*.

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*.

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For more information on the WRI:
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University of Wisconsin-Extension's Central Wisconsin Groundwater Center

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 *http://www.uwsp.edu/cnr-ap/watershed/*.

Well Water Testing

In calendar year 2017, the center helped 4,524 households test their water in conjunction with county extension offices and the Watershed Center's Water and Environmental Analysis Laboratory. Fourteen drinking water education programs helped 1,301 well users in eleven counties understand potential remedies for any problems found and the relationship of land-use practices to groundwater quality. Nitrate screening and information on well water testing was provided at Wisconsin Farm Technology Days and 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 100,576 samples covering the state, including 25 counties with 100 to 500 samples and 37 counties with 500 or more samples. Chemistry data include pH, conductivity, alkalinity, total hardness, nitrate-

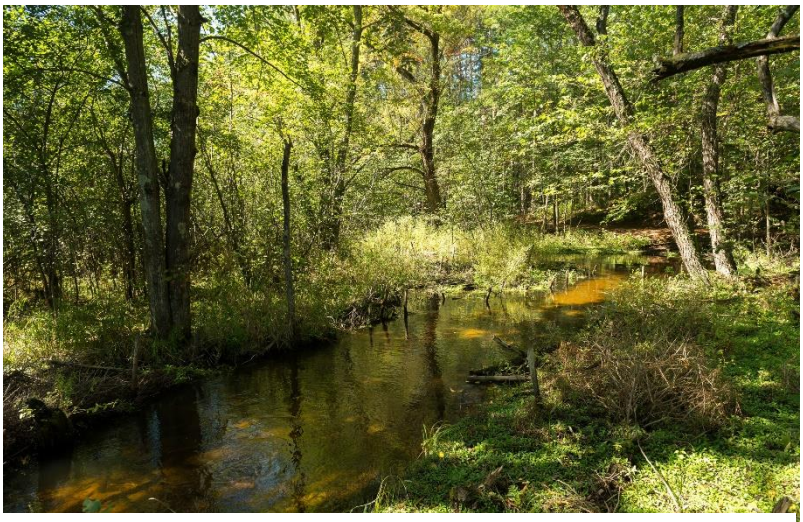
nitrogen, chloride, saturation index, coliform bacteria, various metals and minerals, and atrazine screen. The database primarily covers the period 1985 to the present. The database can be queried, making it an easily accessible source of information for local communities and groundwater managers.

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 2017, 8,527 people accessed the viewer. The viewer is currently being transferred onto a different platform that will allow for access on all browsers as well as mobile devices. Once completed the viewer will also be updated to include data collected since 2014. This process is expected to be completed by the end of 2018.

Central Wisconsin county-based volunteer streamflow monitoring

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



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

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

In 2017, the center was contracted by Portage County to collect and analyze samples from 214 private wells from around the county. Samples were analyzed for nitrate, chloride, pH, total hardness, alkalinity, and conductivity. Groundwater quality as a function of land-use, geology, and soils was investigated. A report of the information was compiled for the county and is available on the center's webpage.

Other well inventories are currently underway in Waupaca and Waushara counties. Waupaca County began sampling wells in the summer of 2017 and will complete their inventory in the summer of 2018. In total they will have sampled almost 800 wells through this current inventory. Samples are being analyzed for coliform bacteria, nitrate, chloride, pH, total hardness, alkalinity, and conductivity.

Waushara County will be testing approximately 150 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. University of Wisconsin-Extension Groundwater Specialist Kevin Masarik and Professor Emeritus George Kraft routinely present information on the science of groundwater quality and groundwater pumping and associated impacts to local and state government officials. 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. George Kraft and Kevin Masarik were active in the groundwater workgroups of WI Land + Water's Food, Land & Water: Toward a Sustainable Wisconsin Initiative. Masarik was co-chair of the Groundwater Quality Workgroup of that initiative.

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

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University of Wisconsin Environmental Resources Center (ERC)

The UW Environmental Resources Center (*ERC*) hosts UW-Extension (UWEX) state and local specialists addressing water resources, land and water conservation, forestry, conservation professional training, citizen engagement, and volunteer monitoring. ERC also coordinates a number of regional and national programs addressing water resources and water-education initiatives related to groundwater.

ERC Regional Water Programs and Conservation Professional Development

ERC 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.

ERC regional collaboration has led to a partnership providing multi-state professional development to conservation professionals (*http://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 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. In 2017, 98% of survey respondents said that their knowledge of Wisconsin's natural resources increased after taking the course.

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

According to 93% of respondents 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.

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 *http://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: *http://erc.cals.wisc.edu/programs/regional-natural-resources-education-program*.

For more information on UW ERC programs related to groundwater:
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University of Wisconsin Nutrient and Pest Management (NPM) Program

Mission Statement

The University of Wisconsin's Nutrient and Pest Management (NPM) Program works with 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 in making management decisions. The program links farmers and researchers to exchange 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* development and implementation. As a result of local delivery of the curriculum from 2000 to 2017, more than 7,144 producers farming approximately 2,051,685 acres in 55 counties have received in-depth education on nutrient management planning. In 2017, approximately 490 farmers operating about 139,000 acres in more than 21 Wisconsin counties added to this accomplishment list. Data are currently being collected for 2018 accomplishments.

- North American Manure Expo (NAME) *2017*. Staff from the NPM Program were part of a team that brought the North American Manure Expo to Wisconsin again in 2017. NAME features the latest in equipment, technology, and education for professional manure management. The 2017 Expo was held at the UW Arlington Ag Research Station on August 22 and 23. Farm tours, field demonstrations, hands-on product and safety education, exhibitor booths, and commercial vendor displays were all components of Manure Expo. In addition, 24 educational sessions were held in four separate themed tents. The themes were: (1) manure safety and manure management tools, (2) manure as a fertilizer resource, (3) manure application techniques and

technology, and (4) manure and environmental protection. A complete list of tours, demonstrations, exhibitors, educational sessions, and sponsorships can be found at the Manure Expo website http://www.manureexpo.org. More than 1,000 people attended Manure Expo-2017.

- SnapPlus nutrient management planning software assistance and refinement in conjunction with the SnapPlus team (UW-Soil Science). NPM staff assist in developing educational online videos (49 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 200 copies requested and delivered.

- Spring Green-area Nitrogen Management. In response to degradation of public and private drinking water resources due to nitrate, NPM (working with a team of county UW-Extension and UW soil scientists) has surveyed farmers in the area on their N management practices. As a follow-up, a series of on-farm demonstrations featuring various N management practices have occurred in the area. Practices initially include manure application timing (with and w/o Instinct), irrigation management, and UW-recommended nitrogen rates for corn on sands.

- Educational support to numerous Wisconsin watershed projects. Activities include coordination and delivery of individual nutrient management plans, phosphorus index model calibration and ground-truthing and manure spreader calibrations. Also, the NPM program provided a key member of the farmer-led, performance-based watershed projects in Barron, Polk, St. Croix, Pierce, Dunn, Green, Grant, Dane, and other Wisconsin counties.

- On-farm demonstrations, field plot research and subsequent educational programs on various topics (corn N rates, cover crops, conservation tillage, manure treatments, etc.) at various locations across Wisconsin.

Pest Management

The NPM program, in conjunction with numerous partners, including UW-CALS, 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 Water Hemp Weed Control Project* involves statewide field trials evaluating the effectiveness of various herbicides and herbicide application timings for the control of water hemp. Water hemp 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.

- The *Continuing Custom Applicator Program,* which develops and delivers an annual educational program for increasing the professionalism of custom pesticide applicators by broadening their knowledge of the products they use, available new technologies, and customer service.

- *UW Madison Dept. of Agronomy Herbicide Evaluation Program.* In both 2016 and 2017 the NPM Program contributed staff resources to ensure the continuation of the herbicide evaluation program. The purpose of this program is to independently verify and document the efficacy of

new and commonly used herbicide products. Twenty-five products were field evaluated at multiple locations.

- *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.

Food Systems

- *Cover Crops Research, Education, and Outreach.* Activities include development and instruction of cover crop demonstration and training, 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. Activities include on-farm demonstrations and research cover crop trials in Sheboygan, Dane, Pierce, Polk, Dunn, Grant, Columbia, and Green and other counties. Special emphasis has recently been placed on interseeding cover crops into existing row crops.

- *Frac Sand Mining Site Reclamation*. 2017 marked the fourth 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.

- *Healthy Grown / Health 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 landscapes in Wisconsin. Utilizing the Healthy Farm concept, NPM staff are involved in similar efforts for pea, sweet corn, and soybean crops.

- *Wis. Potato and Vegetable Growers Association Water Task Force.* NPM staff are active in this consortium of interest groups that is focusing on state-wide groundwater quality and quantity issues with special focus on the Central Sands region of Wisconsin.

- *Water Stewardship Program.* NPM staff are active in this consortium of interest groups focusing on groundwater quantity issues in the Central Sands region of Wisconsin.

Outreach and Communication

- *Grain Management in Low Margins: Series of Meetings, Video Series, and Publication.* Statewide program in partnership with UW-Extension specialists. Topics focused on crop production management decisions for improving farm profitability in years when profit margins are extremely low. A YouTube video series was made to share the presentations with a larger audience. Also, UWEX publication A4137 "*Grain Management Considerations in Low Margin Years*" was created based on materials from the series.

- *Mobile Applications*. The NPM Program is creating mobile applications (apps) for hand-held devices. In 2017-18 two new apps were created: *Manure Tracker,* which allows users to record manure applications on a field-by-field and load-by-load basis, and *Sporecaster,* which assists farmers in making management decisions (timing, etc.) for white mold treatment in soybeans. These apps join six others that are currently available: nitrogen (N) price calculator, corn N rate calculator, integrated pest management toolkit, corn crop calculators, manure and legume nutrient credit calculator, and a soybean replanting decision aid. Collectively, these apps have been downloaded by more than 60,000 users from across the world.

- *YouTube Videos*. More than 220 YouTube educational videos featuring UW-CALS specialists have been prepared and released by the NPM and IPM programs over the past five years. A complete listing can be found at *http://www.youtube.com/uwipm*. A conservative estimate of the number of views is greater than 800 (worldwide) per day. This educational outreach channel has grown by 200% in viewership from 2016-17. In a recent random stakeholder survey, 75% of respondents found these videos very valuable. A milestone 1,000,000 views was reached in March of 2018. Seventeen new videos created in the past year include Wisconsin's Healthy Grown potatoes, forecasting white mold in soybeans, managing herbicide resistant weeds, combine sanitation, and more.

- *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 email distribution list contains 1,000 recipients, with 20,000 PDF downloads in 2017.

- *NPM Publications*. The NPM Program has a long history of publishing timely, pertinent, high-quality publications on the topics of improved agricultural management practices. Formats have ranged from simple pocket-sized cards to extensive manuals and workbooks. A listing of NPM's print publications can be found at *http://ipcm.wisc.edu/downloads/*.

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

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

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

- 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.

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 disaster strikes. 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

- 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:
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DEPARTMENT OF SAFETY AND PROFESSIONAL SERVICES

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

FY 2018 Highlights

- Over 98% of statewide private on-site wastewater treatment systems (POWTS) have been inventoried and more than 75% 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
- The Department partnered with numerous technical colleges 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. Updates to the associated POWTS codes were discussed with the POWTS Code Advisory Council to address minor revisions/updates.

Data Management

DSPS is continuing its data integration information technology (IT) initiative. 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. The Department is working with those few counties which did not meet the deadline. Counties must also initiate new or enhance existing reporting programs related to inspection, maintenance and servicing events by October 1, 2019. Over 98 % of statewide POWTS have been inventoried and more than 75% of counties are operating a maintenance program for all POWTS in their jurisdiction.

For further information:
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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. I am a current member of the WPVGA.

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 $6.4 billion and the industry generates over 35,000 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, Wisconsin Public Service, USDA-Natural Resources Conservation 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.
- 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 http://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 begins on July 1, 2018. It involves 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 will be 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 and 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.

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.

Protecting Groundwater from Nonpoint Source Contamination

What's the issue?

Any time rainfall or snowmelt runs across the land surface, this water picks up some amount of soil, nutrients and other pollutants. Just as this runoff can cause water quality problems in streams and other surface water bodies, it can also carry contaminants to groundwater when it seeps into the soil. On agricultural landscapes, runoff may pick up bacteria, nutrients or pesticides through contact with soil, manure or crops. In urban areas, road salt and organic compounds from impervious surfaces are typical nonpoint contaminants.

Flooded fields after manure spreading can quickly carry nitrogen and other nonpoint source pollution to the groundwater. *Photo: Marty Nessman, DNR.*

Protecting groundwater from nonpoint source contamination is a complex management challenge. In contrast to "point source pollution," which comes from an easily identifiable source like a pipe, it is very difficult to sort out relative contributions from sources scattered across the landscape. Even when the contributing areas are well known, the effectiveness of alternative management strategies can be highly dependent on landscape characteristics like soils and slopes that vary considerably from site to site. In addition, many nutrients and other pollutants in groundwater respond very slowly to changes in inputs. Although groundwater sometimes responds within months or a few years, it is not unusual for it to take decades to see environmental results from a change in management strategy.

Because of this high variability and long timescales, long-term monitoring and scientific research that evaluates management practices for nonpoint contaminants are routinely identified as priorities by the Groundwater Coordinating Council (GCC). Approximately 25% of all research projects funded by the Wisconsin Groundwater Research and Monitoring Program since 1984 have been related to nonpoint contaminants. Agricultural contaminants are of particular concern, since nitrate is one of the top drinking water contaminants in the state and pesticides and their metabolites are estimated to exist in approximately 42% of all Wisconsin wells (DATCP, 2017).

