NITRATE

What is it?

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

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

What are the human health concerns?

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

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

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

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

Biotic effects

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

How widespread is elevated nitrate in groundwater?

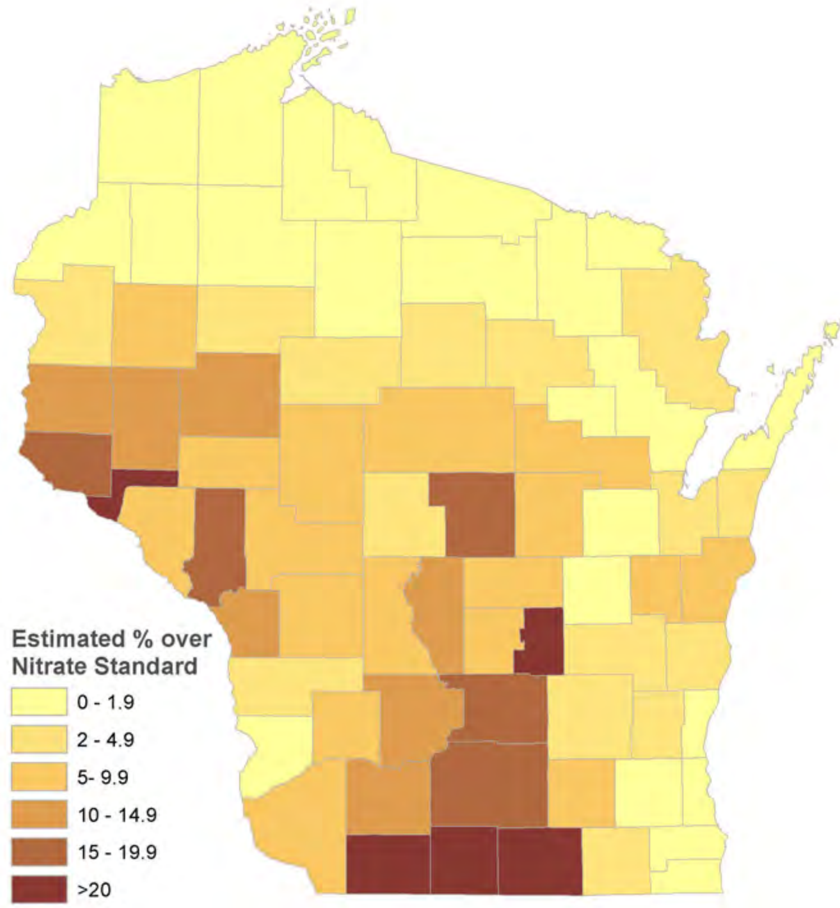
Nitrate is Wisconsin's most widespread groundwater contaminant. Nitrate contamination of groundwater is increasing in extent and severity in the state (Kraft, 2003; Kraft, 2004; Kraft et al., 2008; Saad, 2008). A 2012 survey of Wisconsin municipal water-supply systems found that 47 systems have had raw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

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

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

In 2014 NR 812 code (Well Construction and Pump Installation) was changed to require sampling of 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. In 2020 for new well and pump work there were 17,029 samples taken. 1080 were greater than 10 ppm (6.3%).

Beginning in October of 2014 until late 2018 the department has received over 80,000 sample results. This last spring the department analyzed the data set. This is probably the least biased large data set available in Wisconsin. Overall 7% of sample results were greater than 10 ppm for nitrate. However, some counties have a much greater percentage of well testing above the 10 ppm standard. See map below for individual county results.



