Safe drinking water has become a major bipartisan priority in Wisconsin. Governor Tony Evers has declared 2019 the year of Safe Drinking Water and Assembly Speaker Robin Vos has commissioned a taskforce on Water Quality. This inaugural edition of the Nelson Institute for Environmental Studies Issue Brief focuses on the most widespread groundwater contaminant: Nitrates. This is an environmental and public health hazard faced by Wisconsinites statewide.

The great majority of the state’s drinking water comes from groundwater wells, and approximately 940,000 households are served by 676,000 private wells for which no testing is generally required. The state’s Groundwater Coordinating Council estimates that 42,000 private wells across the state have nitrate concentrations above 10 parts per million—the level considered unsafe for consumption by the U.S. EPA. The Wisconsin Department of Health Services (DHS) considers nitrate exposure at this level to pose a serious risk of metabolic and neurological disorders in infants. In addition, DHS cites that some studies suggest that high levels of nitrates may be linked to birth defects, thyroid problems, and certain kinds of cancer.

UW–Madison faculty are doing research relevant to this public health and environmental challenge, and are available to local governments and state leaders as they consider the ways to limit groundwater contamination while minimizing impacts to farm income and residential property rights. We hope these research summaries will stimulate linkages between the UW community and Wisconsinites statewide who are facing water quality problems and looking for answers grounded in world-class research. Please reach out to the researchers highlighted in this report if you have further questions about their work.

Nitrate levels are too high in wells used by an estimated 94,000 Wisconsin households that have private water wells. Agricultural areas and those with porous bedrock or sandy soil are most susceptible to nitrate contamination. It comes from fertilizers, including manure and other sources.

CREDIT: Katie Kowalski/Wisconsin Center for Investigative Journalism

» Understanding nitrate content in groundwater can help farmers manage their nitrogen application more efficiently.

» Groundwater nitrate contamination is a product of manure, fertilizer, and septic systems.

» Changes in agricultural practices to reduce nitrate applications can have significant impacts on groundwater quality.

» Increased well monitoring of private wells and septic system mapping better informs decisions about where to locate septic systems.

» Collaboration among state agencies, the University and farmers is key to understanding and addressing groundwater quality issues.
Does changing nitrogen application change nitrate leaching? Changing the land cover can have a large impact because different amounts of nitrogen are taken up by different plant communities. For instance, our simulations of Midwestern cropping systems show higher levels of nitrate leaching under corn than under soybeans. Simulations of the Yahara watershed in south-central Wisconsin show that increased coverage of perennial grasses and decreasing nitrogen applications result in decreased nitrate leaching.

Nitrate research in the Central Sands. The Wisconsin Central Sands (WCS) is a major vegetable producer, but due to the region’s sandy soil, irrigation is required in combination with applications of nitrogen fertilizer. This makes the region prone to leaching of nitrate and groundwater contamination. Irrigation water drawn from wells that tap into contaminated groundwater is already high in nitrate, but it is unclear how nitrate levels in groundwater change across space and time. Thus we want to know how to account for the nitrogen applied through irrigation water, as opposed to the nitrogen directly applied through fertilizer, in farmers’ mandatory nitrogen management plans. By accounting for irrigation-water nitrogen, farmers may be able to reduce synthetic fertilizer applications, saving money while reducing nitrate losses to the groundwater system. Additionally, crops’ efficiency in using water and nitrogen will shift with a changing climate, which may change how we can reduce nitrate leaching to groundwater.

Kucharik research: https://www.kucharik-lab.com/

UWLandLab and Grassland 2.0. Managed grazing using perennial grass systems across Wisconsin can reduce nitrate leaching while also providing a sustainable livelihood for dairy and beef producers in a challenging economic environment. In the UWLandLab we (along with Claudio Gratton, Michael Bell, and Bradford Barham) work with farmers, scientists, distributors, processors, and consumers to incentivize moving livestock production toward perennial grassland grazing. UWLandLab aims to serve as a roadmap for those interested in moving from input-intensive annual cropping systems towards perennial grassland-dominated landscapes, a vision we call Grassland 2.0.