GCC in Action: *The Atrazine Rule*

The development of the Atrazine Rule (ATCP 30, Wis. Adm. Code) illustrates how the benefits of long term state-funded research and monitoring can build on one another over time to effectively protect public health and the environment while upholding a strong economy.

The herbicide atrazine was first detected in monitoring wells and private drinking water wells in the mid-1980s. This prompted a statewide well sampling program in 1988, which revealed that atrazine was present in 12% of the Grade A dairy farm wells (LeMasters and Doyle, 1989). Follow-up research supported by the GCC notably demonstrated that normal agricultural applications of atrazine, rather

Atrazine is an herbicide popularly used on corn in Wisconsin and across the US. *Photo: DATCP*

than only point spills and mishandling, could lead to groundwater contamination (Cowell and LeMasters, 1992). Armed with the understanding that this was a nonpoint source pollution problem, the Department of Agriculture, Trade and Consumer Protection (DATCP) first evaluated a modeling approach to try to simulate contaminant transport and identify vulnerable areas. However, early results indicated that the behavior of atrazine in the environment was too complex to be reliably predicted by modeling (Muldoon et al., 1994). A more empirical approach, relying on actual well test results and analyses of soils, geology, production intensity and application practices more successfully identified areas with the highest susceptibility to atrazine contamination (Daniel et al., 1990; Bradbury and McGrath, 1991; Hanson et al., 1996). Critically, these studies showed that areas with highly permeable sandy soils were not uniformly susceptible to contamination and areas with medium textured loamy soils were not uniformly safe – nuanced differences in soil type and regional production intensity had substantial effects on groundwater susceptibility. Ultimately, this allowed DATCP to develop and refine an atrazine rule that limits statewide use of atrazine and prohibits it only in certain highly vulnerable areas where atrazine in wells has exceeded the groundwater enforcement standard. In the atrazine prohibition areas, atrazine levels generally drop below the groundwater enforcement standard in two to seven years (DATCP, 2010).

The intensive monitoring and research efforts supported by the GCC allowed for a more tailored rule to be developed. This resulted in a rule that benefited both the agricultural economy by allowing continued uses of an inexpensive herbicide in most areas of the state, while also protecting groundwater and public health in environmentally sensitive areas of the state by prohibitions on use where data showed a need.

Other Projects in Other Places

DATCP Statewide Survey of Agricultural Chemicals

An integral element of nonpoint monitoring in Wisconsin is the statewide statistical survey of agriculture chemicals that is periodically performed by DATCP. As agricultural practices have evolved and laboratory methods have improved, the number of pesticide compounds analyzed in this study has grown from one compound (atrazine) in 1994 to 31 compounds in 2007 and to 100 compounds in 2016. According to the last survey conducted in 2016, an estimated 8.2% of wells exceed the nitrate standard (10 mg/L) and 42% of wells contain a detectable level of at least one pesticide or pesticide metabolite (DATCP, 2017). As demonstrated by the development of the Atrazine rule, regular assessment of the extent of nonpoint source contaminants is critical to prioritizing issues and making fair and effective management decisions.

Reducing Nitrate Inputs to Groundwater

Nitrate is Wisconsin's most widespread contaminant. Agriculture accounts for about 90% of the nitrate in Wisconsin groundwater (Chern et al., 1999), so efforts to address this problem overwhelmingly focus on management of manure and fertilizer application. Nutrient management plans specify the amount and timing of all nutrient sources applied to a field as well as other best practices that both optimize economic input and reduce groundwater quality impacts. Not all farms have a nutrient management plan, but DATCP provides free resources and training for farmers to encourage total coverage across the state.

While there is still significant potential to reduce statewide nitrogen inputs with increased adoption of NMPs (nutrient management plans), improvement in nitrate levels in groundwater has remained frustratingly elusive after years of efforts. In light of this, the DNR began a new program to work with communities on nitrate demonstration projects. This is a long-term program targeted at reducing nitrate levels in groundwater by making the most efficient use of nitrogen in agricultural production. At agricultural fields in selected demonstration communities, activities include: measuring all current nitrogen inputs and baseline groundwater nitrate levels; calculating agricultural input and production costs; determining and implementing best nitrogen management practices that optimize groundwater conditions and agricultural production efficiency; and measuring whether predicted results are achieved. After several years of monitoring and modeling, costs of nitrogen management will be compared to water treatment costs for nearby public water supply wells to identify optimal nitrogen management systems.

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Understanding Natural Geochemistry

What's the issue?

Natural geologic formations are sources of trace elements that can be released to groundwater under certain circumstances. *Photo: WGNHS*

As groundwater flows through rock formations and past mineral deposits, it dissolves metals and other elements into the water. Even groundwater that looks clear typically has many substances in it. Often, these chemicals are dissolved at non-toxic concentrations and do not affect how safe the water is to drink. Some of them – such as iron and sulfate – we remove for aesthetic reasons. Occasionally, natural elements do dissolve at high enough concentrations that they can affect the safety of humans and the environment.

A complex combination of geochemical factors affects whether or not an element will leach into groundwater at dangerous levels. For any element that exists in a rock formation, the stability of the mineral in which it is incorporated as well as the temperature, pH, and oxygen dissolved in the groundwater strongly control the degree to which it mobilizes. Identifying where and why naturally occurring substances are released to groundwater requires detailed local information about all of these factors as well as extensive understanding of when small changes in one property might cause large changes in another. Developing this basic scientific knowledge is the critical first step toward developing recommendations for public water systems, homeowners, and well drillers that effectively protect the health and safety of the people of Wisconsin.

GCC in Action: *Discovery of Naturally-Occurring Arsenic in Wisconsin Groundwater*

An early example of advances in geochemical understanding in Wisconsin leading to protection of public health is the story of arsenic. Naturally-occurring arsenic was unexpectedly discovered in 1987 during a feasibility study for a proposed landfill in Winnebago County. Follow up sampling by the Department of Natural Resources (DNR) and reports from nearby homeowners indicated the problem appeared to be widespread in the region, more likely due to natural sources than industrial contamination. As a result, in 1992 DNR, 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 counties and later surrounding counties to analyze where and why arsenic levels were elevated (Burkel, 1993; Burkel and Stoll, 1995). These initial studies confirmed that the arsenic was naturally occurring and isolated the geologic formations acting as sources. Further geochemical studies linked arsenic mobilization to oxidation of pyrite and associated it with low pH and fluctuating groundwater levels. This information helped DNR outline a Special Well Casing Depth Area (SWCDA) and develop well construction guidelines to protect drinking water wells in this area from exposure. 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, 2002; Zierold et al., 2004).

In the early 2000s, the Environmental Protection Agency (EPA) lowered the maximum contaminant level for arsenic from 50 ppb to 10 ppb (the current standard), which raised concerns for schools and residents in southeastern Wisconsin that had been observing arsenic levels in the 10-50 ppb range. Initial testing by the DNR and 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 sources and mechanisms of arsenic release in the region and develop more appropriate guidelines (Sonzogni et al., 2003; Bahr et al., 2004; West et al., 2012). One of the important outcomes of more recent studies has been 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). While chlorination must be limited in much of northeastern Wisconsin since it has a similar effect as oxygen on sulfide-bound arsenic, it does not affect arsenic bound to iron compounds in southeastern Wisconsin and may in fact help reduce arsenic levels in those areas by controlling microbes that contribute to iron dissolution.

DHS and DNR staff presenting on health implications of arsenic at an Ozaukee County well water informational event attended by over 150 residents. *Photo: Ozaukee County Public Health Department*.

Understanding the occurrence of arsenic in Wisconsin's groundwater is a classic example of interagency cooperation. Initial work with DHS and local health departments and town boards in the early 1990s effectively defined the problem and raised awareness. Research supported by the joint solicitation helped define the extent and mechanisms of release in northeastern Wisconsin. With assistance from well drillers, DNR used this scientific information to identify drilling methods that reduce arsenic in the SWCDA. Importantly, when evidence emerged that southeastern Wisconsin is also vulnerable to high arsenic, the solutions that were effective in northeastern Wisconsin were not simply applied to the area. Rather, careful study informed more appropriate and effective solutions for the new region of concern, leading to better protection of drinking water and public health. Recently, wells in the western part of the state have also turn up with high arsenic results. Sulfides are again the problem and proper well construction can alleviate the problem.

Other Projects in Other Places

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

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

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

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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).

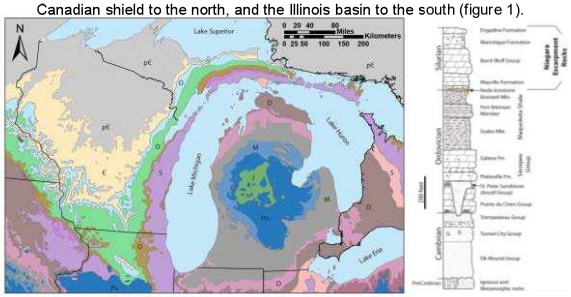

Figure 1 (left): Generalized bedrock geologic map showing eastern Wisconsin and the ancestral Michigan basin. Base map from Luczaj (in press). Figure 2 (right): Stratigraphic column of northeastern Wisconsin (Luczaj, in Press).

- 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).

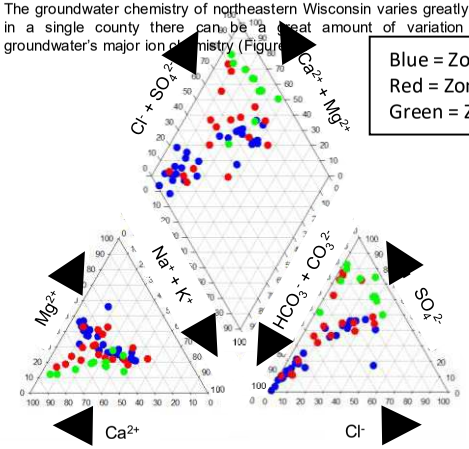

Figure 3: General chemistry of Brown County, WI. Data shown were collected by Joe Baeten and John Luczaj of the UW-Green Bay. Each zone represents a different area of Brown County that is separated by one ore more mapped faults in the region.

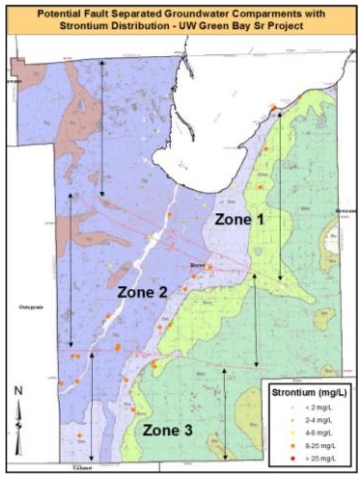

Figure 4: Geologic map of the buried bedrock surface in Brown County, Wisconsin (Luczaj, 2011). Dark blue and brown areas in western Brown County are the Sinnipee Group (Og and Op). Light blue (Om) represents the Maquoketa Shale. Green colors indicate Silurian dolostone units. Red lines indicate major 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

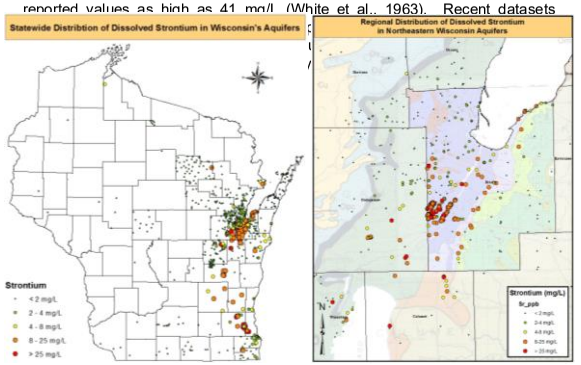

Figure 5a (left): statewide distribution of dissolved strontium in Wisconsin's aquifers. Data were compiled from various sources. Figure 5b (right): strontium distribution in northeastern Wisconsin showing subsurface bedrock.

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

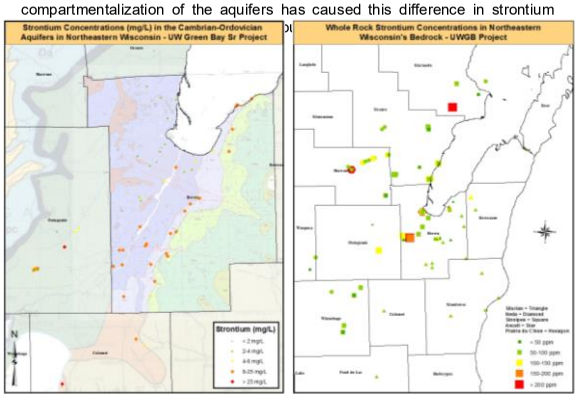

Figure 6 (left): Regional distribution of strontium concentration in northeastern Wisconsin from samples collected for the UWGB Sr Project. Figure 7 (right): Spatial distribution of whole rock samples collected by Luczaj and McIntire (in preparation) showing bedrock strontium concentrations. These samples 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).

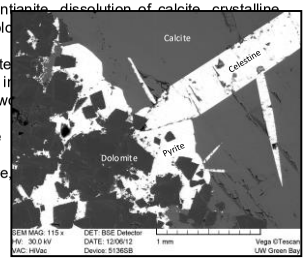

Figure 8 (right): SEM image showing bladed $SrSO_4$ (Celestine) from the Lawrence Quarry near De Pere, Wisconsin. Mineral sequence shows dolomite first, followed by celestine, pyrite, and late calcite.

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.

