Jefferson County Well Water Quality Inventory 2023

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We would like to thank all of the Jefferson County community members that agreed to submit samples or have samples collected from their wells. Without their interest and willingness to participate, this report would not have been possible.

Cover photo: Eli Wedel

Executive Summary

Groundwater is the principal water supply for Jefferson County municipalities, industries, and rural residents. While municipal water supplies are regularly monitored and required to meet drinking water standards, private well owners are responsible for deciding when to test, what to test for, and what to do if there is a problem. This work summarizes a one-year effort of Jefferson County and the University of Wisconsin – Stevens Point Center for Watershed Science and Education to characterize well water quality accessed by Jefferson County residents. The information will be used to assist rural residents with the management of groundwater and private well water systems for common well water quality problems and better understand how land use and geology are impacting this important resource.

In total, 828 samples were collected and analyzed for sixteen different water quality parameters as part of the 2023 sample inventory. Jefferson County's groundwater can generally be characterized as basic (mean pH = 8.2), hard water (mean total hardness = 415 mg/L as $CaCO_3$), and as having high alkalinity (mean = 356 mg/L as $CaCO_3$). These aesthetic characteristics of the water are largely influenced by the geologic materials groundwater is stored and transported in and are typical for southeastern Wisconsin. Slightly higher hardness and other dissolved minerals were observed in northeastern Jefferson County.

Nitrate is a common health-related contaminant found in Wisconsin's groundwater. Jefferson County's groundwater has a mean nitrate-nitrogen concentration of 2.6 mg/L. Seven percent of wells tested above the 10 mg/L nitrate-nitrogen drinking water standard and were considered unsuitable for drinking with respect to nitrate. Statistical analysis suggested soil drainage was the strongest predictor with agricultural land cover and septic density also being significant for explaining both the extent and magnitude of nitrate in Jefferson County's groundwater.

Chloride provides additional insight into the effects of land-use on water quality. The mean chloride concentrations in Jefferson County was 42.0 mg/L. Elevated chloride concentrations were related most significantly to development density (i.e. roads and septic systems) followed by soil drainage and agricultural landcover.

Arsenic is naturally occurring but occurred above the health-based drinking water standard of 0.010 mg/L in 7% of samples and was measured at detectable levels in 27% of well samples. Manganese and iron are common aesthetic concerns associated with Jefferson County groundwater. Approximately 30% and 23% of wells had levels of iron and manganese respectively that would likely contribute to taste and staining issues without some sort of treatment. Additionally, 1% of wells detected manganese greater than health-advisory levels of 0.300 mg/L.

This work provides a robust baseline dataset of well water quality in Jefferson County for common health and aesthetic water quality concerns of rural residents of Wisconsin. The data can be used to effectively target well water outreach and testing in areas that are more at risk for nitrate and other contaminants such as arsenic. In addition, predictive models help to provide insight into well water quality throughout the county for nitrate and chloride. Lastly, the information outlines recommendations for future outreach and land management efforts in Jefferson County.

Background

Introduction to Jefferson County Groundwater

Wisconsin receives on average about 32 inches of precipitation annually. Almost 2/3 (approximately 20 inches) of this precipitation ends up back in the atmosphere by direct evaporation or by passing through plants in the process of transpiration. The remaining 12 either soaks into the ground past the root zone of plants, or may runoff directly into lakes, rivers, streams or wetlands. The rate at which water soaks into the ground is determined mostly by the uppermost soil layer. Runoff is generated when rain falls (or snow melts) faster than water can infiltrate, or soak into the soil.

Fine-textured soils such as clay do not allow water to infiltrate very quickly. They generate more runoff than coarse-textured soils made up of mostly sand, which allow more infiltration. On average, only about 2-6 inches of water reaches Wisconsin lakes and rivers as runoff.

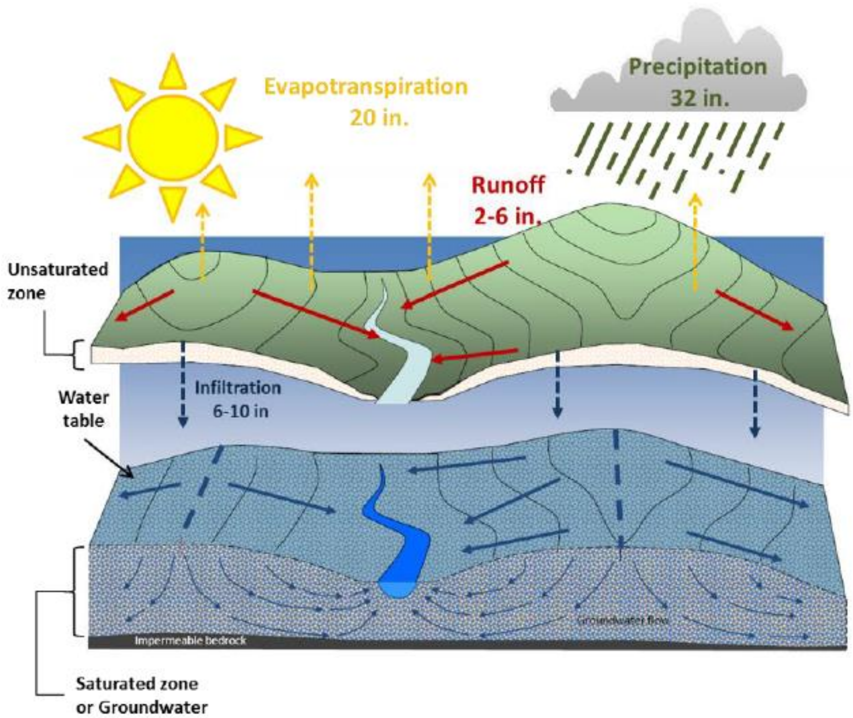


Figure 1. Relative contribution of various components of the water cycle as they relate to Jefferson County. The unsaturated zone is separated from the groundwater to illustrate the water table elevation. Changes in water table elevation are used to infer groundwater flow direction.