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

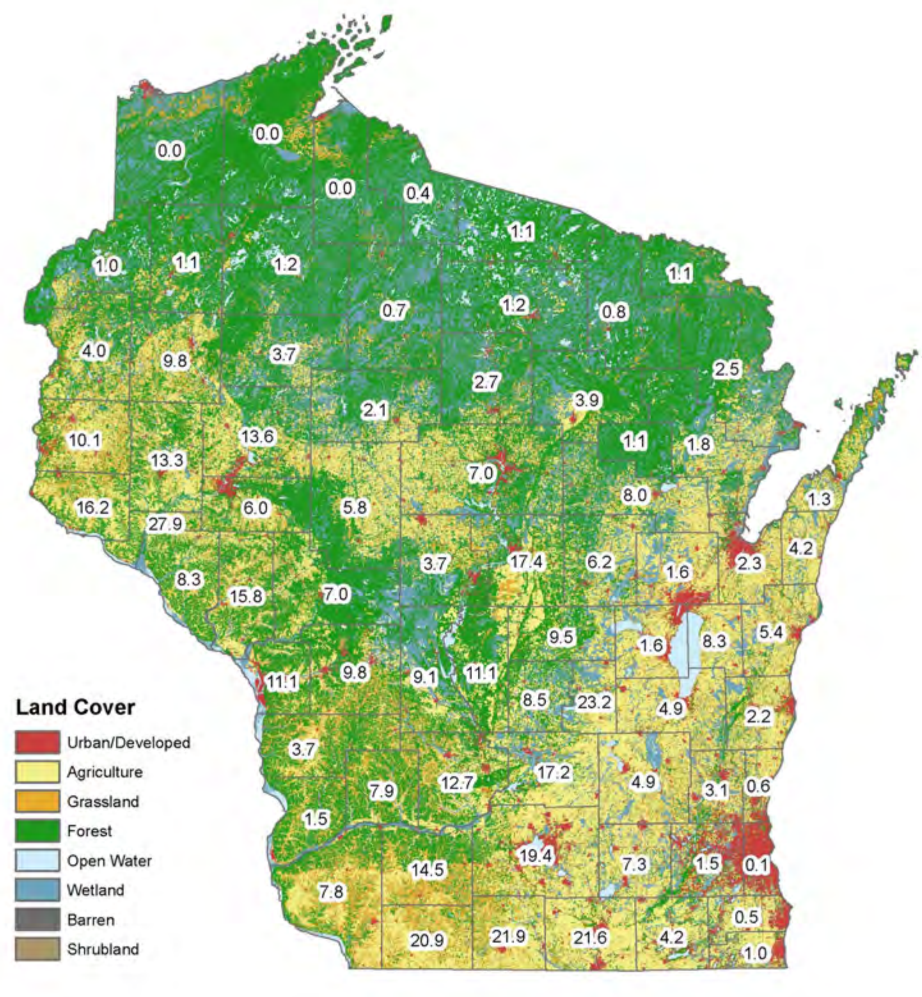
To obtain a safe water supply, private well owners may opt to replace an existing well with a deeper, better cased well or, if available, connect to a nearby public water supply. Owners of nitrate-contaminated private wells can qualify for the state well compensation grant program only if the nitrate-N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

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

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

What makes an area vulnerable to nitrate contamination?