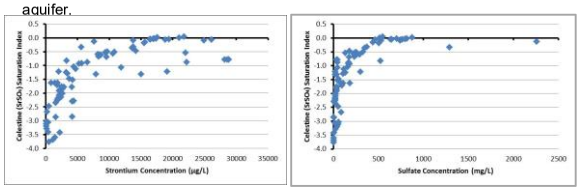

Figure 10: left, strontium concentration plotted against the saturation index of Celestine in the aquifers of northeastern Wisconsin. Right, sulfate concentration plotted against the saturation index of Celestine in the aquifers of northeastern Wisconsin.

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).

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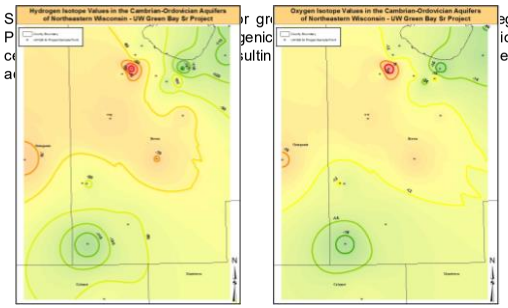

Figure 11: Isotopic analyses for ∂D (left) and $\partial^{18}O$ (right) for groundwater in the Cambrian-Ordovician aquifers in Brown, Calumet, and Outagamie counties. Data from UW Green Bay Sr Project.

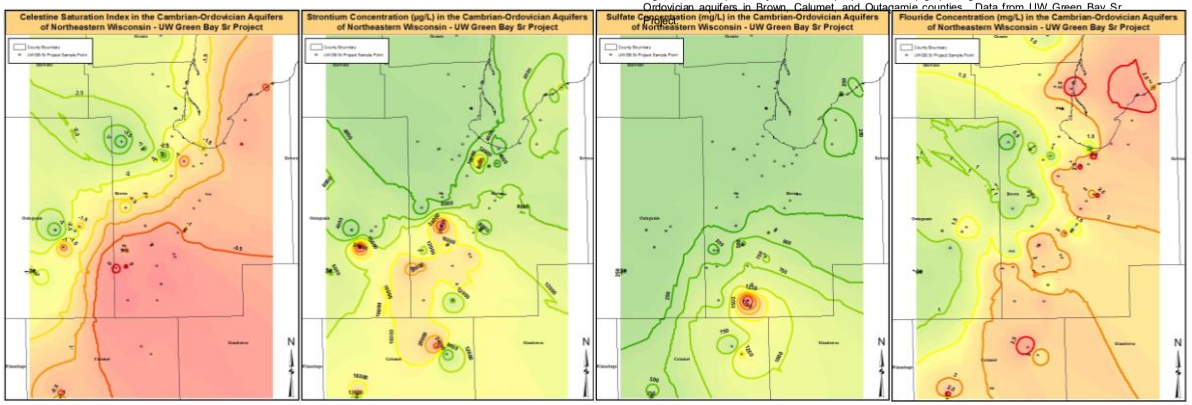

Figure 9: left, Celestine saturation index; middle, strontium concentration; and right, sulfate concentration in northeastern Wisconsin. Contours are based only on those samples collected for the UWGB Sr Project. The saturation index takes into consideration the activity coefficients and ionic strength 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	-
OO234	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
OO234	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".

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Wonewoc Formation and Tunnel City Group Rock

Wisconsin Geological and

Wisconsin Geological & Natural History Survey

UW Extension University of Wisconsin-Extension

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.

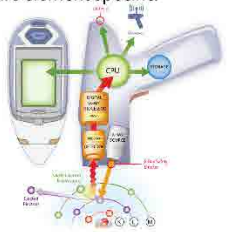

Figure 1 (left): Schematic of the x-ray fluorescence process.

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.

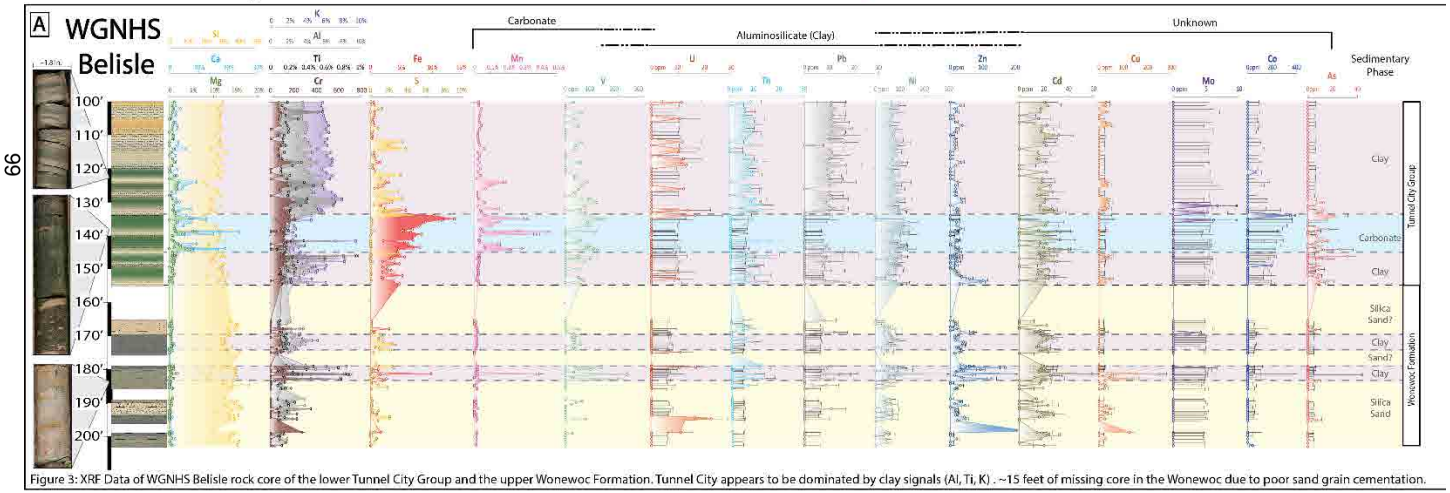

Figure 3: XRF Data of WGNHS Belisle rock core of the lower Tunnel City Group and the upper Wonewoc Formation. Tunnel City appears to be dominated by clay signals (Al, Ti, K) . ~15 feet of missing core in the Wonewoc due to poor sand grain cementation.

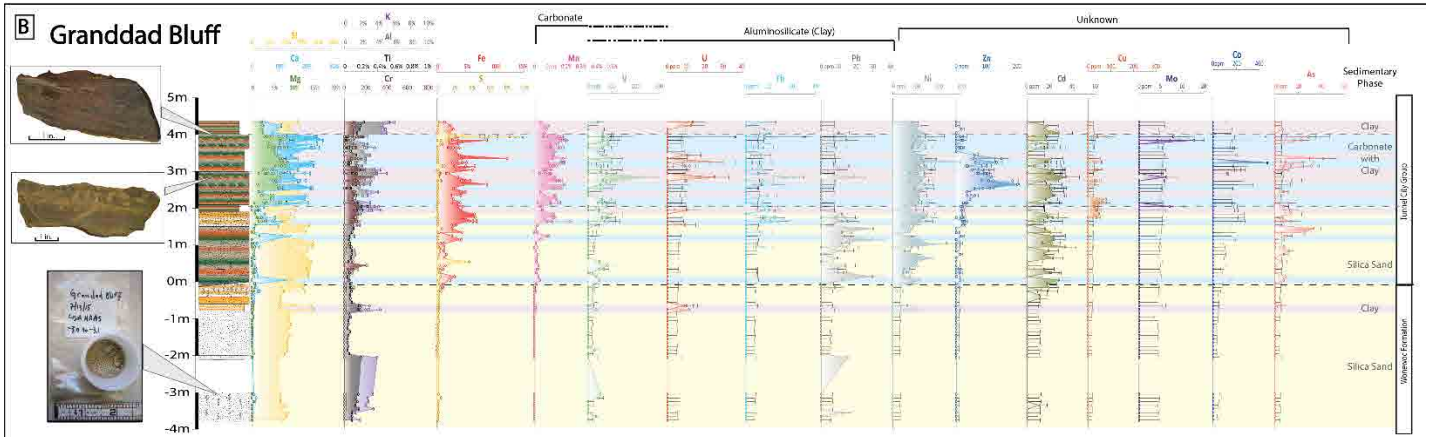

Figure 4: XRF Data of hand samples collected at Granddad Bluff in La Crosse, WI. Samples were collected 5 meters above and 4 meters below the Tunnel City-Wonewoc contact in 10 cm increments. Tunnel City hosts both calcareous (Ca, Mg) and sandy (Si) Rocks.

s: Potential Natural Sources of Groundwater Contaminants in Wisconsin?

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DEPARTMENT of GEOSCIENCE
University of Wisconsin-Madison

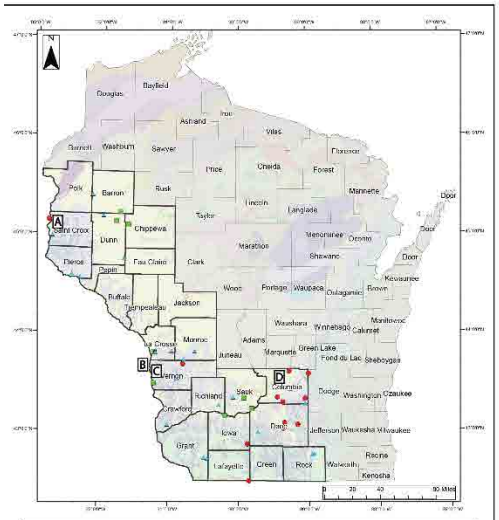


Figure 5: Map of the study area and location of the 45 hand samples, rock cores and cuttings sets studied. **A**) WGNHS Belisle rock core, XRF data displayed left, **B**) Granddad Bluff hand samples, XRF data displayed bottom left, **C**) Arbor Hills cuttings set, XRF data displayed upper right, **D**)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

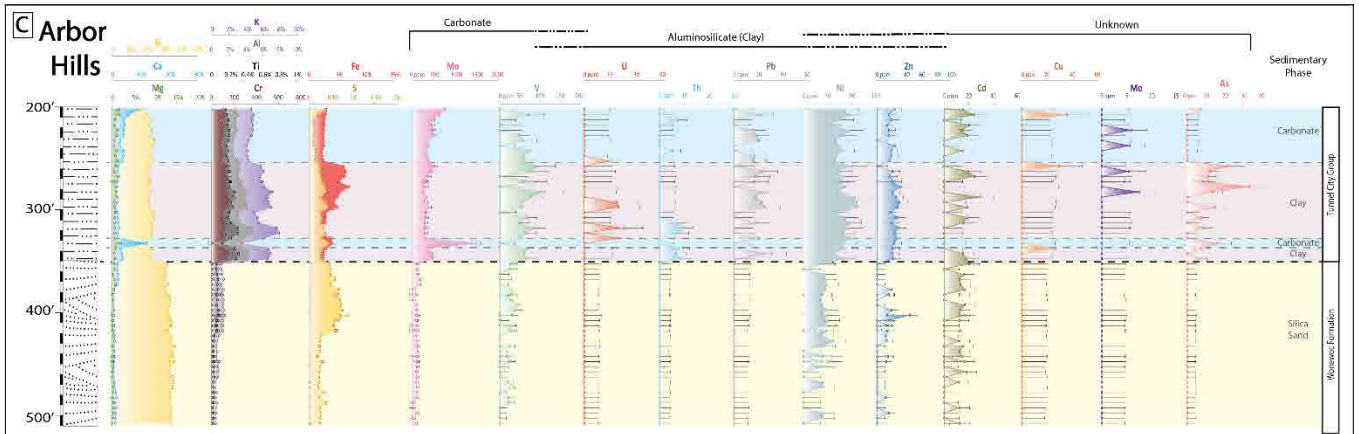


Figure 7: XRF Data of Arbor Hills cuttings set, one mile east of Granddad Bluff. One sample represents 5 feet of homogenized rock thickness. This data includes the entire Tunnel City Group and Wonewoc Formation.

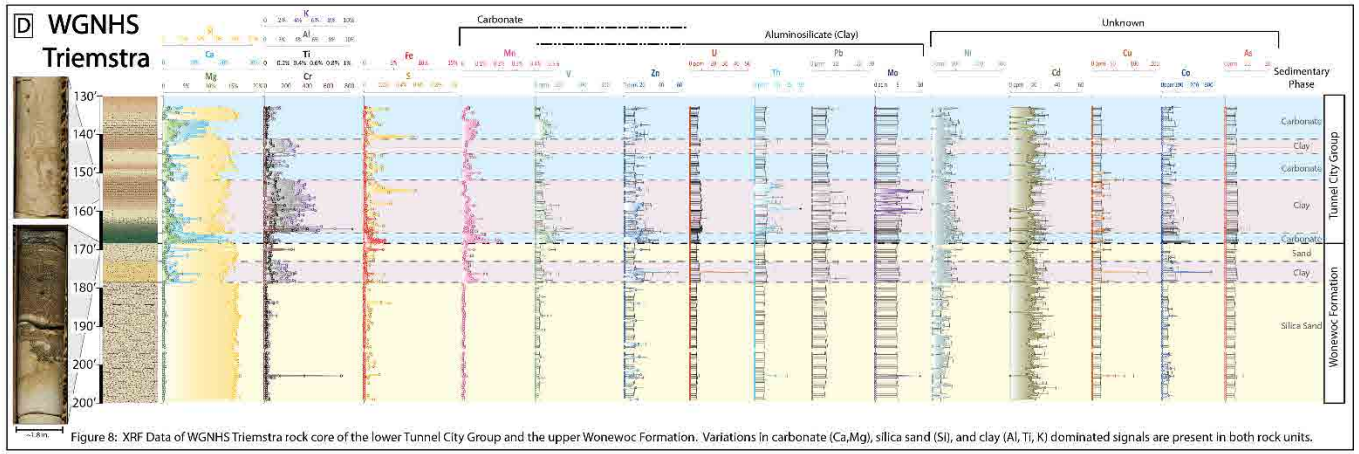


Figure 8: XRF Data of WGNHS Triemstra rock core of the lower Tunnel City Group and the upper Wonewoc Formation. Variations in carbonate (Ca,Mg), silica sand (Si), and clay (Al, Ti, K) dominated signals are present in both rock units.