The remaining 6-10 inches of annual precipitation is an estimate of how much water infiltrates past the root zone of plants and ultimately becomes groundwater. Groundwater recharge is heavily dependent on the drainage classification of the soil (Appendix B). The infiltrating water moves downward because of gravity until it reaches the water table, the point at which all the empty spaces between the soil particles or rock are completely filled with water. The water table represents the top of the groundwater resource. Groundwater moves very slowly between particles of sand and gravel or through cracks in rocks. Water-bearing geological units such as sand and gravel are called aquifers.

Groundwater is always moving. It is able to move because the empty spaces within aquifers are interconnected. The size and connectivity of the spaces within an aquifer determine how quickly groundwater moves, how easily it is contaminated, and how much water a well is able to pump.

Groundwater moves as a result of differences in energy. Water at any point in an aquifer has energy associated with it, and its movement can be predicted by measuring changes in energy between two locations. More simply, groundwater moves from high energy to low energy. One measurement of energy is groundwater elevation. Groundwater elevation maps show the height of the top of the groundwater above a common measuring point, which is sea level. A map of water table elevation available for Jefferson County allows for generalized determination of groundwater flow direction (WGNHS, 1976).

Groundwater generally moves from areas where the water table elevation is higher to areas where it is lower. Arriving at these low spots on the landscape, it discharges to surface waters, such as a river, stream, lake, spring, or wetland. Because they are connected, scientists generally consider surface water and groundwater as a single resource.

To know where water discharging into a lake or stream originated, it is important to understand the idea of a watershed. A watershed is the land area that contributes water to a stream, river or lake – whether that water arrives above ground or below it. The surface and ground- watersheds for a lake or stream are often similar, but not identical.