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

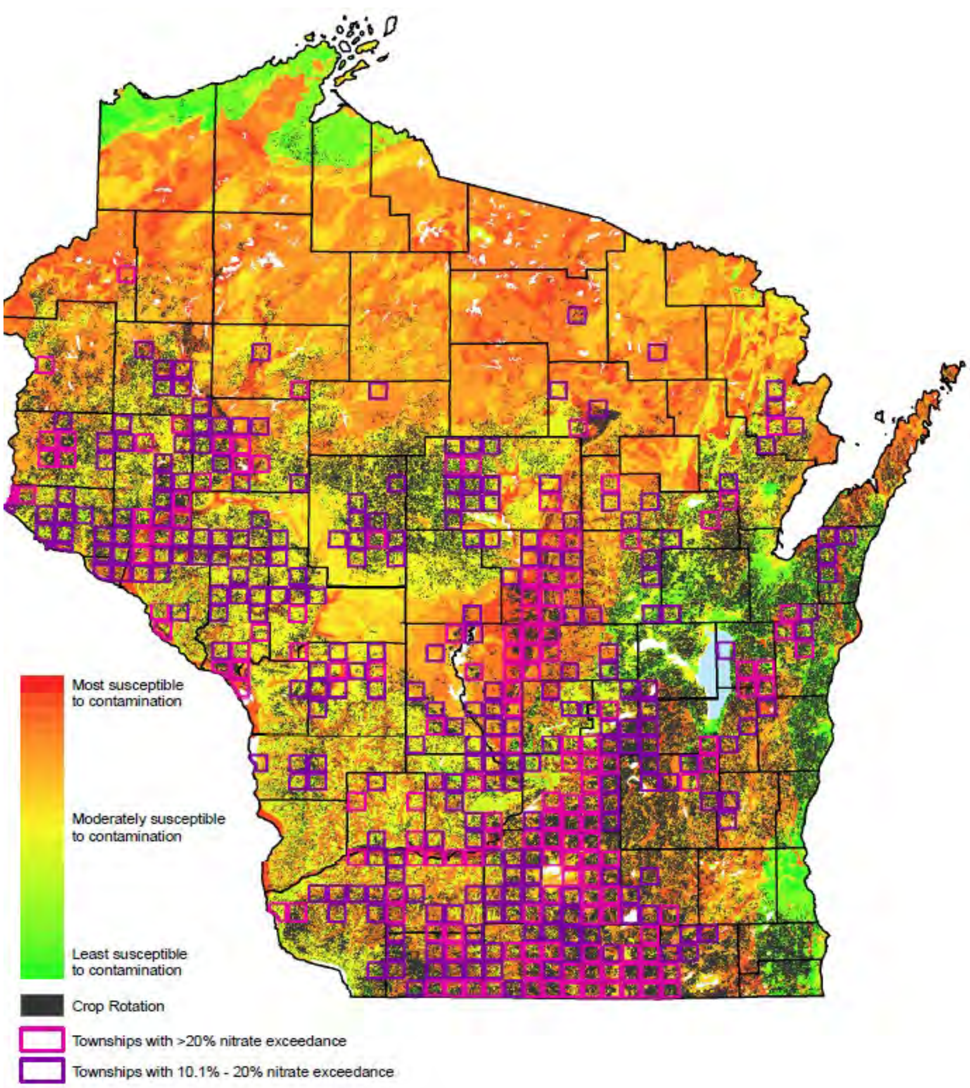


Map of Estimated Percentage of Private Wells over Nitrate Standard by County with Land Cover (October 2014 through April 2021).

percentage of wells over 10 mg/l were noted when grouping the data by surrounding agricultural intensity; the percentage increased from 1.7% when surrounding land was lightly cultivated to 20% of wells exceeding the health based standard when the surrounding land was greater than 75% cultivated (DATCP,2017).

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

The dominant effect of land use in comparison to aquifer sensitivity is also illustrated when overlaying township level private well nitrate data and agricultural land use with the Groundwater Contamination Susceptibility Model (GCSM). The GCSM for Wisconsin was developed by WGNHS, WDNR, and the USGS and is intended to be used at broad scales. Five physical resource characteristics for which information was available were identified as important in determining how easily a contaminant can be carried through overlying materials to the groundwater. These factors are type of bedrock, depth to bedrock, depth



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

to water table, soil characteristics, and characteristics of surficial deposits (geologic materials lying between the soil and the top of the bedrock). Areas with sand and gravel are considered more sensitive to groundwater contamination; areas with silt and clay are considered less susceptible. When viewed at a statewide scale, many parts of the state with only moderate aquifer sensitivity have townships where greater than 10% and frequently greater than 20% of private wells exceed the health-based standard for nitrate in drinking water.

How is groundwater nitrate trending over time?