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:

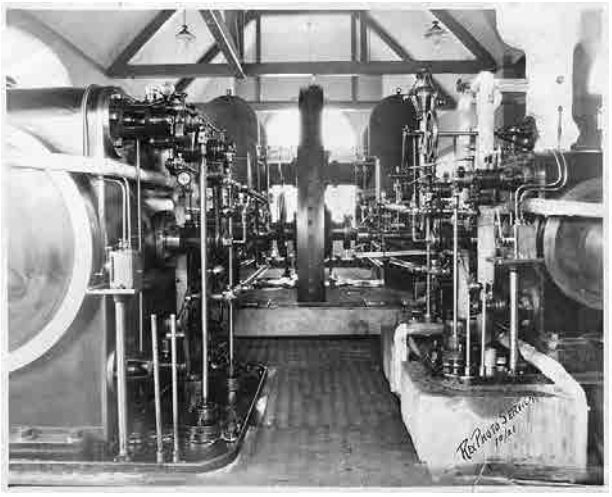
UW Water Resources Institute and the WGNHS provided funding for this project.

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

Tracking Pathogens to Their Source

What's the issue?

Pathogens from human sewage and animal waste are among the oldest and most ubiquitous drinking water contaminants. The term "pathogen" is a general term used to describe all types of disease causing microorganisms including viruses, bacteria, prions, fungi, viroids or parasites.



Early photo of the interior of the Janesville Water Works, ca. 1921. Around this time, many American municipalities were adopting practices that dramatically improved drinking water quality. *Photo: Bill Tunstead*

In the late-1800s, the advent of modern epidemiology and germ theory led to the understanding that many diseases are caused by waterborne pathogens rather than harmful "miasmas" (vapors) in the air. By the early-1900s, many American municipalities had taken steps to keep drinking water sources separate from sewage sources and were adopting basic filtration and disinfection techniques. In 1919 Wisconsin municipalities were required under state law to follow basic sanitary engineering principles, review construction plans for proposed treatment plants and regularly analyze water samples at the State Laboratory of Hygiene. Actions like these improved the quality of drinking water so dramatically that it is still considered one of the greatest global advances in public health. Half of the decline in mortality from 1900 to 1940 – the largest recorded decline in mortality in United States history – is attributed to the introduction of these basic wastewater and drinking water practices (Cutler and Miller, 2005). Wisconsin's last typhoid outbreak attributed to a public water system occurred in 1929.

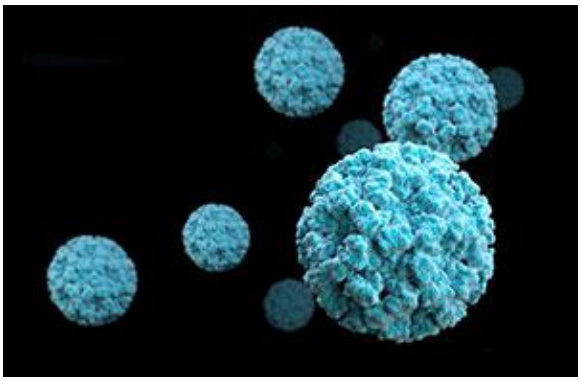
Protecting groundwater from pathogen contamination remains a top public health priority since outbreaks of gastrointestinal illness related to well water still occur periodically. A notable example is the 2007 outbreak of norovirus caused by contaminated well water which sickened 229 diners and staff at a Door County restaurant (Borchardt et al., 2011). In cases like this, multiple treatment technologies are needed to insure safe drinking water.

The risk of waterborne disease outbreaks can be related to how quickly pathogens travel through the soil. If pathogens in groundwater move slowly or travel long distances, the risk of illness can be diminished. By the time groundwater has traveled from a fecal waste source (e.g., septic field, leaking sanitary sewer or manure at the land surface) to a drinking water well, it can be pathogen free due to natural processes that cause pathogens to cling to soil particles or die-off. In areas with thin soils, fractured bedrock or shallow water tables, the risk of waterborne illness is greater because pathogens can travel more quickly to wells. The size of different types of pathogens and their attraction to soil particles affect how they move through soil. This means that the presence or absence of one pathogen (e.g. a type of bacteria) does not always correlate with the presence or absence of others (e.g. viruses).

Because of the complicated nature of pathogen transport and the serious consequences of waterborne disease outbreaks, the Groundwater Coordinating Council (GCC) prioritizes research that evaluates how, when and where pathogens in groundwater may pose a threat to public health.

GCC in Action: *Viruses in Drinking Water*

It is difficult and expensive to comprehensively test for all harmful pathogens, so water samples are typically tested for "indicators" – organisms that are not necessarily harmful themselves, but are a warning sign that other, potentially harmful, pathogens may be present. Traditionally, the presence of coliform bacteria is assumed to be a reasonable indicator of the presence of most harmful microbial agents, including viruses. Since 2000, groundbreaking work by GCC agencies related to the occurrence of viruses in drinking water and the impact on human health have challenged these assumptions.



Norovirus, one of the human enteric viruses detected in drinking water by GCC researchers. *Image: CDC*

An early indication of the significance of the problem came in the early 2000s, when researchers at the Marshfield Clinic Research Foundation demonstrated that viruses in private wells do not exhibit strong seasonal trends and are not correlated with commonly used indicators such as total coliform and fecal enterococci (Borchardt et al., 2003a and 2003b). A subsequent study with the U. S. Geological Survey (USGS) looking at La Crosse municipal wells drew similar conclusions and further concluded that nearby surface waters were not the source for the viruses; rather, viruses in La Crosse wells were likely coming from leaking sanitary sewers (Borchardt et al., 2004; Hunt et al., 2005). This was not shocking in a city like La Crosse, where municipal wells are located in shallow sand and gravel aquifer, relatively close to underground pipe infrastructure. However, municipal wells completed at depth – below confining layers of shale that separate shallow from deep aquifers – were presumed to be well-protected. The geology in the Madison area meets this description, yet collaborators from the Marshfield clinic, the Wisconsin Geological and Natural History Survey (WGNHS) and the University of Waterloo discovered human enteric viruses in Madison municipal wells in 2007, indicating that all aquifers are potentially vulnerable to microbial contamination (Borchardt et al., 2007; Bradbury et al. 2013).

In recognition that disinfection with chlorine or ultraviolet light can dramatically reduce virus populations, a subsequent study compared drinking water quality and illnesses in Wisconsin communities that do not disinfect. This work concluded that 6% to 22% of gastrointestinal illness incidents were directly attributable to viruses in drinking water in these communities (Borchardt et al., 2012). Results were so compelling that the Department of Natural Resources (DNR) quickly developed a rule mandating disinfection of municipal drinking water, although this was repealed by the state legislature in 2011.

Ongoing research funded by the GCC will look at how enteric pathogens travel through the Silurian dolomite aquifer in NE Wisconsin, source tracking of viruses in the field and looking at the impacts of septic systems in SE Wisconsin.

This series of studies exemplifies how work by GCC researchers positions Wisconsin at the cutting edge of protecting the environment, economy and public health. Nationally, the Environmental Protection Agency (EPA) included virus types found in the Wisconsin studies on the list of 30 unregulated contaminants that were monitored from 2013 to 2015 - in 6,000 public water systems across the United States - in order to gather information to support future drinking water protection. Continued research along these lines follows in the footsteps of the great public health advances of 100 years ago to ensure that drinking water, a basic human need, is not jeopardizing public health.

Other Projects in Other Places

Tracking the source of bacteria

Laboratory methods that can distinguish fecal pollution from grazing animals vs. human or other animal sources are among of the cutting edge research supported by the GCC. *Photo: DNR*

Definitively identifying the cause of bacterial contamination in drinking water wells was not always possible. Many projects funded by the Wisconsin Groundwater Research and Monitoring Program have developed new techniques for detecting, quantifying and monitoring microorganisms in groundwater and soils. Impressive results include a rapid molecular method to identify contamination from human waste without culturing organisms; a reliable method for detecting *Heliobacter pylori* in environmental samples; and an assay that distinguishes fecal pollution from grazing animals, like cows, from other sources like pigs or chickens. Improved laboratory methods enhance the ability of GCC agencies to quickly understand the root causes of bacterial contamination and identify appropriate solutions.

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Predicting and Responding to Drought and Flood

What's the issue?

During times of drought, local water tables can decline due to decreased recharge and increased demand for groundwater supplies. This puts shallow drinking water and irrigation wells at risk of going dry, which can lead to reduced drinking water availability or crop yield. These water table declines also affect water levels in streams, lakes and wetlands, with important consequences for aquatic life and recreational value. Even where groundwater quantity remains sufficiently high to meet demands, declines in water table level can alter water chemistry and expose residents using groundwater for drinking water to more heavy metals, organics and other contaminants.

Too much groundwater can also be a problem. Groundwater flooding occurs when extremely intense and frequent rainfall leads to excessively fast recharge of local groundwater levels, causing the water table to rise above the land surface. This type of flood can be very long-lasting because water table decline requires drainage of an entire aquifer. For the months that it takes for this drainage to occur, flood waters 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. Being able to predict where these events are likely to occur, how often they may take place and probable impacts is critical to reducing the damage. The Groundwater Coordinating Council (GCC) encourages the development of data and analyses of likely scenarios for quantity and quality of Wisconsin's groundwater supply.

GCC in Action: *June 2008 Flooding in Spring Green*

A dramatic example of groundwater flooding in Wisconsin occurred when Southern Wisconsin experienced record amounts of precipitation from August 2007 through July 2008. While most of the initial flooding occurred as surface water overflow, longer-term groundwater flooding remained for many weeks or months following the rain events. In Spring Green, about 4,400 acres of land several kilometers away from the floodplain of the Wisconsin River remained flooded by high groundwater for over

Flooding in Spring Green, WI in June 2008. *Photo: WI ASCE*

five months. Recovery in the Spring Green area included a $5.4 million Federal Emergency Management Agency (FEMA) grant in 2009 to acquire and demolish 28 flood damaged homes (Moynihan, 2009).

Groundwater flooding is rare and little studied in Wisconsin. Given the extent of the damage to agricultural, residential, and commercial properties caused by the 2008 flooding, questions about the future likelihood of groundwater inundation naturally arose. Researchers at the Wisconsin Geological and Natural History Survey and UW-Madison funded by the Wisconsin Groundwater Research and Monitoring Program (WGRMP) responded by developing a series of models that simulated groundwater hydrology in the low-lying areas near Spring Green under a range of climate scenarios through 2100. Findings suggest that years of extremely high-water table conditions may still occur but will remain relatively rare in this century (Joachim et al., 2011). Higher evapotranspiration is likely to reduce groundwater recharge overall.

The 2008 floods also highlighted the need for improved mitigation, preparation, response and recovery practices. Capitalizing on momentum, a GCC-sponsored conference, "From Sandbags to Sanity," brought together policy experts, state and local officials, and nonprofit organizations in April 2009 to discuss the policy approaches that can minimize the risks associated with this type of hydrologic disaster (Moynihan, 2009).

These two responses to the June 2008 floods – investment in research to improve scientific knowledge and enhanced coordination among federal, state and local actors – exemplify how the GCC carries out its core missions to enhance the effectiveness and efficiency of groundwater management.

Other Projects in Other Places

Agricultural management in the Central Sands

Corn suffering in July 2012, one of the worst droughts on record in Wisconsin. *Photo: DATCP*

In times of drought, the demand for agricultural irrigation increases substantially, especially in the Central Sands region of the state. For immediate relief, the DNR may approve emergency high capacity wells for irrigation or livestock supply, as it did during the 2012 drought. On a long-term basis, a more reliable strategy for farmers and water systems requires understanding water balance dynamics and crop biophysics at higher spatial and temporal resolutions, so that process-based models can be used to evaluate the effects of different irrigation strategies and climates on water demand. To this end, a study funded by WGRMP conducted an intense field measurement campaign to refine models and evaluate how climate and land management have impacted groundwater recharge and evapotranspiration in the Wisconsin Central Sands over the past 60 years (Kucharik et al., 2015).

Building Resilience Against Climate Effects (BRACE)

The Department of Health Services BRACE program has worked with seven local public health departments, or consortiums of health departments, to facilitate a climate and health community engagement process. Two of the seven local health department pilot projects have chosen to address public health impacts related to groundwater in a changing climate. One such consortium of local health departments (Eau Claire Co., Dunn Co., Pepin Co., and Buffalo Co.) is developing better policy regulating nutrient contaminants (e.g., nitrates, phosphorous). Activities include increased testing and a collaborative group to problem-solve public health interventions. Another local health department pilot project in La Crosse County is working to increase public awareness of drinking water hazards and increase testing among private well owners. This project successfully received funding from the CDC for private well water testing.

Another aspect of the BRACE framework focuses on projecting disease burden related to a changing climate. One projected disease burden the BRACE program is investigating is gastrointestinal illness related to increases in precipitation from a changing climate in Marshfield.

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Fostering Public Awareness

What's the issue?