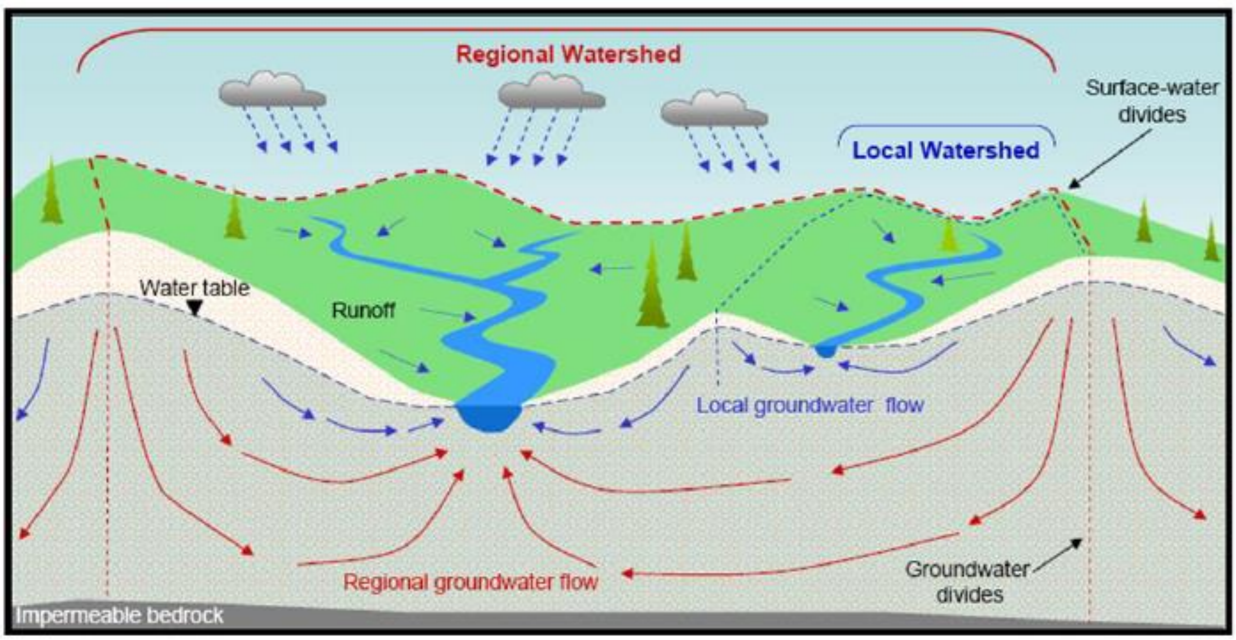


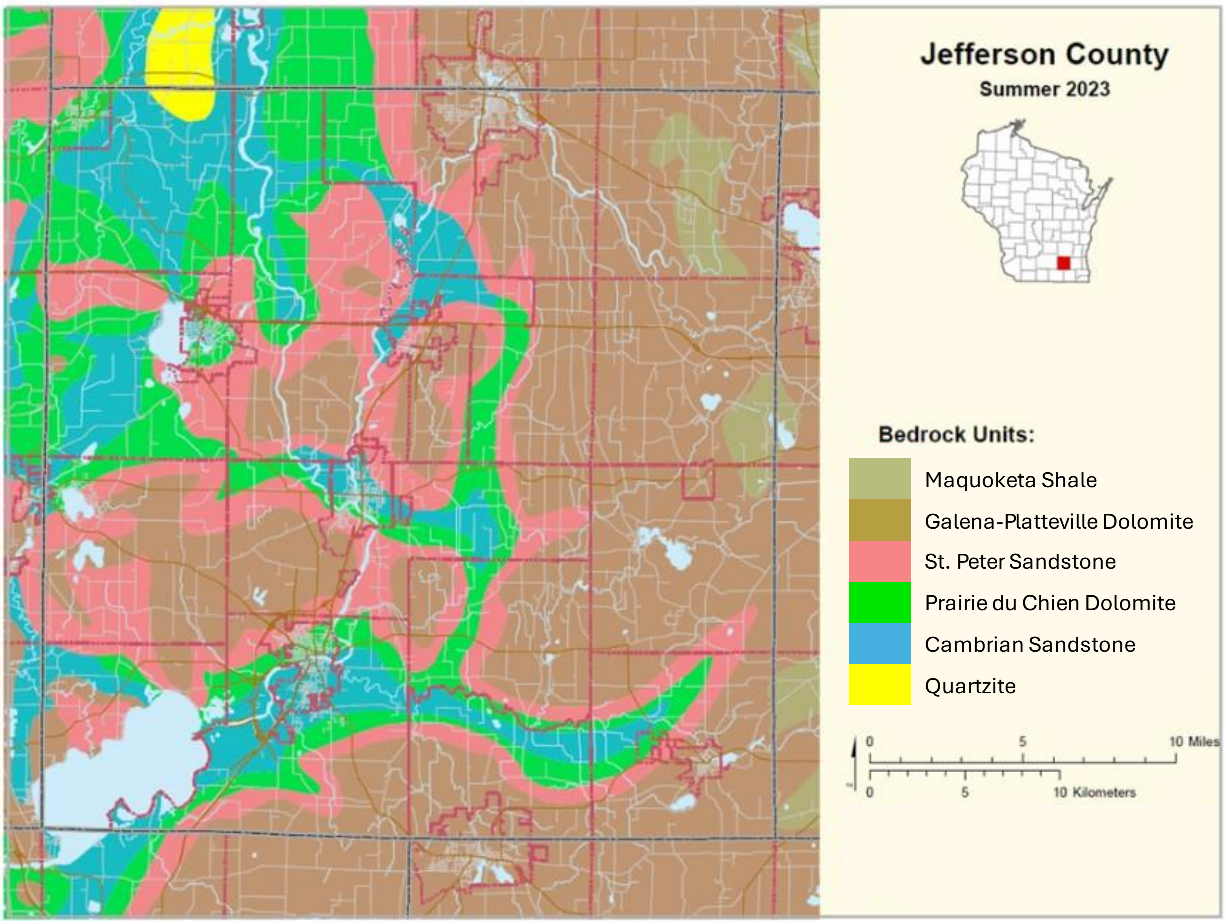
Figure 2. Rain or snow that falls within a watershed boundary moves via runoff or as groundwater flow to a common discharge location, usually a river or stream. Smaller watersheds can be nested within larger regional watersheds.

Topographic maps are used to determine the boundaries of surface watersheds (Appendix A) and water table elevation maps are used for ground watershed boundaries (WGNHS, 1976). These boundaries are often referred to as divides; water on one side of the divide flows in the opposite direction of water on the other side. Small watersheds of tributary streams are nested within the larger watershed of the river or large waterbody that they feed into. All groundwater from Jefferson County eventually ends up in the Mississippi River; the path water takes to get there depends on which watershed the rain or snow is deposited in.

Aquifer Materials of Jefferson County

Aquifers are the geologic materials that store and transmit groundwater. These geologic materials can be quite variable depending on where you are in the county. Here we provide a generalized overview of Jefferson County geology; however for those interested in learning more there is extensive data and resources on the Quaternary and bedrock geology of Jefferson County available from the Wisconsin Geologic and Natural History Survey (Ives and Rawling, 2022; Stewart, 2024).

Figure 3. Generalized bedrock geology of Jefferson County. Map represents the uppermost bedrock unit. Legend indicates layers as they would occur from the oldest layer (bottom) to the youngest layer (top) and the order layers would occur (Map Layer Source: Mudrey et al., 2007).



The lowermost geologic unit found in Jefferson County are layers of Precambrian crystalline bedrock consisting of quartzite, a metamorphic rock that is completely crystalline and lacks the pore space for water to reside in. Groundwater scientists have shown that these ancient crystalline rocks are generally a poor aquifer with limited amounts of water only in fractures. Wisconsin's groundwater is generally stored in the sedimentary geologic units above the crystalline bedrock, which is why groundwater wells seldom extend down into crystalline rock.

Sandstone aquifers deposited during the Cambrian period overlay the crystalline rocks in most of Jefferson County. The exception are small outcroppings of quartzite in northwestern Jefferson County. Sandstone aquifers were formed when a prehistoric ocean covered the area and sand on the ocean floor was naturally cemented together over time to form sandstone. Sandstone has empty spaces between the cemented sand grains that are interconnected allowing water to move with relative ease. As a result, sandstone is a very productive aquifer and a major source of water for Wisconsin residents and communities.

Overlaying the Cambrian sandstones are additional layers of dolostone and sandstone materials deposited during the Ordovician Period when sea levels rose and fell in this part of the world. Dolostone consists of calcium and magnesium carbonate materials that contribute to aesthetic concerns related to water hardness. Dolostone is the uppermost bedrock material encountered by most wells in eastern Jefferson County. Dolostone is susceptible to fracturing, and where fractured dolostone occurs close the surface (less than 25 feet), these areas can be more susceptible to groundwater contamination from rapid infiltration of water from the surface down into the groundwater. Shale may be found as the uppermost bedrock unit in a few discrete areas of eastern Jefferson County. Shale layers do not transmit water very readily and can be associated with less than desirable water quality, as a result most wells will bypass this layer.