Through both field-testing and modeling, we hope to provide the tools to improve ground-water quality and reduce water use. Both will be important as increasing weather variability makes water resources management and nitrogen applications to crops more challenging.

Jackson research: https://jacksonlab.agronomy.wisc.edu/

WHAT AFFECTS A RURAL TOWN’S WELL WATER?

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Like many smaller municipalities in Wisconsin, Spring Green, in Sauk County is experiencing increasing nitrate concentrations in the wells supplying its drinking water. Through DNR-funded research, we measure nitrate entering the groundwater under different management conditions and crop types. We are also working with farmers near Spring Green to assess how climate and agricultural practices contribute to the nitrate leaching to groundwater beneath agricultural fields. Farmer participation is crucial to the success of this project. We have found that consistent communication with farmers about our goals, experimental plans, and preliminary findings has helped to build trust in this relationship and avoid interference with farm operations. Farmers can supply vital specialized information, including records of irrigation, nutrient applications, and planting plans.

We use edge-of-field wells and an inert tracer in order to calculate net nitrate leaching from fields. In Spring Green we have quantified the contribution of a portion of a field to nitrate in groundwater as climatic conditions, crop plantings, and fertilizer applications have all varied. We will ultimately develop a dataset capable of relating nitrate mass loss from fields to climate, crop, and fertilizer management conditions. We will thus produce a real-world database as a basis for recommending agricultural “best practices” for nitrate management. This data will also help municipalities determine economical methods for reducing nitrate concentrations at municipal wells, which may include incentivizing change in crop types, revised fertilization rates, land purchases, or deepening of water supply wells.

Cardiff research: http://geoscience.wisc.edu/geoscience/people/faculty/michael-cardiff
Septic systems collect, treat, and release wastewater into the groundwater. According to the U.S. EPA, failing septic systems are the second greatest threat to groundwater quality. Densely-clustered systems can introduce nitrates, bacteria, and viruses into local water resources.

We identified housing clusters in southeastern Wisconsin that may pose risks of groundwater contamination.

Wisconsin’s plumbing code allows rural houses to be served by private wells and on-site septic systems. Land-use policy now allows clustered housing development on rural sites that were once considered unsuitable for septic systems due to environmental constraints, but such clusters can create “hot spots” of groundwater contamination. At a density of two septic systems per acre, the estimated annual nitrate loading is equivalent to the nitrate leached from one acre of corn field. This contamination may cause private wells to exceed the EPA’s maximum contaminant level, but may go unnoticed since less than 10 percent of such wells are tested annually.

Local land use regulations in Wisconsin typically require minimum lot sizes of at least 0.5-acre for new rural homes served by septic systems. But in Ozaukee County, 624 acres of residential subdivisions exceeded this per-acre septic density in 2010. About 42 percent of this land is classified as having “high” groundwater vulnerability. About 200,000 septic systems in Wisconsin predate current regulations, and many of these systems have reached the end of their functional lives. As of 2015, 38 percent of septic systems in Ozaukee County were installed before permitting requirements were adopted in 1971. There is little information on the performance of these older systems.

Periodic well monitoring and septic system maintenance can help households protect their drinking water. For local governments, GIS analyses of existing septic systems and land suitability can ensure that future septic systems minimize risks to the environment and human health.

**HOW DENSE SHOULD SEPTIC SYSTEMS BE?**

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LaGro research: https://dpla.wisc.edu/staff/james-a-lagro-jr/

**HOW DOES THE RESIDENTIAL DEVELOPMENT OF FARMLAND AFFECT NITRATE IN GROUNDWATER?**

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What happens to groundwater when rural farmland is converted to residential homes with on-site septic systems? We use monitoring and flow modeling to understand the relationship between land use and nitrate contamination in groundwater.

**Savannah Valley – Near Sun Prairie.** We monitored groundwater quality for 10 years in Savannah Valley, a 78-acre unsewered subdivision in south central Wisconsin. We used groundwater monitoring wells measuring nitrates in both a shallow gravel and a deep bedrock aquifer. Monitoring began in 2002 while the site was primarily used for corn, soybean, and alfalfa production, and continued as it was converted to residential homes.