Successful groundwater management depends on dispelling myths and fostering public understanding of the resource. Through the cooperation of GCC agency partners, a new generation of students, parents and teachers are more aware of the complex relationship we have with groundwater, our valuable buried treasure. UW-Cooperative Extension - through the UW Water Resources Institute, the Environmental Resources Center and the Wisconsin Geologic and Natural History Survey (WGNHS) - takes the lead for outreach on general groundwater topics while each state agency provides information on their specific regulatory programs. Experience has shown that person-to-person outreach is the best way to engage the public in groundwater protection.

A variety of resources are available from each agency:

- WGNHS has downloadable publications on Wisconsin geology and groundwater: http://wgnhs.uwex.edu/.
- The Center for Watershed Science and Education has information for well owners about well testing and hosts the Well Water Quality Viewer: https://www.uwsp.edu/cnr-ap/watershed/Pages/default.aspx.
- The UW System through the Water Resources Institute and the Environmental Resource Center consists of programs including the Conservation Professional Training Program and the North Central Region Water Network that facilitate groundwater protection: http://erc.cals.wisc.edu/programs/.
- DNR has information on well construction, how to diagnose private well problems and contaminants in drinking water systems: http://dnr.wi.gov/topic/DrinkingWater/. Water use statistics can be found here: http://dnr.wi.gov/topic/WaterUse/WithdrawalSummary.html.
- DNR has statewide information regarding water quantity data collection including stream baseflow, groundwater levels and lake levels: https://dnrmaps.wi.gov/H5/?viewer=Water_Use_Viewer.
- DATCP provides information on pesticide and nutrient handling and a published report on Agricultural Chemicals in Wisconsin Groundwater: https://datcp.wi.gov/Pages/Programs_Services/GroundwaterReports.aspx.
- DSPS provides information on private onsite wastewater treatment: https://dsps.wi.gov/pages/Programs/POWTS/Default.aspx and approved treatment devices for contaminants in private wells.
- DHS provides information on the health effects of environmental contaminants in drinking water: https://www.dhs.wisconsin.gov/water/index.htm and maintains County Environmental Health Profiles which track drinking water data: https://www.dhs.wisconsin.gov/epht/profile.htm.
- DOT regulates salt storage and tracks salt use on highways to ensure groundwater protection while providing safe winter driving conditions: http://wisconsindot.gov/Pages/doing-bus/local-gov/hwy-mnt/winter-maintenance/rd-slt-strg.aspx.

- USGS collaborates with other agencies on research and hosts a webpage on groundwater protection through land use planning, organized by county: http://wi.water.usgs.gov/gwcomp/index.html.

Groundwater Workshops for Educators

What is the best way to help people appreciate how the groundwater under our feet works? Make it visible! The groundwater sand tank model does exactly that. The sand tank model represents a slice or cross-section view of the earth so students can "see" groundwater and interactively explore how water and contaminants flow through different geologic materials. Concepts such as water table levels, groundwater recharge and the effects of pumping on groundwater flow come alive when students see the model.

Students eagerly waiting to see how "contamination" flows from a seepage pond. *Photo: Doug Gouff*

To get these sand tank groundwater models [video link] into the hands of educators, DNR, WGNHS and UW-Stevens Point Center for Watershed Science and Education host teacher training workshops every year. Using funding from a federal wellhead protection grant, 20 educators from schools and nature centers around the state can attend a one-day training session and receive a sand tank model and classroom materials.

Wisconsin Geological and Natural History Survey

Educating Wisconsinites about state geology and water resources is a major objective for WGNHS scientists and staff. Scientists broadened their audience in 2016 using social media. By the numbers, staff had 17,200 educational contacts, 2,400 Facebook likes and 1,500 Twitter follows. Updating professional geologists, engineers and hydrologists on cutting edge research is another important function of the survey. Staff presented 142 talks and professional papers at scientific conferences. Highlights included:

- In July, staff talked with over 500 farmers and their families at Farm Tech Days near Lake Geneva in Walworth County. This worthwhile effort will be repeated when researchers go to Farm Tech Days 2017 in Kewaunee County;
- Staff interacted with about 400 people about drinking water quality in two days at the UW-Madison science fair;
- Scientists and staff hosted events on geology and groundwater at locations (including breweries in Madison and Minocqua) all over the state;

- Scientists presented two lectures at the popular "Wednesday Night at the Lab" series. These lectures are available online:
    - May 3, 2017 – Sewer Leakage: The Distribution of Pharmaceuticals, Artificial Sweeteners, and Enteric Viruses in Urban Groundwater - Madeline Gotkowitz http://www.biotech.wisc.edu/webcams?lecture=20170503_1900
    - October 12, 2016 - Wisconsin's Geoheritage: How Geology Shapes Wisconsin's Past, Present, and Future – Ken Bradbury http://www.biotech.wisc.edu/webcams?lecture=20161012_1900
- Outreach staff continue to work with teachers during "A morning of Wisconsin Geology" at the annual Wisconsin Society of Science Teachers conference;

Survey scientists updated all 500 registered hydrologists in the state on the predictive groundwater flow model for the Little Plover River.

The Center for Watershed Science and Education

The Center for Watershed Science and Education is located within the UW-Stevens Point campus in the agriculturally important and geologically vulnerable Central Sands region. Center staff provide Wisconsin communities with a unique drinking water program which can be organized at the request of Wisconsin communities. Programs offer participants a convenient opportunity to test water from their private wells for some of the most common health-related contaminants and other water quality concerns. Water test results are returned at an educational program presented by UW-Extension water quality specialists. In 2016, fourteen community-based drinking water education programs reached over 1,200 well users in 10 counties (Clark, Dodge, Green, Green Lake, Kewaunee, Sauk, Sheboygan, St. Croix, Taylor and Trempealeau). By the end of the program participants:

- gained a better understanding of the safety of their home water supply; an increased knowledge of local geology and groundwater movement;
- a better understanding of the processes and practices that may cause groundwater contamination;
- an increased understanding of local groundwater quality; and
- learned about practices that can improve or protect groundwater quality.

In 2016, UW-Extension staff worked with WisContext on a series of articles related to Understanding Well Water and Improving its Quality. The series received the Milwaukee Press Club's Silver Award for Best Public Service Award or Series. Center Staff assisted County Extension Faculty, Land Conservation Department staff, Natural Resource Educators, County Health Departments, DNR/DHS staff and planning and zoning departments with their outreach efforts. Staff and researchers from the Center also had well water testing booths for well owners at Farm Technology days, the Midwest Renewable Energy Fair and Central Wisconsin Water's Edge. Outreach staff held a water taste testing contest at the Wisconsin State Fair. The online Well Water Viewer they maintain had 8,212 unique queries for groundwater contaminants.

Wisconsin Groundwater Research and Monitoring Program (WGRMP)

One of the most compelling reasons to foster public awareness about groundwater is that about half of the Wisconsin residents who get their drinking water from groundwater rely on private wells. While public water systems are regulated by state and federal safe drinking water legislation, the protection and maintenance of a private well – including regular testing of water quality – is largely up to the owner. To protect the health of their families, it is important that these owners know that they should test, what to test for and how to obtain and interpret results. Surveys by researchers funded through the Wisconsin Groundwater Research and Monitoring Program (WGRMP) find that statewide, no more than 10% - 16% of private well owners have tested their well water for *any* contaminant within the past year (Knobeloch et al., 2013; Schultz et al., 2015).

To improve the effectiveness of GCC agency outreach efforts, a WGRMP-funded research project explored the barriers to testing private wells (Schultz et al., 2015). Survey results reveal that a critically important predictor of well testing is whether owners feel that they have sufficient knowledge about what to test for. When asked to identify more specific reasons why they did not test, the most common barriers included:

- perceptions that well water is safe to drink;
- lack of previous problems identified in a community; and
- feelings of security after drinking water for years.

This indicates that knowledge sharing about groundwater at a local level is key to encouraging the testing behaviors that protect human health. Findings like these underscore the importance of fostering public awareness of groundwater and help GCC agency members continue to adjust their outreach messages to target the most prevalent sources of confusion. Tools such as the Wisconsin Well Water Quality Viewer, the Environmental Public Health Tracking county profiles and targeted testing programs by local public health departments are some of the ways GCC partners work to bring knowledge about local groundwater quality risks to residents.

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Creating Community Based Solutions

What's the issue?

Whether we realize it or not, most of us in Wisconsin interact with groundwater on a daily basis. Around 70% of Wisconsinites rely on groundwater for drinking water and over 97% of agricultural irrigation water in the state is drawn from below ground (Maupin et al., 2014). While communities across the state are united in this dependence on groundwater, hydrogeological settings and pressures on groundwater resources are unique to each locality. As Groundwater Coordinating Council (GCC) agencies advance groundwater science and exchange information with one another, an equally large emphasis is placed on communicating this information to the public and empowering local communities to design groundwater solutions that make sense for them.

GCC in Action: *Comprehensive Planning*

By Wisconsin law, as of 2010 all cities, villages, towns and counties that adopt or amend zoning, land division or official mapping ordinances must do so consistent with a comprehensive plan. Communities that rely on groundwater as their sole source of water need to assess the magnitude and limits of their water source, but many need additional expertise to quantify and plan for their water supply. The Wisconsin Groundwater Research and Monitoring Program has funded several projects to help communities locate, evaluate and incorporate good groundwater information and data in their plans.

For example, researchers partnered with Richfield, WI to determine what kinds of groundwater supply information are most relevant and usable for planning from a community's perspective (Cherkauer, 2005). They determined that a good basic understanding of geology, sources, sinks and water balance of its aquifer system is needed so that residents and community leaders know where their water comes from. Interaction with users at all levels is also crucial to developing the awareness needed to create long-term plans and supporting laws to ensure a sustainable water supply under foreseeable future conditions.

A related project evaluated whether and how Wisconsin communities address groundwater in their comprehensive plans and what tools would help them do so (Markham et al., 2005). This led to the creation of a statewide website with relevant groundwater information for use in comprehensive planning and a suggested process for integrating this information in plans (Markham and Dunning, 2007). All of Wisconsin's 72 counties have a dedicated page that includes a snapshot of local data about groundwater susceptibility, sources of drinking water, groundwater quality, potential sources of contaminants, groundwater quantity and money spent on cleanup and groundwater protection strategies. Long term hosting and maintenance of the site is undetermined, but the emphasis on getting groundwater information into the hands of local decision makers in ways that are most useful to them remains an important focus of GCC work.

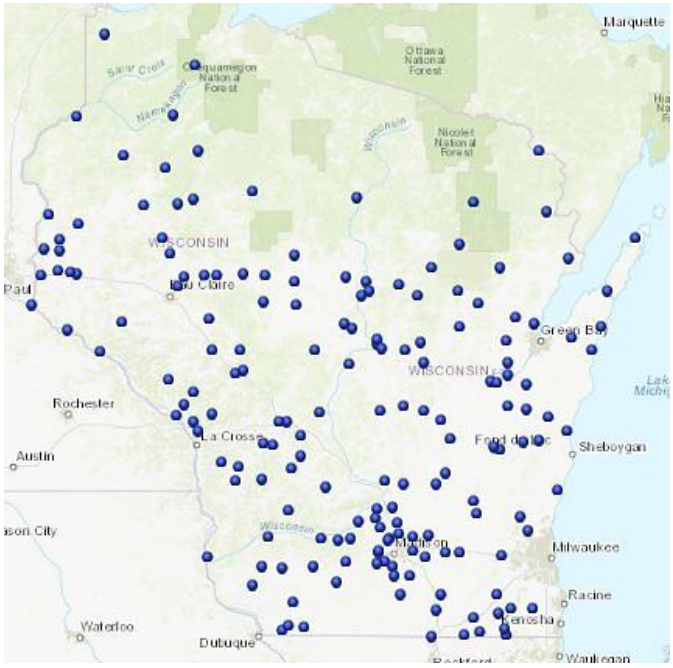
Other Projects in Other Places

Environmental Public Health Tracking

Environmental health data, including information on groundwater and drinking water supplies, is not always easy for local leaders to access and interpret. To assist with this, the Department of Health's Environmental Public Health Tracking program pulls data from several sources and combines them into one public portal. Community leaders and residents can explore environmental health issues such as air quality, water quality, asthma, cancer and childhood lead poisoning via tables, charts and maps designed specifically for their county.

In fall 2015, the Wisconsin Tracking team announced a new mini-grant program, *Taking Action with Data.* Five Wisconsin counties used data from their County Environmental Health Profile to propose projects addressing drinking water-related environmental public health issues in their communities. Staff from the Wisconsin Environmental Public Health Tracking program provided technical assistance on epidemiology, communications, evaluation, etc. Using these funds, these five counties have been able to achieve tangible results, such as increased private well testing and the creation of tools that can be used to better understand groundwater quality within the county. After the success of the first year, a second round of funding was announced in July 2016. Additional information about these projects can be found on the Wisconsin Tracking website.

Source Water Protection



Communities with protective plans for all wells that supply public drinking water as of August 2015. *Figure: DNR*

The DNR, in partnership with Wisconsin Rural Water Association (WRWA), Wisconsin Land and Water Association, Wisconsin Geologic and Natural History Survey, USGS and several UW departments, is making what they call "strategic interventions" to support community based solutions. As examples, the City of Waupaca and the Villages of Spring Green and Fall Creek are receiving technical and financial support to try innovative methods of working with neighboring landowners to tackle rising nitrate in public supply wells. In a different corner of the state, the Village of Luck updated its wellhead protection plan with assistance from WRWA and is considering a range of management possibilities that DNR groundwater programs are available to support. Luck is on a short list of communities with susceptible wells and active interest in water supply protection that DNR and partners are working with in order to provide new examples of local innovation

for others to emulate. These examples and additional resources are available on the DNR's Source Water Protection webpage, which seeks to link communities with the information they need to develop source water protection plans, as well as recognize communities that already have plans and ordinances in place.