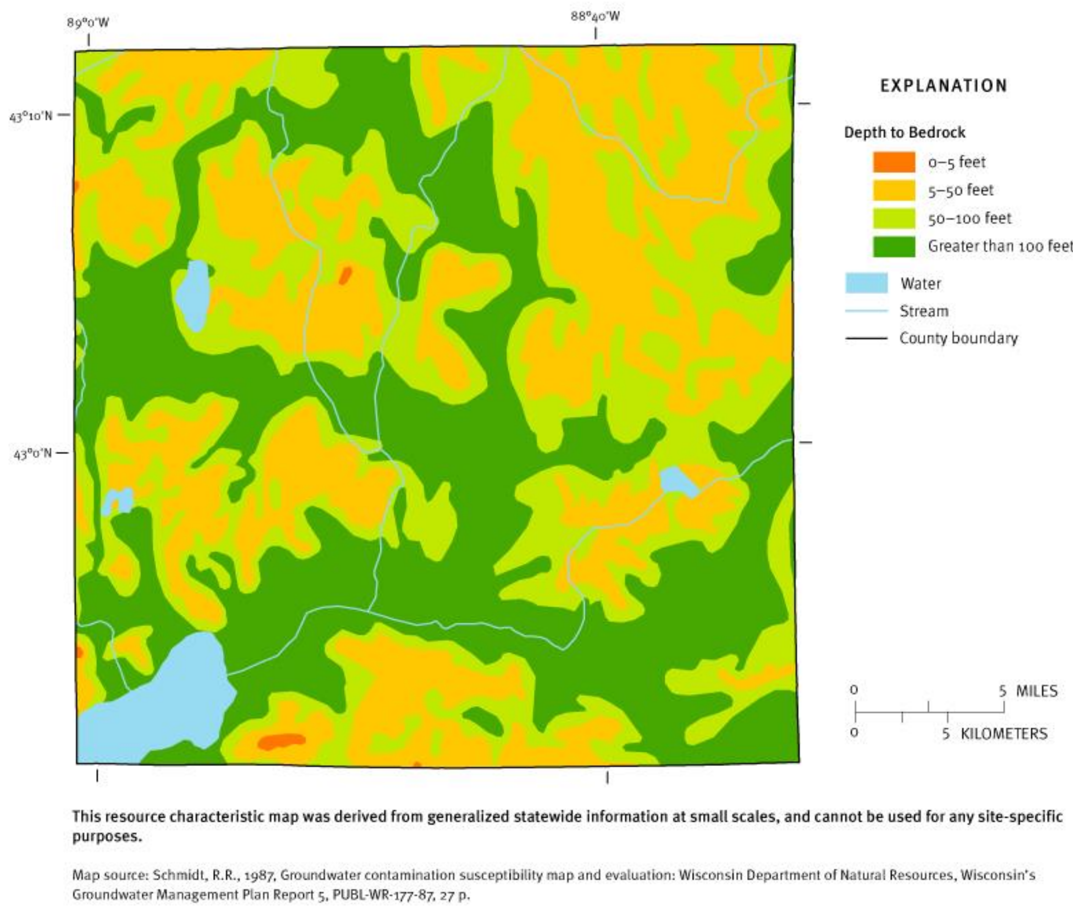


Figure 4. Generalized depth of unconsolidated surficial materials before encountering bedrock (Map Layer Source: Protecting Wisconsin's Groundwater Through Comprehensive Planning, 2007)

Lastly, are the surficial deposits consisting of meltwater stream sediment, lake sediments, organic sediments, or glacial sediment which were deposited recently by geologic standards. These materials are the result of Jefferson County's glacial past. Since the materials left behind by the glaciers are not cemented together, geologists refer to these materials as unconsolidated deposits. These materials consist of sand, gravel, peat, loam, clay, and organic sediments that can be less than 5 feet thick before encountering bedrock to more than 100 feet thick in some of Jefferson County's river valleys. The spaces between the particles are often well connected and allow for abundant water storage and easy movement of groundwater through the aquifer. This ease of water capture and movement can also make it more vulnerable to contaminants. The depth of these unconsolidated materials also have implications for well construction methods, depths, and casing.

Wells and Well Construction

All Jefferson County residents rely on groundwater as their primary water supply. Wells are used to extract water from the ground for a variety of human activities. Rural residents rely on private wells which typically serve an individual home. Residents of cities and some villages rely on municipal water systems, which often consist of multiple high-capacity wells. High-capacity wells are also used to irrigate fields for growing crops or may be used by other industries and activities in Jefferson County.

A private well used to supply water to rural residential home.

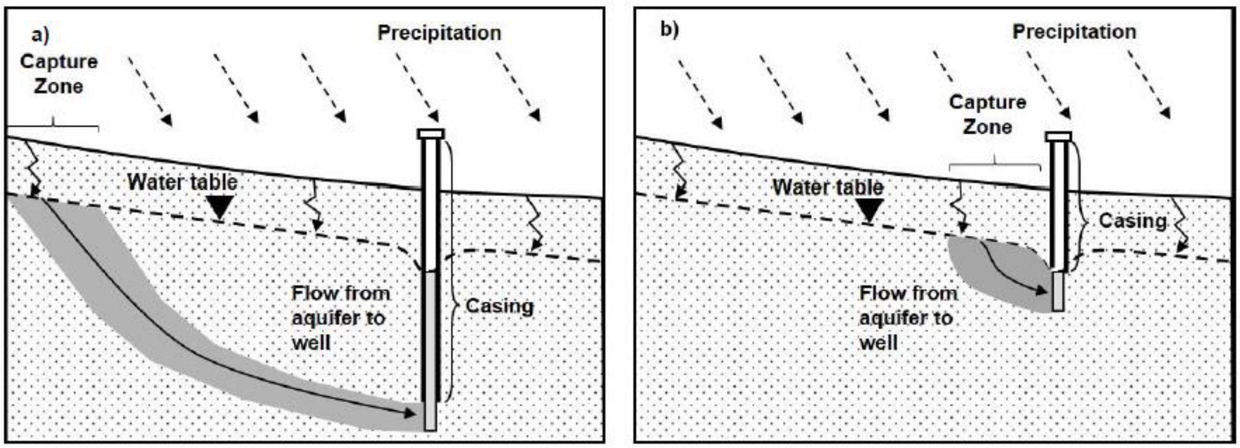
A well is a vertical hole that extends into the soil and/or rock. Wells must be deep enough so that they extend past the water table into the groundwater aquifer. The groundwater may be very close to the land surface for wells located near a lake, river or stream. However, for those located on the top of a hill, the well needs to be deeper simply because the distance to access the water table is greater.