Prior to development, groundwater quality showed high variability in both space and time. Nitrate in the shallow wells exceeded 10 mg/l in some wells, and there was evidence of other effects from agricultural use and highway salting in many wells. Concentrations in deeper wells, although lower and less variable, also showed evidence of impacts from land use.

Between 2002 and 2013, nitrate concentrations showed statistically significant decrease in 6 of 12 (50 percent) of the wells most frequently sampled. In 2002, seven wells exceeded the 10 mg/l (as N) nitrate standard; in 2013 only one well exceeded the standard. With decreased use of agricultural fertilizers and manure in farm fields as land use has changed, nitrate levels have substantially decreased in over half the wells sampled.

Groundwater testing near Sun Prairie, Wis. Photo credit: Ken Bradbury

Nelson Issue Brief • May 2019, Volume 1, Number 1 • nelson.wisc.edu
Municipal Wells
Capture Zones
Well #2
Well #3
Well #5
Well #6

City of Waupaca. Nitrates concentrations in a municipal well field serving Waupaca, Wisconsin have demonstrated large spatial and temporal variability, and data between 2006 and 2018 show that maximum annual concentrations are increasing. In order to understand how nitrate reaches Waupaca’s municipal supply we need to identify land areas where water infiltrates and flows towards the well, areas known as the well’s “capture zone”. We developed a model to simulate groundwater flow through a 26 square mile watershed contributing to the Waupaca wells in order to find the capture zone. We found that the capture zone providing water to Waupaca’s well within one year (the “short-term capture zone”) is covered by unsewered residential areas and cultivated cropland. Changes to this pattern of land use may thus result in significant changes to well water quality. Other research has shown that targeted land management changes have proven effective in reducing groundwater nitrate concentrations.

Our research finds that long-term monitoring is necessary in order to draw conclusions about how nitrates in groundwater respond to land use changes and provides some guidance for land management approaches to reducing groundwater nitrate.

Nitrate concentrations are increasing. In order to understand how nitrate reaches Waupaca’s municipal supply we need to identify land areas where water infiltrates and flows towards the well, areas known as the well’s “capture zone”.

Parts of the Mexican state of Yucatan are classified as extremely vulnerable to aquifer contamination due to bedrock with rapid groundwater flow, in which contaminants quickly move into groundwater wells. As in Wisconsin, a large part of the rural population gets their water from groundwater wells.

Yucatan lacks the infrastructure for large-scale sanitary engineering and providing safe drinking water. Analysis of well water found concentrations of nitrates in Yucatan’s agricultural zone that are far above levels allowed by national and international norms. Average concentrations were at 102 ppm and peak concentrations of 141 ppm, over ten times the US EPA’s limit of 10 ppm.

This high concentration suggests strong negative repercussions for the public health and safety of the ethnically Mayan agricultural regions of Yucatan, where the rates of cancer, congenital deformities, and neural deficiencies are high.

Mayan activists have focused political attention on the link between agricultural practices and human health. Alliances of scientists, international foundations, and Mayan leaders who denounce the use of chemical fertilizers. This has led in turn to interest in reviving ancient Mayan sustainable agricultural practices such as milpa (cyclical fallowing through forest regeneration). Water quality concerns also lead to a focus on protecting cenotes – groundwater-fed lakes beneath sinkholes in a karst landscape which are sites of deep spiritual significance and recreation. Water quality concerns reach every aspect of life in rural Yucatan and water quality is inseparable from rural life and health.

WATER QUALITY AND RURAL LIVES

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Nutrients used in industrial agriculture transform landscapes and affect rural livelihoods worldwide. We focus on people’s understanding of the pollution of water by nitrogen fertilizers in agriculture. Public awareness and response are a crucial part of understanding any public health crisis.

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Beilin research: https://spanport.wisc.edu/staff/ beilin-katarzyna-olga/