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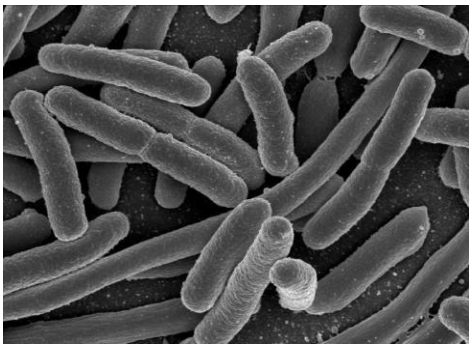
Pathogens

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.

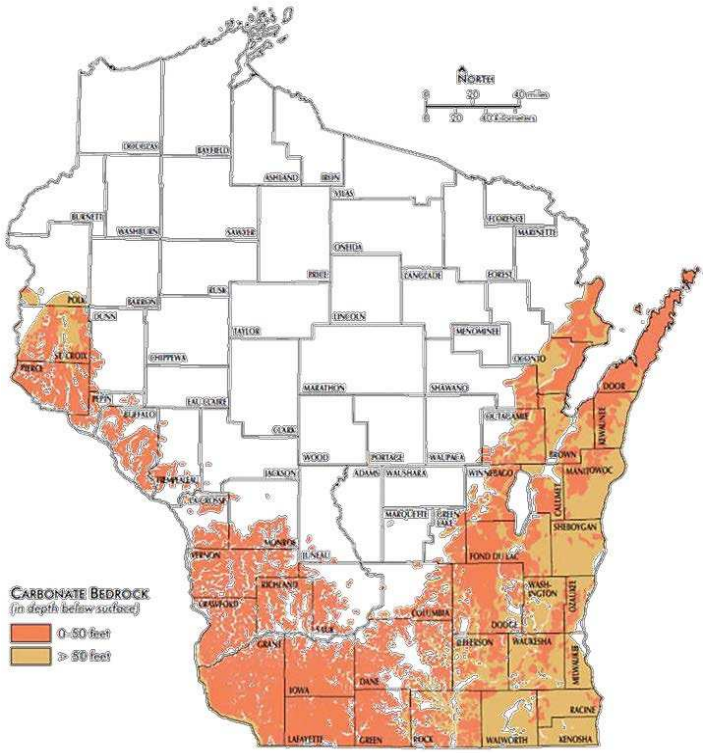
Coliforms are a broad class of bacteria that are naturally present in the environment and are used as an indicator that other potentially harmful microorganisms may be present. Fecal indicators, such as *E. coli*, enterococci and coliphages, are microbes whose presence more specifically indicates that 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).

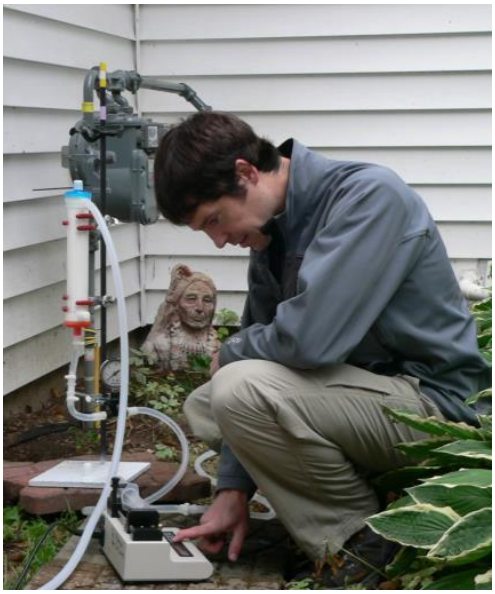
Research studies, utilizing PCR methods, have detected human enteric virus genomic material in both public and private wells in Wisconsin (Borchardt et al., 2003a, 2004, and 2007). There is limited statewide groundwater virus occurrence data since testing for viral genomic material is expensive, not 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]

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Nitrate

What is it?

Nitrate (NO_3) is a water-soluble molecule that forms when ammonia or other nitrogen rich sources combine with oxygen. The concentration of nitrate in water is often reported as "nitrate-N" which reflects only the mass of nitrogen in the nitrate (ignores the mass of oxygen). Nitrate levels in groundwater are generally below 2 parts per million (as nitrate-N) where pollution sources are absent. Higher levels indicate 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

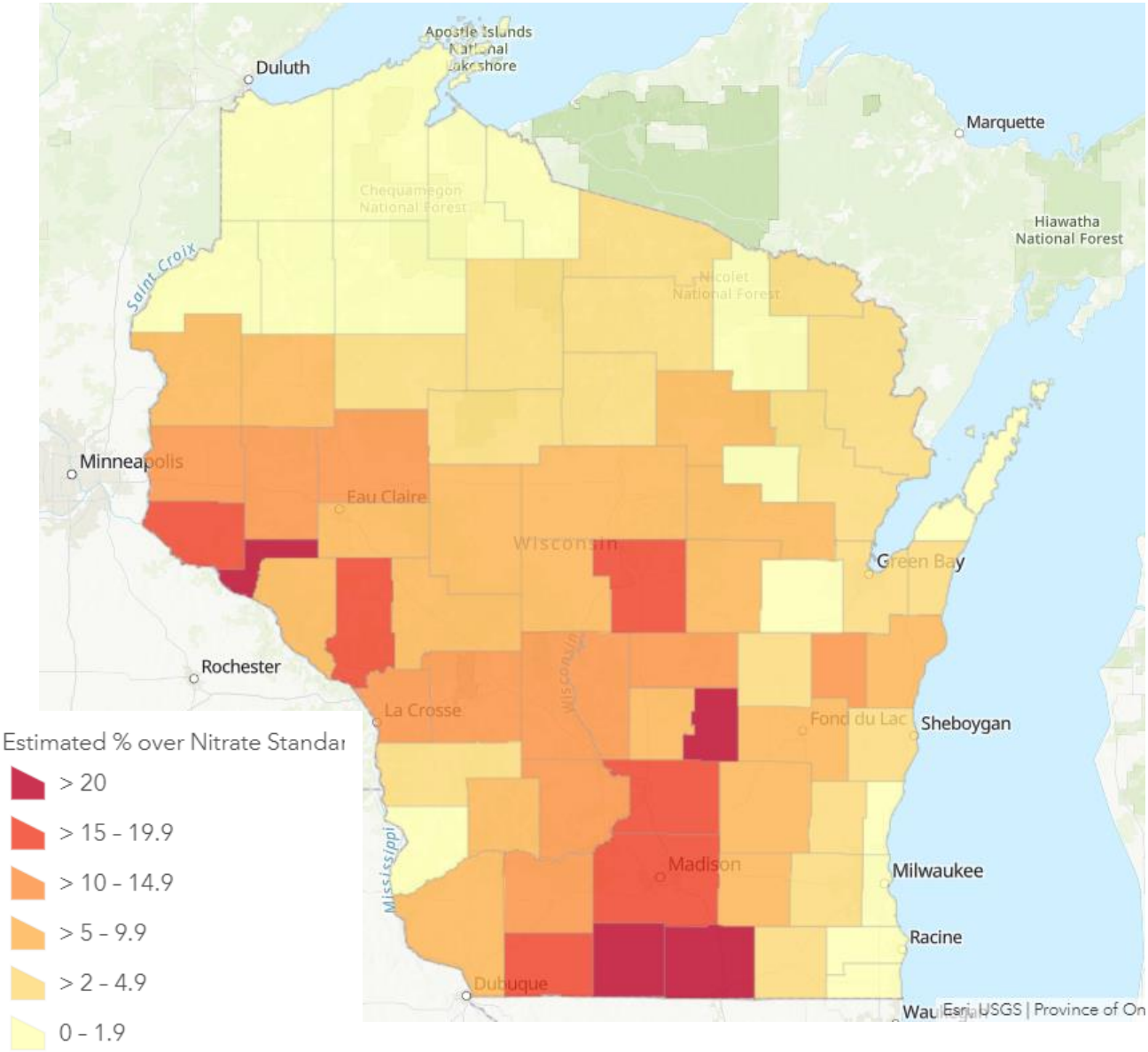
Nitrate is Wisconsin's most widespread groundwater contaminant. Nitrate contamination of groundwater is increasing in extent and severity in the state (Kraft, 2003; Kraft, 2004; Kraft et al., 2008; Saad, 2008). A 2012 survey of Wisconsin municipal water-supply systems found that 47 systems have had raw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

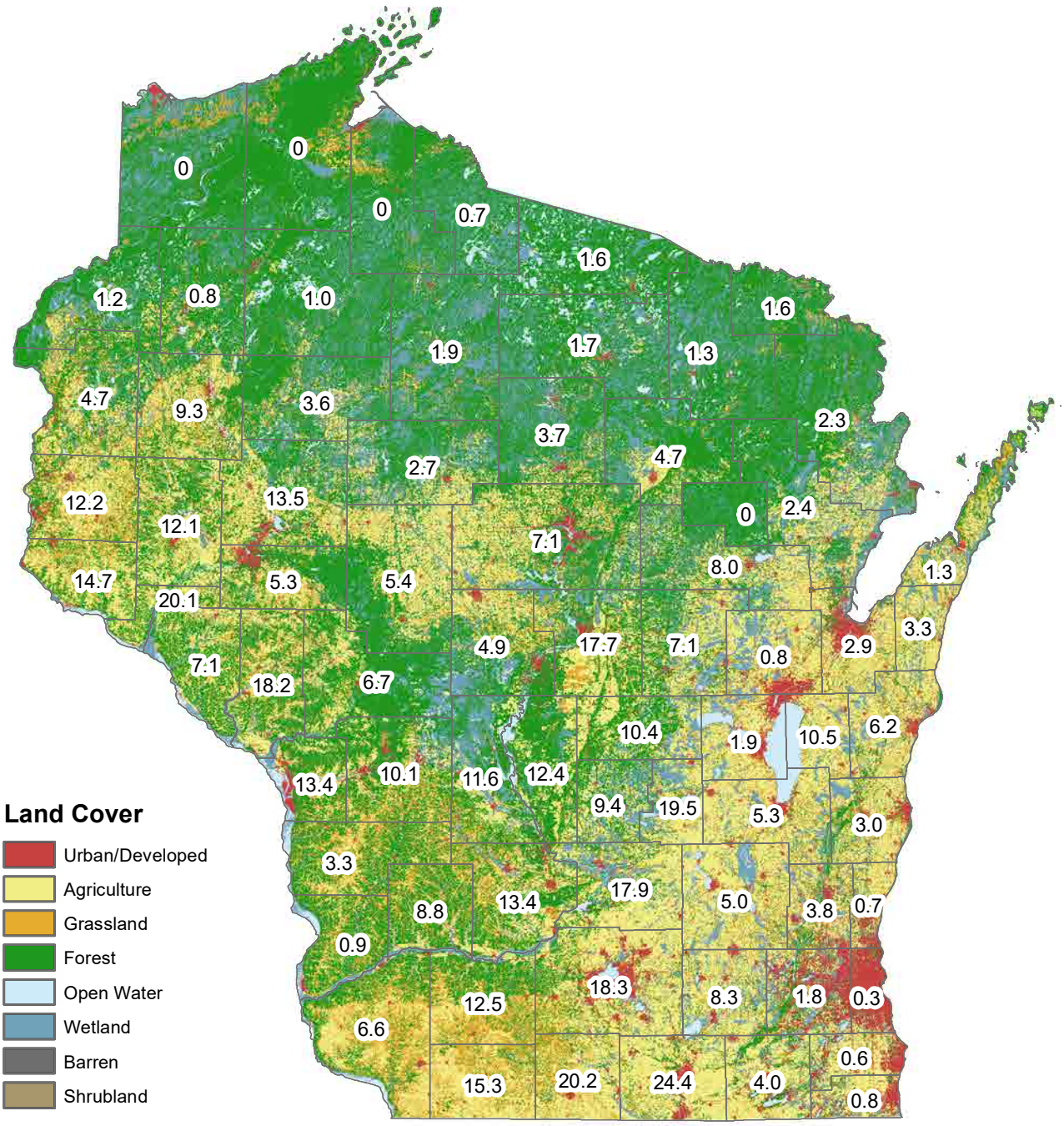
Since October of 2014 the department has received 55,000 sample results. This last spring the department analyzed the data set. This is probably the least biased large data set available in Wisconsin. Overall 7.6% of sample results were greater than 10 ppm for nitrate. However, some counties have a much 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.



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

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.

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.

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

The DNR began a program in 2012 to work with stakeholders on the "Wisconsin Safer Drinking Water Nitrate Initiative". This long-term program is targeted at reducing nitrate levels in groundwater by making the most efficient use of nitrogen in agricultural production. Activities in project areas include measuring current nitrogen inputs and baseline groundwater nitrate levels, calculating agricultural input

and production costs, determining and implementing best nitrogen management practices that optimize groundwater conditions and agricultural production efficiency, and measuring whether predicted results are achieved. Project areas are focused in areas where drinking water systems are approaching unsafe levels of nitrate contamination. DNR is currently working with stakeholders to determine and apply optimal nitrogen management systems to project areas. 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.

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.

Improved management strategies, technical tools, and incentives to promote efficient use of nitrogen are another top priority. The Wisconsin Safer Drinking Water Nitrate Initiative is designed to address many of these issues and will hopefully expand beyond the initial project areas in future years.

Throughout all of this, continued groundwater monitoring is also needed to assess existing problem areas and identify emerging areas of concern.

Further Reading

DNR overview on nitrate in drinking water [link]

DNR overview on nutrient management planning [link]

DATCP overview on nutrient management [link]

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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) (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 knocked out wells from La Crosse to Barron counties.