A well's casing and screen help to prevent the well borehole from filling in with sediment and other geologic material. The depth of casing or location of a well screen also determines where in the aquifer the well is receiving water from. Casing depth or screen location determines the capture zone or area of influence for a given well. As water is pumped or removed from the well, water is contained in the spaces in adjacent rock or sand/gravel material replaces the water that was removed. While people might like to think of groundwater as being very old, the truth is most water supplied to wells in Jefferson County is likely to be only a couple of years to maybe decades old.

Unlike high capacity municipal or irrigation wells, private residential wells generally do not use enough water to create a significant cone of depression (i.e. lowering of the water table around the well). Assuming each individual in a household uses 50-100 gallons per day of water, this is not enough to greatly alter the flow direction of groundwater or cause a cone of depression. We can think of private wells in most instances as simply intercepting groundwater along its normal flow path.

The capture zone of a well will be close to the well if pulling water from near the top of the water table. Knowing the exact capture zone for wells cased deeper into the water table can be more difficult to determine. Wells in the Jefferson County inventory range from shallow wells only 34 feet deep to drilled wells up to 400 feet deep.

Figure 5. Diagrams illustrating how well and casing depth influence the capture zone of a well. Wells in which the casing extends further below the water table will tend to have capture zones that are located further away from the well (a) than one in which the casing does not extend as far or may not extend past the water table (b).



While well depth can be important for water quality, casing depth below the water table also plays a critical role in determining what part of an aquifer a well is pulling water from. Wells with casing that finishes above the static water level (SWL) or extend a short distance into the aquifer are generally accessing water that is younger and originated at a distance closer to the well. If the casing extends deeper into the aquifer; the water is generally going to be older and accesses water that may be influenced by a combination of flow paths coming from further away. In this situation, land-use impacts may be less noticeable because of dilution from various landcovers that influence water quality at greater aquifer depths.

Figure 6. Diagram illustrating casing depth below the aquifer. Colors correspond to symbol colors used in Figure 7.

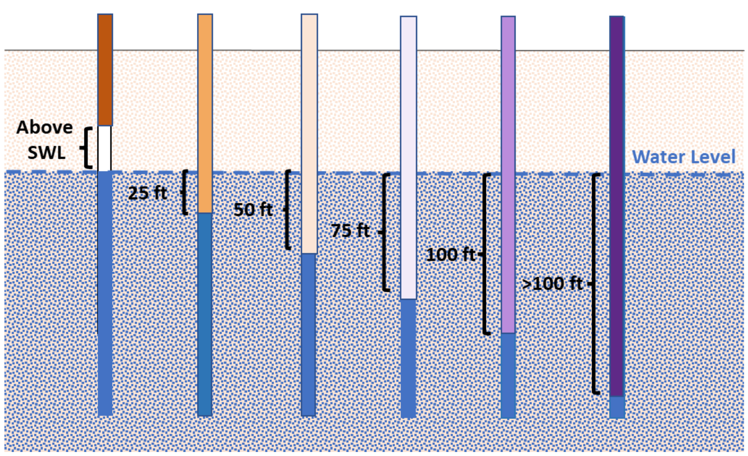
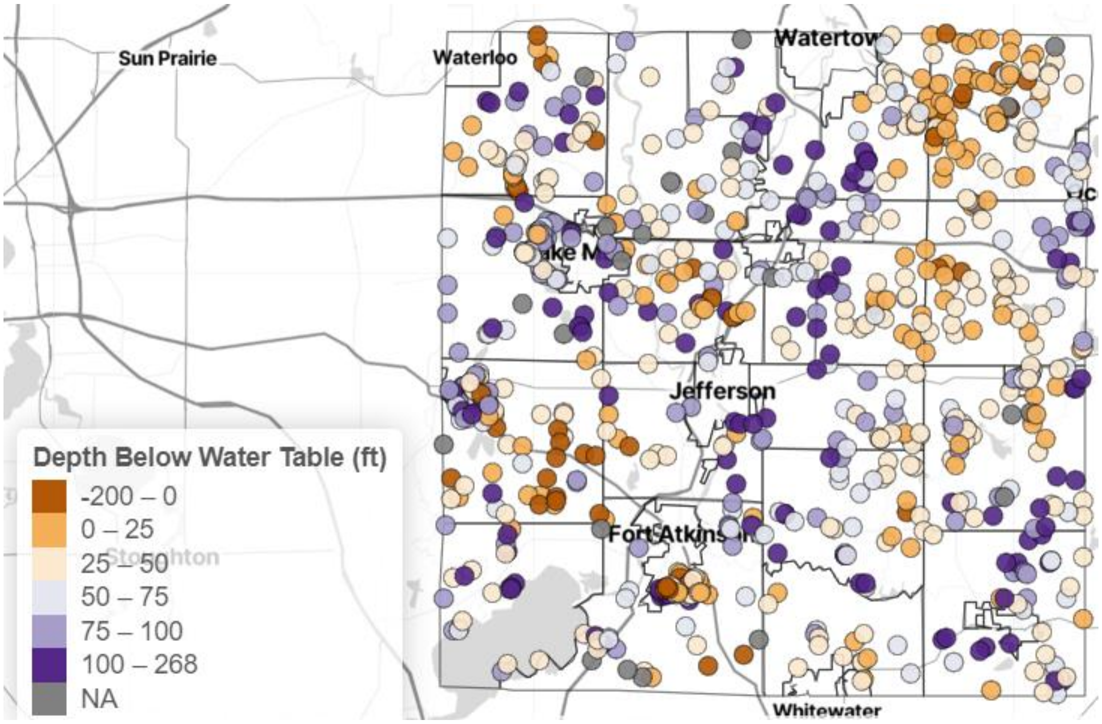