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

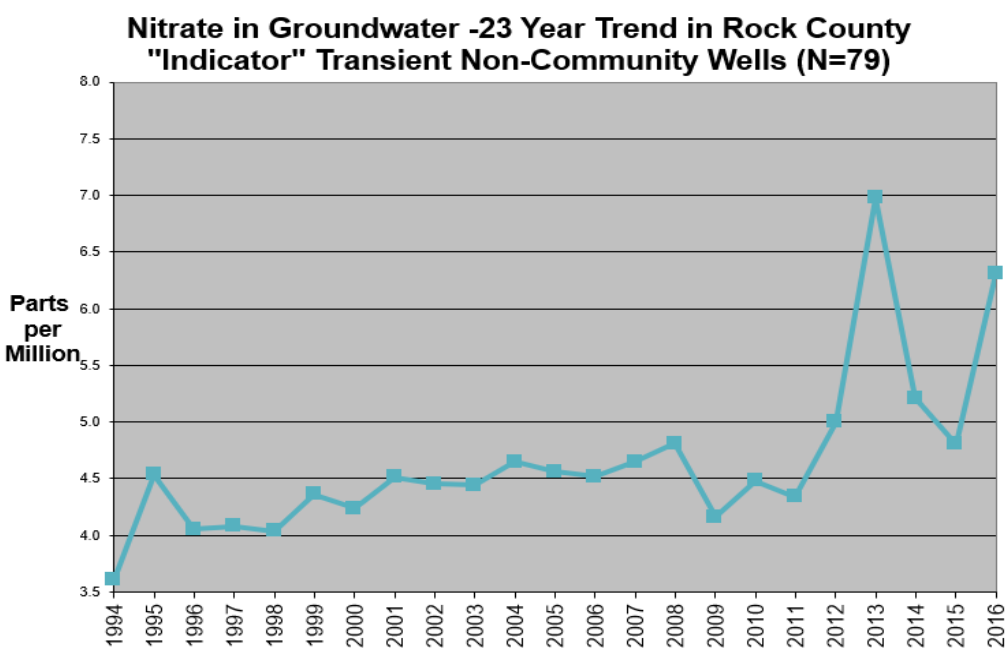
An assessment of overall statewide nitrate trends using existing private and public well data is challenging for several reasons. Fundamentally, public water data sampling is focused on the goal of providing water at the tap meeting required maximum contaminant levels (MCLs) and not to track changes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

One available data set with a large number of wells distributed across the state is the Safe Drinking Water Act compliance data set for non-community public wells (e.g. small businesses, schools, and churches). There are approximately 11,0000 wells of this type active at any given time, and they are required to submit nitrate sample results to DNR at least annually. In review of the historical record of public supply well data since 1975, we find a relatively consistent number of wells exceed the 5 mg/L and 10 mg/L nitrate thresholds in any decade (i.e. about 18.3% of non-community water systems exceed 5 mg/L and about 6.5% exceed 10 mg/L). However, when looking at these public wells for the full period of record, there is a much larger set of wells represented (>20,000 wells) and the total number of wells exceeding these thresholds at any point in time is greater than in any discrete decade. Over the full record of the WDNR Public Water System database, approximately 21% of these wells exceeded 5 mg/L and approximately 8.3% exceeded 10 mg/L. Many of the nitrate impacted wells have dropped out of the data set over time. This is to be expected, as these are wells providing drinking water and subject to regulation to meet drinking water standards. The table below lists the MCL violation for nitrate over the last 5 years by well type.

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

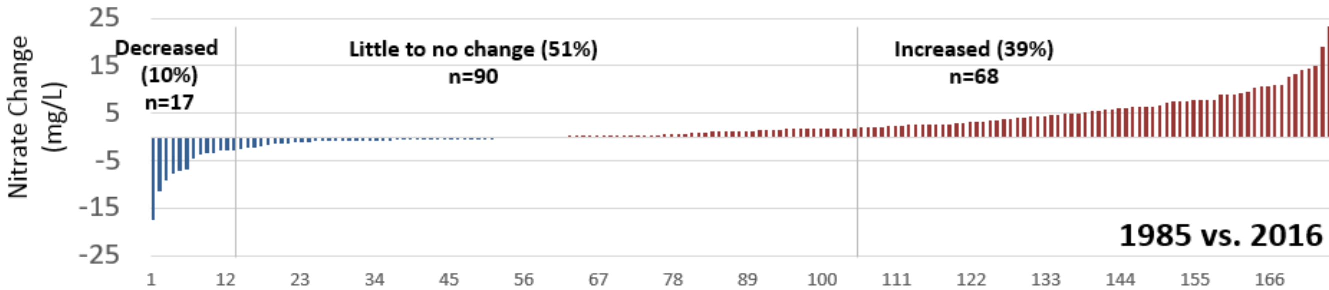
The numbers for TN systems do not include the wells on continuing operation between 10 ppm and 20 ppm.