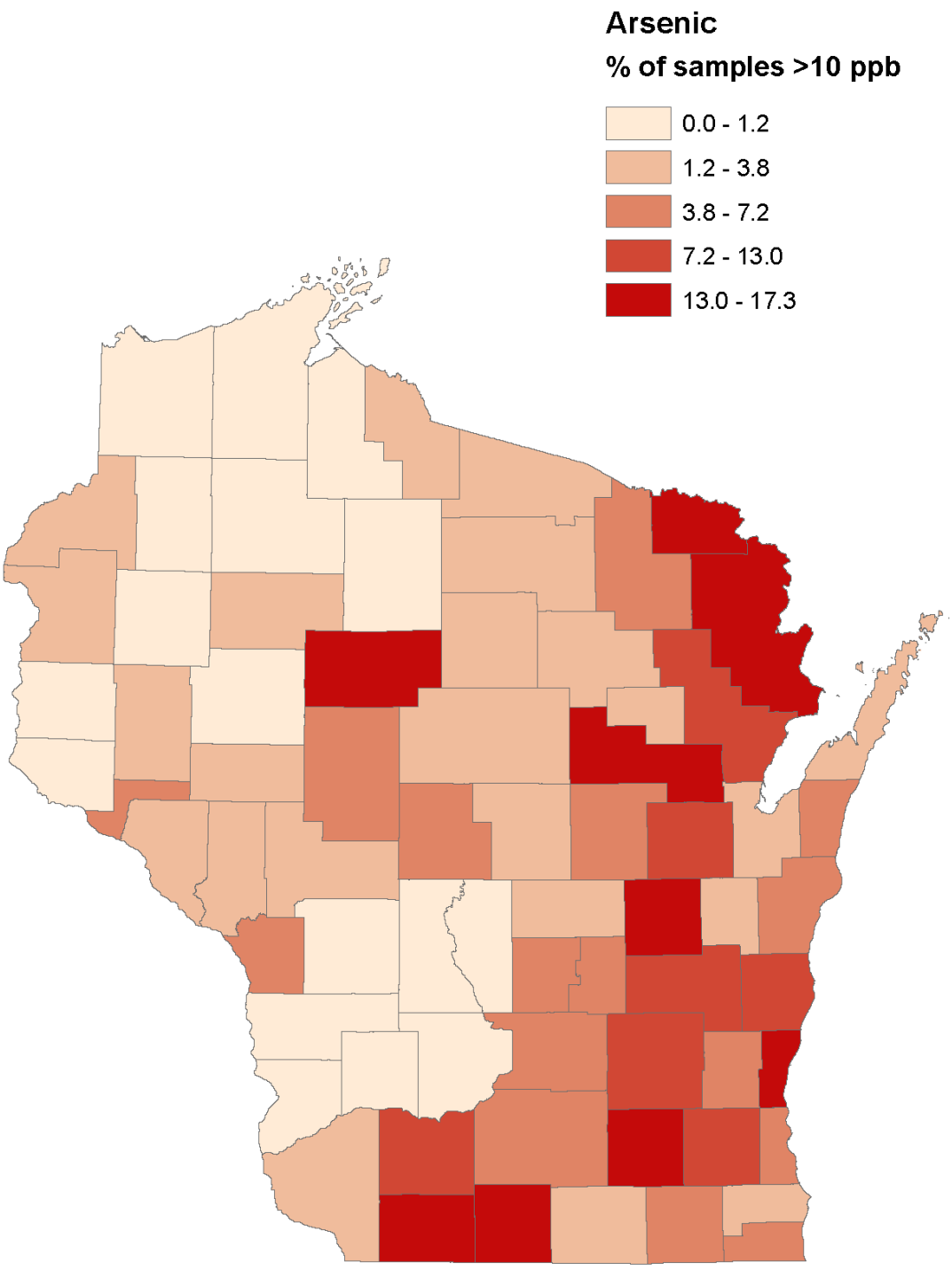
GCC Agency Actions

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 20,000+ samples collected over the first 3 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
Adams	0.8		
Ashland			
Barron	0.6	0.2	
Bayfield	0.8		
Brown	2.6	0.5	0.2
Buffalo	3.3		
Burnett	3.0		
Calumet	3.7		
Chippewa	0.4		
Clark	4.4	2.2	2.2
Columbia	5.3	1.7	0.3
Crawford			
Dane	4.5	0.9	0.5
Dodge	13.0	6.1	4.6
Door	2.0	0.2	
Douglas			
Dunn	2.0	0.3	
Eau Claire	1.6		
Florence	15.6	2.0	1.0
Fond du Lac	11.1	4.9	2.7
Forest	6.3		
Grant	1.5		
Green	13.7	4.1	1.4
Green Lake	5.7	0.6	
Iowa	10.1	3.4	3.4
Iron	3.2		
Jackson	1.4		
Jefferson	14.3	4.6	1.5
Juneau	0.6		
Kenosha	4.3	0.6	0.2
Kewaunee	6.6	1.9	
La Crosse	3.9		
Lafayette	15.4	5.9	3.7
Langlade	3.8		
Lincoln	3.1		
Manitowoc	5.2		

County	% >10	% >50	% >100
Marathon	1.7	0.7	0.3
Marinette	16.8	4.3	2.7
Marquette	4.5	1.3	0.6
Menominee	3.4		
Milwaukee	6.6		
Monroe	0.9		
Oconto	9.0	2.5	1.7
Oneida	2.0		
Outagamie	12.0	2.2	0.7
Ozaukee	16.4	2.6	0.9
Pepin	5.3		
Pierce			
Polk	1.4		
Portage	1.6	0.3	0.3
Price	1.2		
Racine	3.7	0.2	
Richland			
Rock	1.4		
Rusk	1.3		
Saint Croix	0.8		
Sauk	0.7		
Sawyer	0.8		
Shawano	17.3	3.0	1.8
Sheboygan	10.8		
Taylor	14.9		
Trempealeau	1.7		
Vernon			
Vilas	2.9		
Walworth	7.2	1.2	0.5
Washburn			
Washington	6.3	0.7	0.2
Waukesha	8.7	1.0	0.2
Waupaca	7.1	0.3	0.3
Waushara	1.7		
Winnebago	15.5	2.3	0.7
Wood	4.0	0.5	0.5

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.

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]

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Pesticides

What are they?

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

Pesticide application sign. *Photo*: DATCP.

The health effects of exposure to pesticides or pesticide metabolites vary by substance. About 30 pesticides (and some pesticide metabolites) currently have a ch. NR 140 groundwater quality health-based enforcement standard (ES) (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). Commonly detected pesticides which have 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 application. 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 pesticides products. Atrazine and its family of metabolites, total chlorinated residues, (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 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.

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 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).

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.

Organic agriculture in Wisconsin continues to grow at a steady pace. The number of organic farms in Wisconsin has grown 77 percent since 2005 (UW-Madison, 2015). One of the benefits of organic farming is the significantly decreased potential for pesticides in groundwater where organic practices are followed. As the organic market continues to expand due to increased consumer interest in organic food and reports of increased profits by organic producers (DATCP, 2011b), this may help reduce the amount of pesticides reaching groundwater.

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.

Further Reading

DHS resources for contaminants in drinking water [link]

DNR overview of pesticides in drinking water wells [link]

DATCP water quality reports [link]

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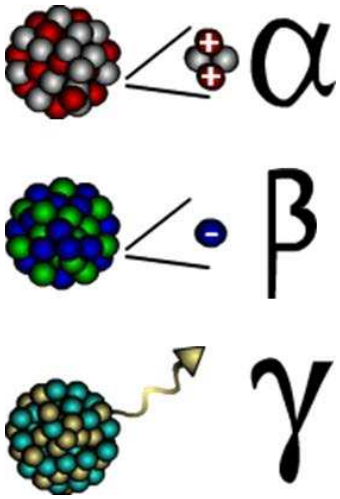
Naturally-Occurring Radionuclides

What are they?

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



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

There are no 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).

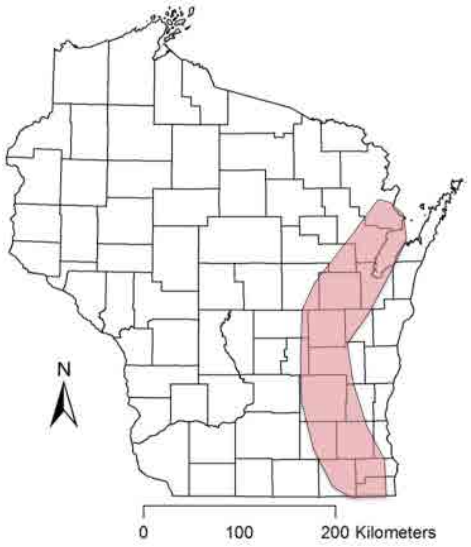
Occurrence in Wisconsin

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]

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Volatile Organic Compounds

What are they?

Volatile Organic Compounds (VOCs) are a group of common industrial and household chemicals that evaporate, or volatilize, when exposed to air. Examples of products containing VOCs include gasoline and industrial solvents, paints, paint thinners, drain cleaners, air fresheners and household products such as spot and stain removers. Chemical names for the VOCs in these products include benzene, 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 890.24). 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, 20,000 LUSTs and 8,000 other facilities which are required to monitor groundwater. The DNR also tracks approximately 33,000 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 with 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 approximately half of the 140 sites that fall into this category. 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]

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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 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.

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.

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).

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 perfluoroalkyl substances (PFASs), 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. It is suspected they may be present in groundwater at other locations near firefighting training sites and facilities that manufacture products containing PFASs.

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

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

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.

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.

Further Reading

DNR overview of pharmaceuticals and PCPs in the environment [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]

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Water Use

Chapter 281 of the Wisconsin Statutes requires annual reporting to the Wisconsin Department of Natural Resources of monthly withdrawals from all wells and surface water withdrawal systems capable of supplying water at a rate of 100,000 gallons per day or more. This includes water uses such as public supply systems, energy production, paper manufacturing and agricultural irrigation. The reported water use data is spatially located, w hich 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 2016 water use reporting showed that the largest category of groundwater withdrawals was municipal public water supplies, accounting for 93 billion gallons in 2016, down from 94 billion in 2015 (DNR 2018). The second largest category of groundwater withdrawal in the state was agricultural irrigation, totaling 65.5 billion gallons, a 19% decrease from 2015.

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

Reference:

Wisconsin Department of Natural Resources. 2018.

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Withdrawals. Technical Memo. 9p.

Groundwater/Surface Water Interactions

Studies including the 2017 Little Plover River groundwater model indicate that groundwater withdrawals have the ability to reduce streamflow. The degree to which groundwater withdrawals influence surface water stage can be site specific and further studies are underway to understand the role of water withdrawals on lake levels. 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 that are 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.

With financial support from DNR, the Wisconsin Geological and Natural History 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, 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.

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Regional Drawdowns

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

Lower Fox River Valley

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

By 2005, increased pumping from the communities surrounding Green Bay caused water levels to decrease to the low levels seen in 1957. In response to that drawdown, six suburban communities in the Lower Fox Valley reduced consumption of groundwater by about 8.2 million gallons per day by switching to surface water supplied by pipeline from Lake Michigan in 2007. As a result, water levels in the deep sandstone aquifer in and around Green Bay have risen. These changes at one well can be seen in Figure 1.

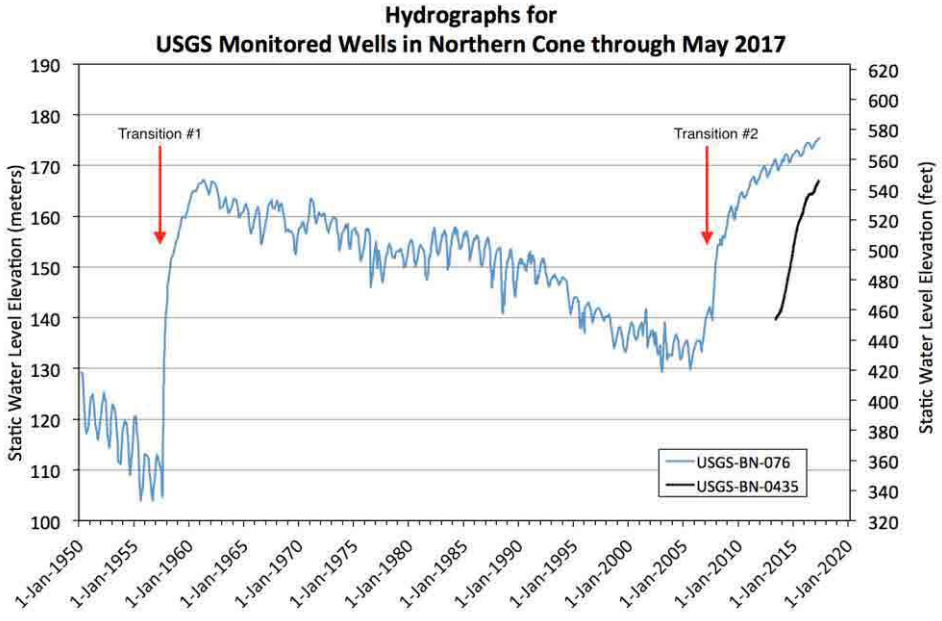

Figure 1: Changes in groundwater levels in a groundwater level monitoring well in Green Bay, Wisconsin. Transition 1 is City of Green Bay Switch to surface water. Transition 2 is Green Bay suburbs switch to surface water. (Luczaj)