Figure 7. Diagram illustrating casing depth below the aquifer.



Municipal systems are required to regularly test their water and have an obligation to ensure it meets government standards. Meanwhile, in rural areas, residents are largely on their own because they rely on private wells for their daily water needs. Private well owners benefit from well construction regulations, but they do not benefit from the day-to-day oversight of municipal water systems.

The state's well code, administered by the Wisconsin Department of Natural Resources, is based on the premise that a properly constructed well should be able to provide water free of bacteria without treatment. A mandated bacteria test performed after a well is first drilled is meant to verify if it is providing sanitary water at the time of construction. Updates to the state well code now require new wells to be tested for nitrate; however the majority of wells are not tested as frequently as recommended and most have not been tested for anything beyond bacteria or nitrate. Each owner must decide whether – and how – to verify their well continues to produce quality water.

The objective of the Jefferson County Well Water study was to provide a current assessment of Jefferson County well water quality with regard to some of the common health contaminants and other elements relevant to water aesthetics, geologic and land-use considerations. Information gained from testing of wells will be used to inform outreach efforts, guide future management decisions, target wells for more in-depth testing, and provide a baseline of water quality that can be used to understand whether groundwater quality is changing over time.

Methods and Materials

Recruitment

Using available well construction records and other publicly available datasets, the Center for Watershed Science and Education worked to develop a recruitment list of wells and landowner contact information. Only wells assigned a Wisconsin Unique Well Number and locatable well construction information (i.e. well depth, casing depth, static water level) were sampled as part of this project. In addition to well construction information, additional information on soil drainage, geology, and land cover within a 500 m buffer was also summarized for each well.

A total of 2,019 wells were selected as part of the initial recruitment. The recruitment list provided a good representation of groundwater being used to provide water to rural residential wells and accounts for those areas where more people are relying on private wells. There are parts of Jefferson County's groundwater that may be underrepresented because there are no landowners with private wells located in those areas (i.e. large wetlands, state parks, etc.).

Recruitment materials consisted of a mailed letter describing why the landowner was being contacted along with additional information about the project. Landowners were asked to respond using a pre-paid postcard. A total of 948 landowners (47% of those initially contacted) indicated their willingness to participate in the well monitoring program.

Sampling kits were mailed in late April 2023. Each kit included a sample bottle, sampling instructions, and a pre-paid mailer for participants to enclose materials in. Participants were instructed to sample an untreated faucet. If not sure which faucet to use, they were asked to collect the sample from their cold-water kitchen faucet which is generally untreated in most households. Following sample collection, participants were asked to take the pre-paid mailer to a Postal Service counter. Participants were given approximately three weeks to submit their samples. Landowners that did not submit a sample prior to the deadline were sent a reminder indicating that we would still accept samples up to an additional month beyond the original deadline.

A total of 828/948 (87%) samples were successfully sampled prior to the cutoff date and were analyzed by the Water and Environmental Analysis Laboratory which is state-certified by the Wisconsin Department of Natural Resources to perform analysis of potable water for common well water quality concerns included in this inventory.

Individual well test results were mailed to participants following completion of water quality analysis. Each participant received a copy of their individual test results along with an interpretive guide and overall summary of the results. Results were also integrated into an online dashboard that's part of Jefferson County Well Water Quality Inventory. The dashboard can be assessed online at: http://68.183.123.75/wisconsinwater/JEFFERSON/

Statistical Analysis

Summary statistics were computed using R version 4.4.1 (R Foundation for Statistical Computing). Ordinary least squares (OLS) regression was used to understand relationships between nitrate and chloride to other factors such as percentage of various land cover categories and a weighted soil drainage rank. The same attributes were determined for the centroid of every parcel in Jefferson County. The statistical models were then applied to the data for each parcel to develop maps of inferred nitrate-nitrogen and chloride concentrations for Jefferson County.

Results and Discussion

In this section we provide information on each of the parameters and overall summaries of the results for the 828 samples that were part of the Jefferson County Well Water Quality Inventory. Countywide statistics for each parameter are summarized in Table 1. Results of the Jefferson County inventory are mostly reported in units of milligrams per liter (mg/L). Please note that milligram per liter is equivalent to parts per million.

Additional, information on each of the individual analytes including maps and boxplots by municipalities can be found in the subsequent sections.

Figure 8. Boxplots are used to summarize results by individual municipalities and other factors. The following diagram describes how to interpret boxplots used in subsequent pages.