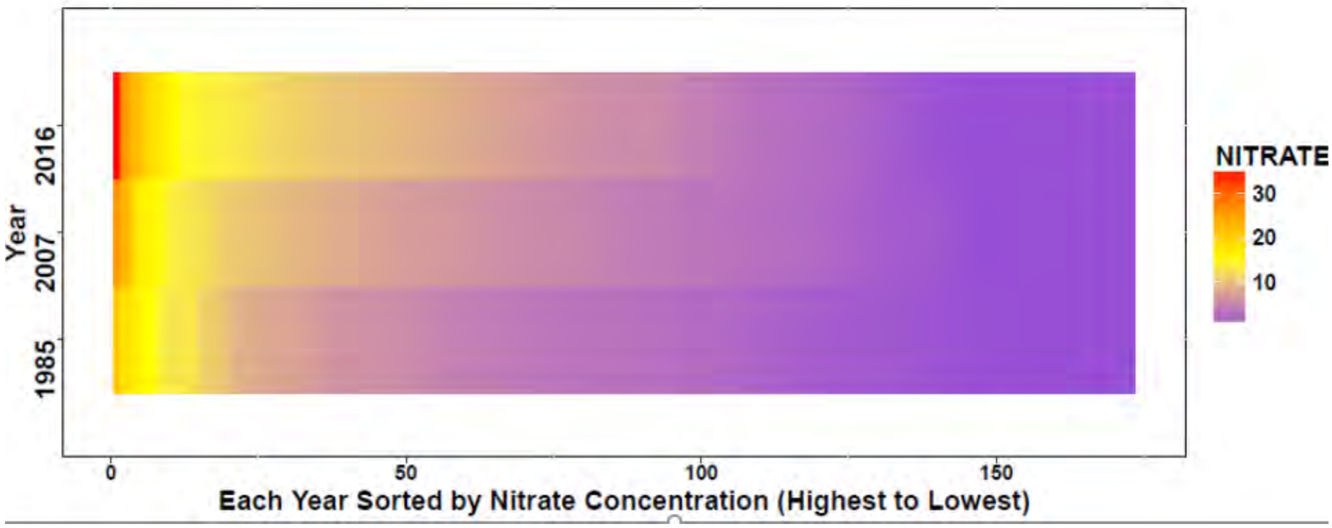
Upward nitrate trends over time are frequently observed when reviewing regional or local trends in well water quality, particularly where wells are vulnerable to nitrate contamination. For example, the Rock County Health department has been sampling and maintaining a dataset based on a consistent set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



Source: Rock County Department of Public Health

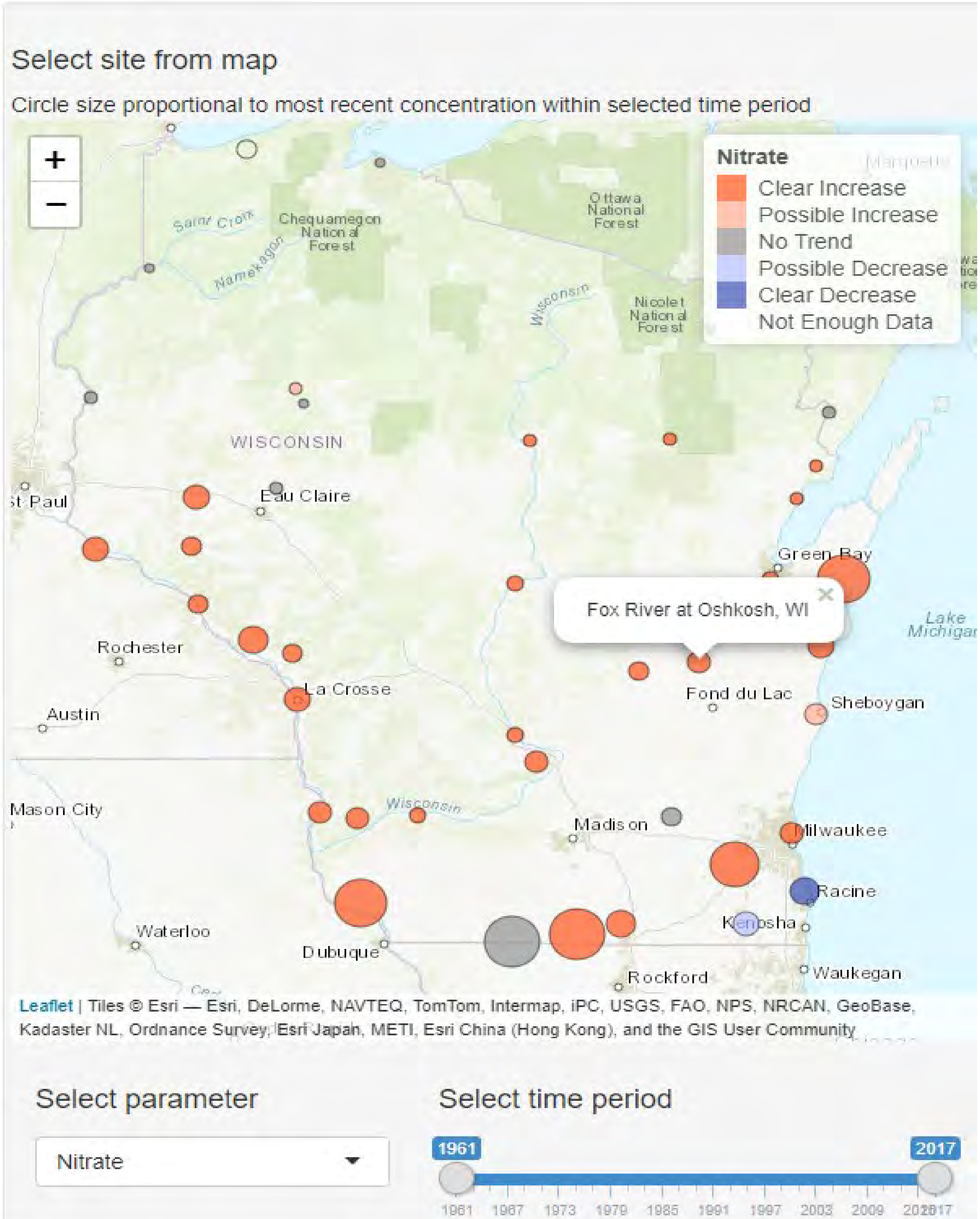
Chippewa County provides another example where a consistent set of private wells (175) were sampled multiple times over thirty years. This data set shows the importance of location: most wells saw little or no change over the 30 years (51%) and some wells showed a decrease (10%), while 39% showed an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