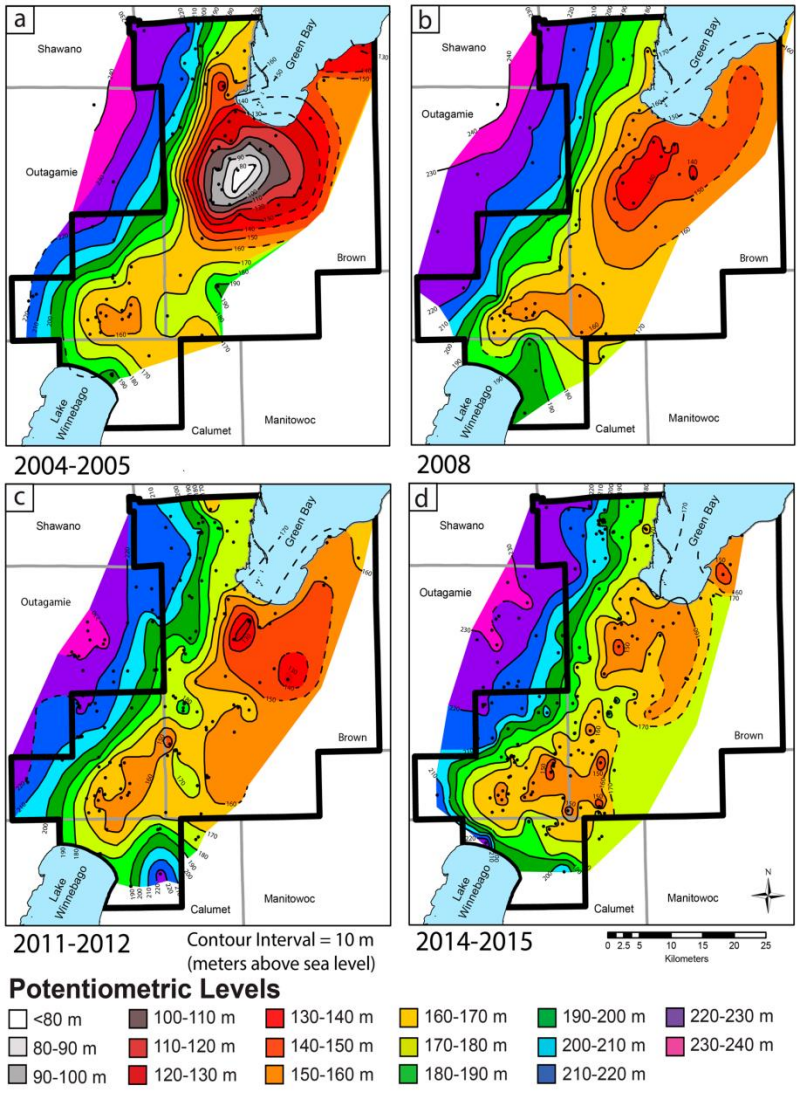

Figure 2: Water table elevations in Brown County (WGNHS).

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.

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.

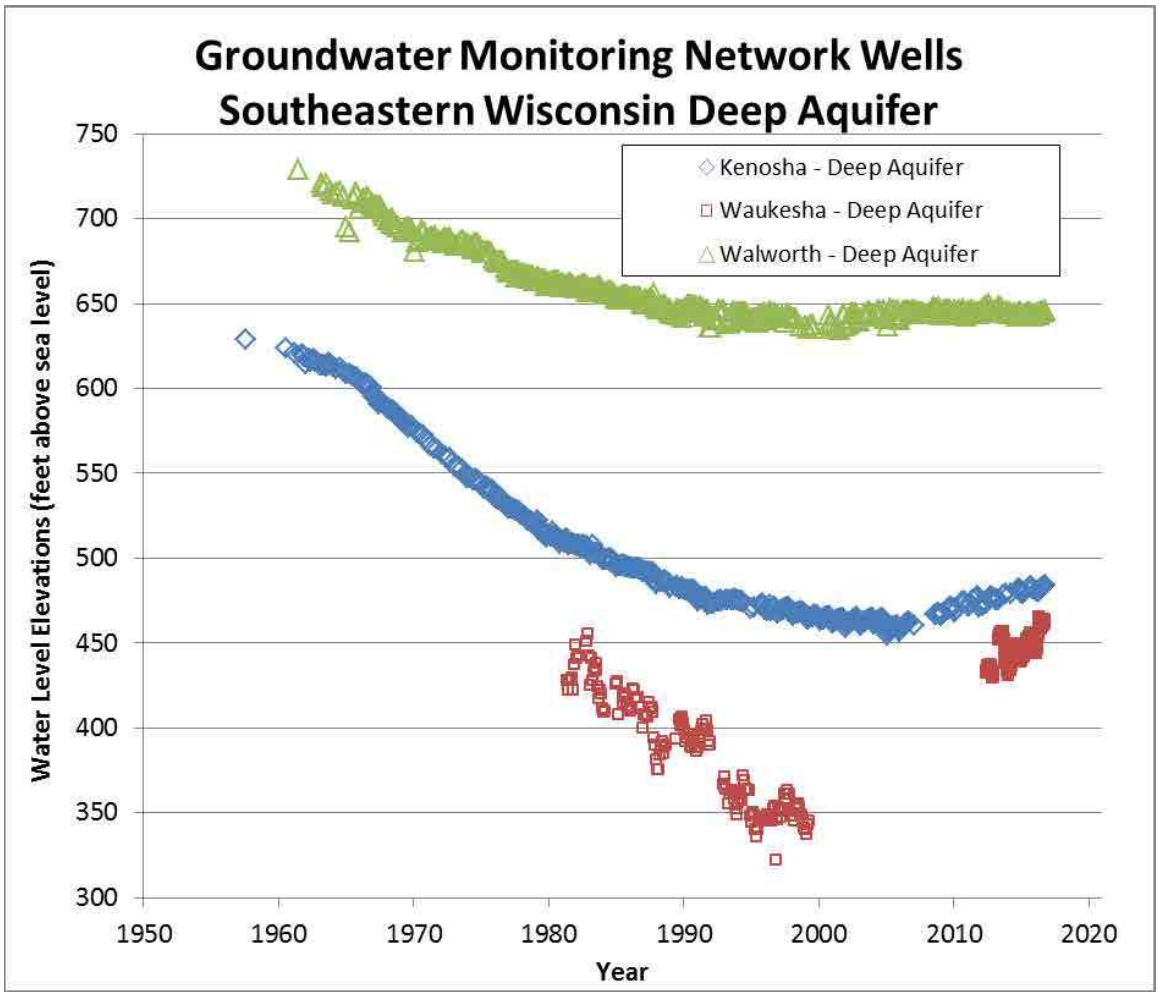

Figure 3: Water levels in a groundwater level monitoring wells in Kenosha and Walworth counties (DNR).

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 latest version of the Dane County model, begun in 2010 and slated for publication later this year (2013), 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 will provide 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 60 million gallons per day. The next largest withdrawals are made by irrigation (under 10%) and aquaculture (under 5%).

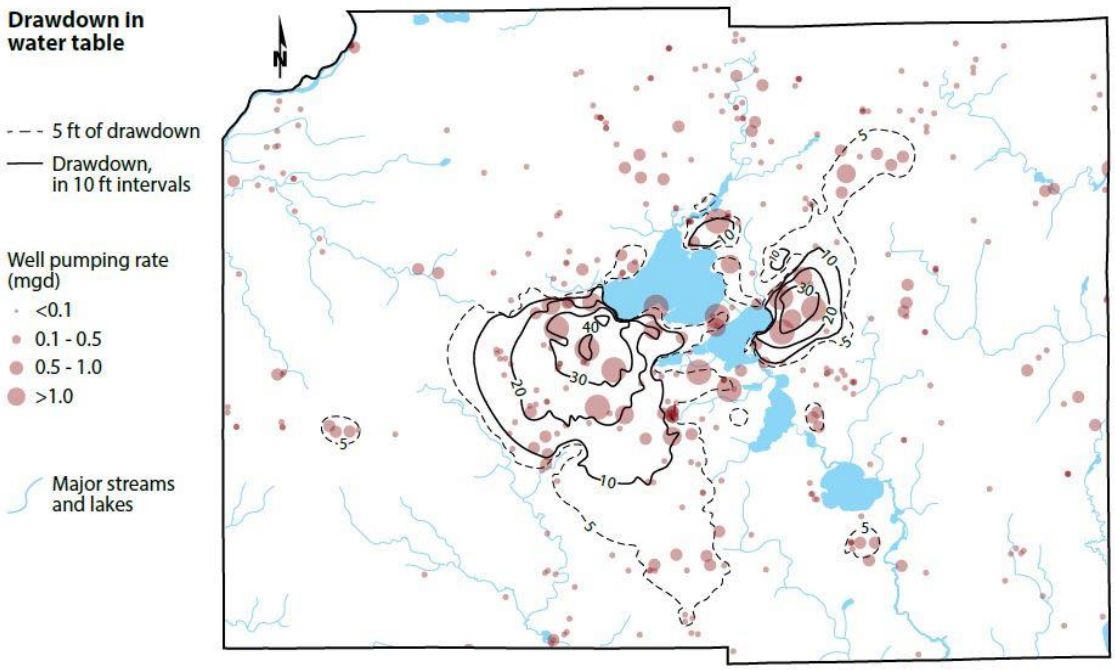

Figure 4 - Simulated drawdown (feet) in the Mount Simon Sandstone; predevelopment to 2010. The Mount Simon Sandstone, located several hundred feet below land surface and up to 800 feet thick, is the lowermost aquifer unit within Dane County. This porous sandstone is a highly productive aquifer which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

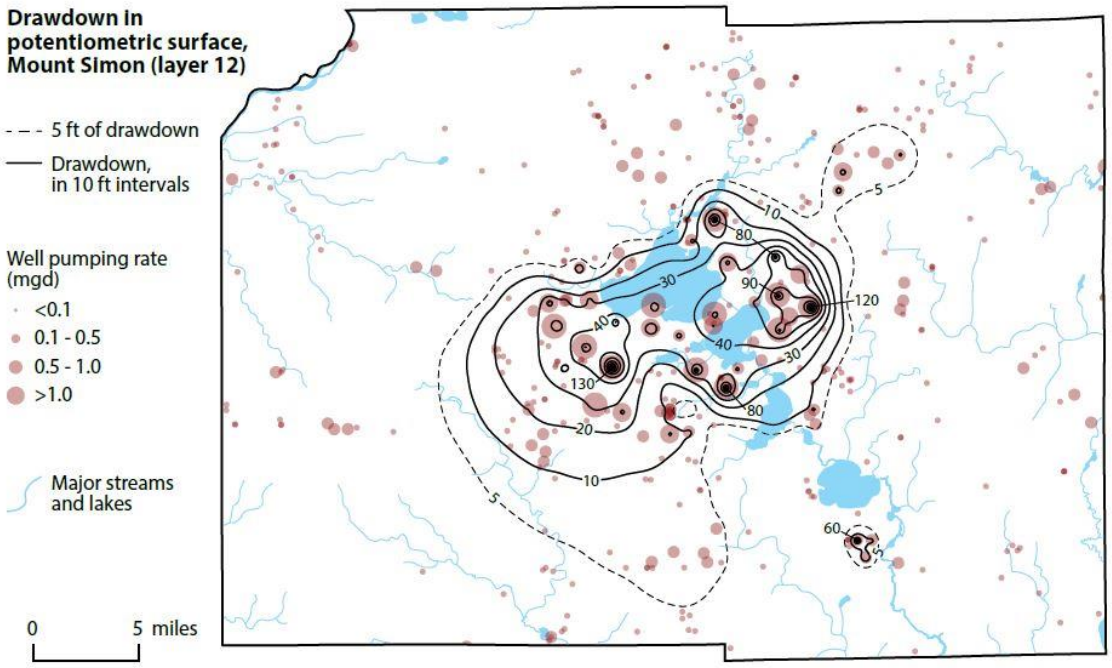

Figure 5 - Simulated drawdown (feet) at the water table; predevelopment to 2010. Drawdowns from the lower Mount Simon aquifer system propagate upwards to the shallow sand and gravel and upper bedrock aquifer systems to create drawdowns at the water table. (WGNHS)

Water use data collected for the updated 2013 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. Once the updated 2013 model is complete, it will improve 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.

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Groundwater-Level Monitoring Network

Wisconsin's groundwater-level monitoring network has been operated jointly by the Wisconsin Geological and Natural History Survey (WGNHS) and the U.S. Geological Survey (USGS) since 1946, working in close cooperation with the Department of Natural Resources (DNR). As of June 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 http://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 2018, DNR committed $120,000 to the Core Network and provided additional funding to USGS to install monitoring equipment on 21 short-term project wells in support of the Central Sands Lakes Study.

In FY 2018 WGNHS and USGS both obtained grants from the USGS National Ground-Water Monitoring Network (NGWMN) program. WGNHS received $83,728 to repair four wells and replace another. USGS received funding to improve well metadata for 11 wells, conduct slug testing and evaluation of eight wells, and add one well to the Climate Response Network.

Central Sands Lakes Study

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Chippewa county Groundwater Model

Chippewa County is working with WGNHS and USGS to conduct a 5-year study of groundwater resources in western Chippewa County. The goal of the study is 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? These questions are being answered through a combination of data collection and a groundwater flow model developed of western Chippewa County to understand current conditions and test hypothetical future scenarios.

Little Plover River Model and Watershed Enhancement Project

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

Beginning in 2017 stakeholders including the Village of Plover and agricultural producers in conjunction with DNR, consultants, and the Wisconsin Wetland Association, formed the Little Plover River Watershed Enhancement project with the goal of achieving sustained flow and aquatic health within the river. The stakeholders are utilizing the groundwater flow model as one tool to assist with establishing land and water best management practices. Learn more at: https://dnr.wi.gov/topic/groundwater/documents//LittlePloverRiverProjectUpdate.pdf.