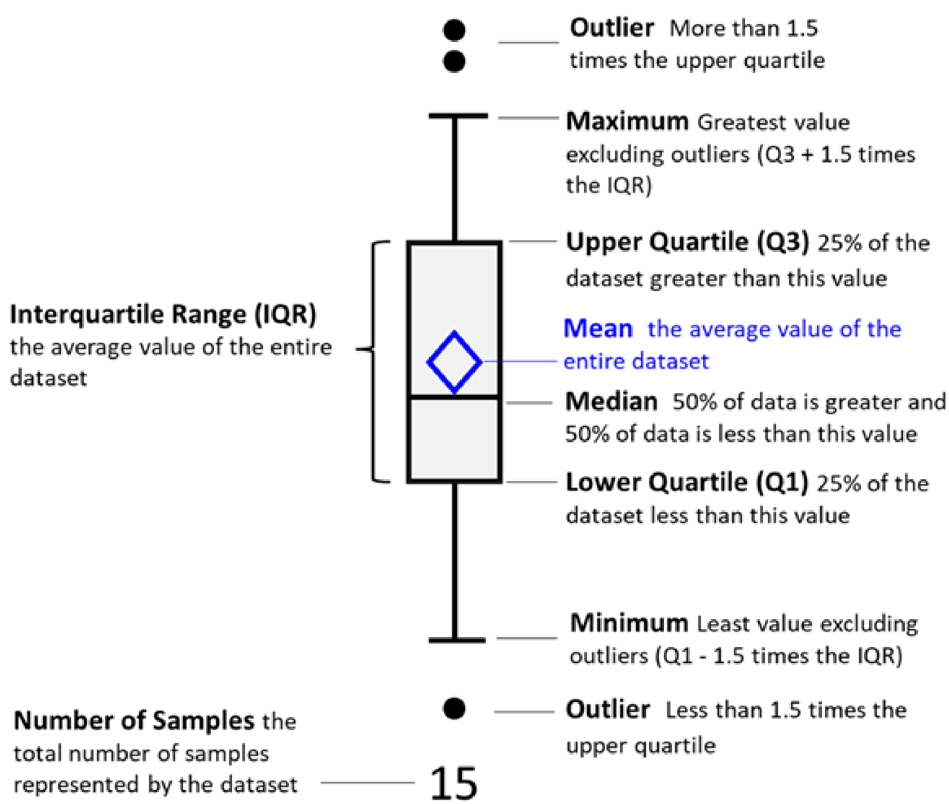


Table 1. Summary statistics for countywide 2023 Jefferson County well water samples.

	Units	Minimum	Mean	Median	Maximum	# of samples
Total Hardness*	**mg/L as $CaCO_3$**	369	415	411	1260	729
Alkalinity	**mg/L as $CaCO_3$**	26	356	356	535	828
Conductivity	**µmhos/cm**	161	839	798	3190	828
pH	**Standard units**	7.1	8.2	8.2	8.9	828
Nitrate-Nitrite-Nitrogen	**mg/L**	<0.1	2.6	<0.1	28	828
Chloride	**mg/L**	0.6	42	24	817	828
Arsenic	**mg/L**	<0.005	0.007	<0.005	0.081	828
Iron*	**mg/L**	<0.007	0.900	0.037	62.0	729
Calcium*	**mg/L**	18.4	86.9	87.0	252	729
Manganese*	**mg/L**	<0.001	0.049	0.015	4.1	729
Phosphorus	**mg/L**	<0.005	0.012	<0.005	0.39	828
Sulfate	**mg/L**	<0.1	38	34	243	828
Potassium	**mg/L**	0.038	1.9	1.3	42	828
Magnesium*	**mg/L**	27.8	48.1	47.1	153	729
Sodium*	**mg/L**	1.7	18.5	7.4	288	729

*Softened samples removed from summary statistics for Total Hardness
"<" symbol in front of number means that value is below limit of detection.

Table 2. Summary of parameters with health-based standards.

	Health-based standard	Samples above standard / Total number of samples	Percent greater than standard
Arsenic	**0.010 mg/L**	58/828	7.0%
Manganese	**0.300 mg/L**	9/729	1.2%
Nitrate-Nitrite-Nitrogen	**10 mg/L**	59/828	7.1%

Nitrate-Nitrogen

Nitrate is a form of nitrogen commonly found in agricultural and lawn fertilizer that easily dissolves in water. Nitrate is also formed when waste materials such as manure or septic effluent decompose. The natural level of nitrate in Wisconsin's groundwater is less than 1 mg/L of nitrate-nitrogen. Levels greater than this suggest groundwater has been impacted by various land-use practices. There is a health-based drinking water standard of 10 mg/L reported as nitrate-nitrogen.

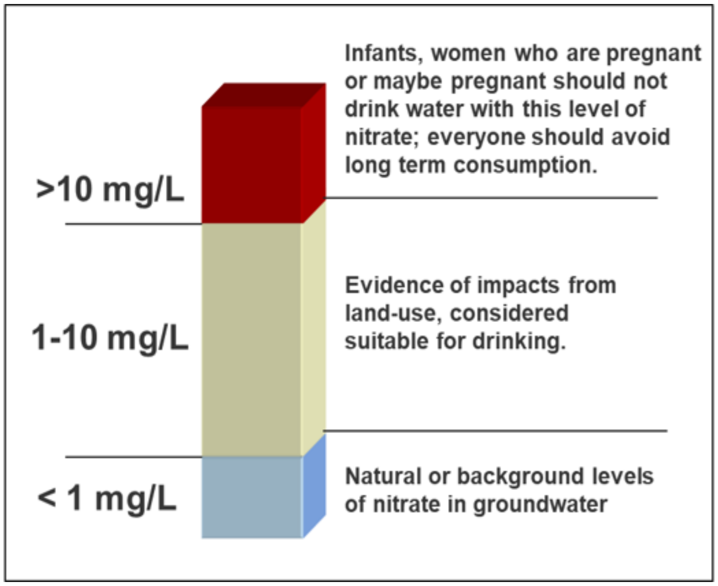
Why Test for Nitrate

Nitrate is an important test for determining the safety of well water for drinking. In addition, nitrate is a test that allows us to understand the influence of human activities on well water quality. Because nitrate has multiple sources and moves easily through soil, it serves as a useful indicator of land-use impacts to a well. An annual nitrate test is useful for better understanding whether water quality is getting better, worse, or staying the same with respect to certain land-uses/sources mentioned above.