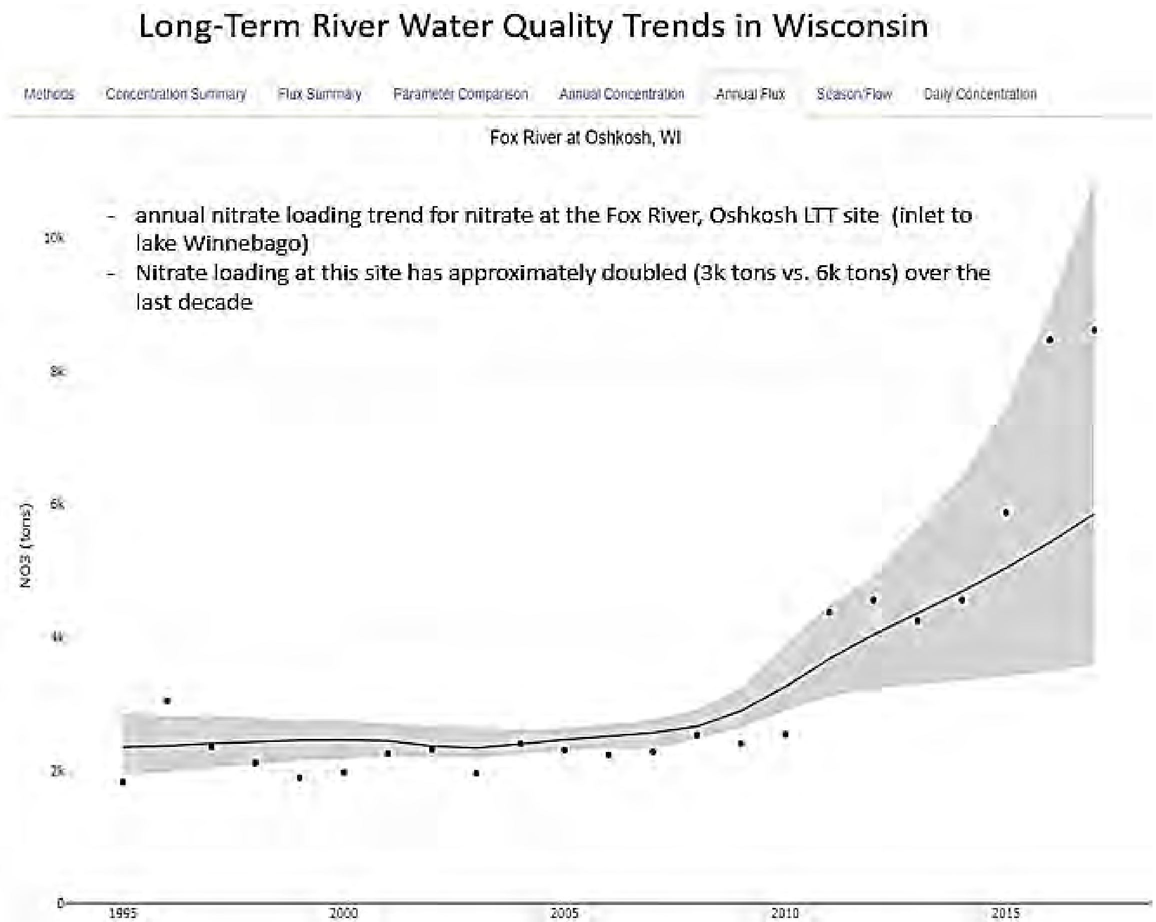


Source: Masarik et al., 2016 In preparation.

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



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



Estimated costs in Wisconsin to mitigate Nitrate

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

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

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

An estimate of the cost to well owners who have already replaced their well due to elevated nitrate was calculated by reviewing well construction reports submitted to the department where nitrate was listed as the reason for the new well. This likely underestimates the number of wells replaced for nitrate, 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

	Estimated # of private wells	Estimated % of well over 10 ppm Nitrate Standard	Estimated # of private wells over Nitrate Standard	Estimated Replacement Cost (millions)
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**	**$446M**

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

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

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

What is being done by GCC Agencies to address nitrate?

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

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

In addition to regular well sampling surveys performed by DATCP, DATCP supports the development of nutrient management plans (NMPs). These plans specify the amount and timing of nutrient sources applied to a field to optimize economic input. Approximately 31% of the agricultural land in Wisconsin is covered by an approved management plan (DATCP, 2015). 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.

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

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

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

This has led to the recommendation for the State, on a collaborative basis with all drinking water stakeholders, to engage in a multi-stage process to develop new technical tools that will enable the realization of the goal of protecting our sources of drinking water while maintaining robust and profitable agricultural production. Such tools would assist local resource managers with creating landowner and producer partnerships to implement "groundwater protective" nutrient management plans in areas contributing recharge to potable wells.

Groundwater and nitrogen fertilizer decision support

In 2019 the WDNR developed "stage 1" workplans with technical partners to begin the development of a suite of Groundwater and Nitrogen Fertilizer Decision Support tools (GW & Nitrogen DSTs) for ultimate use by community water supplies, conservation departments, the agricultural community, and other drinking water stakeholders to help achieve groundwater protection in the context of nutrient management planning. Nitrogen fertilizer decision support tools will be developed and improved over time based on contributions from the full range of stakeholders. Guiding principles include creating tools that are complimentary and supplementary to the existing Nutrient Management Planning programming in the state. Starting with basic tools and progressing to more advanced applications over time, stakeholders will be engaged to develop collaborative solutions to existing data and research gaps, as well as barriers to adoption. Early products will focus on "the basics" such as nitrogen budgets and "mass balance" type analysis. More advanced products will utilize models in order to incorporate nitrogen cycle drivers and simulation of the effects of weather variability. The goal is pair with existing NMPs (e.g. a user might export a data file from SNAP+ and process separately with a Nitrogen DST to generate estimates of nitrate leaching potential and explore options to reduce losses). To protect our sources of drinking water, resource managers and the agricultural community need tools with the flexibility to scenario test potential nutrient management plans that incorporate various beneficial management practices. Because the nitrogen cycle is inherently "leaky", we expect some nitrate leaching to occur under the best of circumstances. The goal is to provide reasonable expected ranges of the nitrate leaching below the root zone that would be expected to occur (based on the details of a nutrient management plan). This information is needed in order to devise groundwater management plans that assure that potable wells located hydraulically downgradient will remain below the health-based standard for nitrate. To achieve the dual goal of source water protection while maintaining farm profitability, we must also elucidate any tradeoffs in productivity. Where economic offsets are expected to occur, quantification of these costs could serve as the basis for utilizing existing state and federal conservation practice funding sources in new ways that protect drinking water sources and safeguard the public health.

This long-term project will provide a framework for the continued development and improvement of nitrogen fertilizer decision support products as more research and data is incorporated over time. To be successful, and develop the capacity in the state to protect our sources of drinking water even in agriculturally intensive settings, the full range of drinking water stakeholders in the state, including the agricultural community, will need to share "ownership" and responsibility for continuous development and improvement of these tools (analogous to the existing programming in the state that develops and improves the science supporting nutrient management planning in general).

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

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

Initial work began in early 2020 on the Groundwater and Nitrogen Decision Support Tool development. The development partnership is expected to expand over time, and incorporate multi-disciplinary technical contributions from researchers at the University of Wisconsin, and from other state agencies and organizations such as the Wisconsin Geologic and Natural History Survey (UW-Extension), the Wisconsin Department of Agriculture Trade and Consumer Protection, the Department of Health Services and the Wisconsin Rural Water Association. Key federal partners include USGS, USDA-NRCS, and EPA. The Wisconsin Land and Water Conservation Association is providing essential connections to county conservation and county health departments. Through these local connections, the range of participating agricultural stakeholders will expand, providing essential feedback and data for developing robust decision support and enable protection of drinking water supplies while sustaining profitable agricultural production.

Nitrate Targeted Performance Standard

In 2019, Governor Tony Evers directed DNR to pursue rulemaking through NR 151 to reduce nitrate contamination by establishing targeted nitrate performance standards for soils that are most likely to experience nitrogen contamination. The Wisconsin Natural Resources Board approved the DNR's Statement of Scope in December 2019. Which states that "The purpose of the proposed revisions to ch. NR 151, Wis. Adm. Code, and limited incorporation by reference of those proposed revisions to ch. 243, is to establish agricultural nonpoint source performance standards targeted to abate pollution of nitrate in areas of the state with highly permeable soils which are susceptible to groundwater contamination (sensitive areas) for the purpose of achieving compliance with the nitrate groundwater standards." The Scope further states that "The rule revisions will define sensitive areas in the state and the performance standards needed to protect surface and groundwater quality in these areas. Soil maps based, in part, on soil permeability in conjunction with groundwater quality information may be used to define sensitive areas." The promulgation of proposed rules generally takes about 31 months. Presently, the rule making committee has formed a Technical Advisory Committee (TAC) and is holding meetings open to the public. For further information, please see NR 151 rule changes for nitrate.

Future Work

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

Further Reading

DNR overview of nitrate in drinking water

DNR overview of nutrient management planning

DATCP overview of nutrient management

DHS overview of nitrate health effects

DNR, DATCP, and DHS water quality recommendations

NR 151 rule changes for nitrate

References

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

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

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

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

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

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

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

Davis, T.W., Bullerjahn, G.S., Tuttle, T., McKay, R.M., and Watson, S.B. (2015). Effects of Increasing Nitrogen and Phosphorous Concentrations on Phytoplankton Community Growth and Toxicity During Planktothrix Blooms in Sandusky Bay, Lake Erie. Environmental Science & Technology, 49(12), 7197-7207

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

Harke, M.J., Steffen, M.M., Gobler, C.J., Pttem. T.G., Wilhelm, S.W., Wood, S.A., and Paerl, H.Q. (2016). A review of the global ecology, genomics, and biogeography of the toxic cyanobacterium, Microcystis spp. Harmful Algae, 54, 4-20.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Vitousek, P. M., et al. 1997. Human alteration of the global nitrogen cycle: causes and consequences. Ecological Society of America Volume7, Issue3 https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/1051-0761%281997%29007%5B0737%3AHAOTGN%5D2.0.CO%3B2

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

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

Xu, G., P. Song, P.I. Reed. 1992. The relationship between gastric mucosal changes and nitrate intake via drinking water in a high-risk population for gastric cancer in Moping county, China. European Journal of Cancer Prevention, 1(6):437-443.

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