Health Effects of Nitrate in Drinking Water

Nitrate-nitrogen levels greater than 10 mg/L may result in the following potential health concerns:

- **Infants less than 6 months old –** blue baby syndrome or methemoglobinemia is a condition that can be fatal if left untreated
- **Women who are or may become pregnant –** may cause birth defects
- **Everyone –** may cause thyroid disease and increase the risk for certain types of cancer



Infants less than 6 months old and women who are or may become pregnant should not drink water or consume formula made with water containing more than 10 mg/L of nitrate-nitrogen. Everyone should avoid long-term consumption of water with greater than 10 mg/L of nitrate-nitrogen.

Ways to reduce nitrate in your drinking water

Sometimes drilling a new well or reconstructing an existing well may provide water with less nitrate. If you have high nitrate, extending the casing deeper into the water table can sometimes result in lower levels of nitrate. If drilling a new well or reconstruction is not possible, another way to reduce nitrate is to install a water treatment device approved for removal of nitrate. Please note that if using treatment for nitrate, routine testing is necessary to make sure it is functioning properly.

Water Treatment for Nitrate
While efforts should be made to reduce the amount of nitrate that reaches groundwater rather than rely on treatment; water treatment can be a necessary short-term or long-term solution for obtaining safe drinking water. Treatment for nitrate is very specific and requires certain treatment technologies. Treatment devices labeled as having NSF/ANSI 53 certification have been vetted by the National Sanitation Foundation. The following types of systems may be appropriate depending on the amount of water you are looking to treat:

1) ***Point-of-use devices*** *treat enough water for drinking and cooking needs*
   - Reverse Osmosis
   - Distillation
2) ***Point-of-entry systems*** *treat all water distributed throughout the house*
   - Anion Exchange

Jefferson County Results
The Jefferson County mean nitrate-nitrogen concentration was 2.6 mg/L; meanwhile 61% of wells measured levels less than 1 mg/L which is generally considered to be natural or background levels of nitrate in groundwater. Seven percent of wells sampled exceeded the 10 mg/L nitrate-nitrogen drinking water standard which is similar to the current statewide average of 7.3% (DATCP, 2023).

The Towns of Koshkonong and Aztalan reported the highest mean concentrations of nitrate-nitrogen followed by Oakland, Waterloo, and Cold Spring (Figure 10, 11). While deeper casing did not always result in low nitrate levels, nitrate levels generally decreased as the casing depth below the water table increased (Figure 12). In addition, as soils become more poorly drained, nitrate-nitrogen concentrations decreased (Figure 13).

Figure 9. Nitrate-nitrogen results for the 2023 well testing.

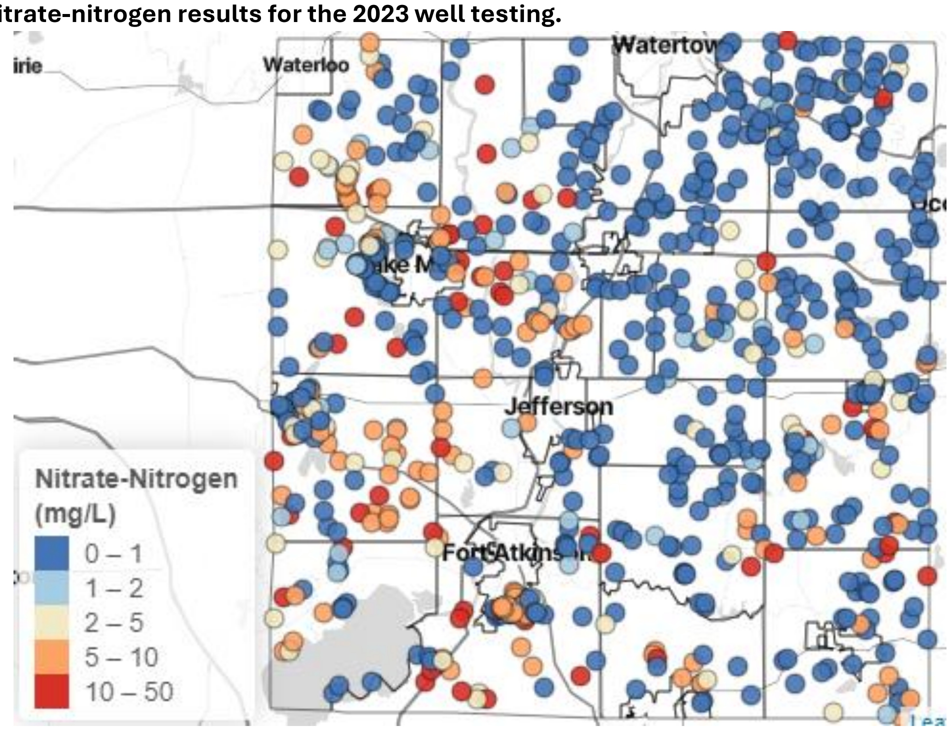


Table 3. Summary table of nitrate-nitrogen for countywide test results.

Nitrate-Nitrogen (mg/L)	Number of Samples	Percent
Less than 0.1	415	50%
0.1 – 2.0	146	18%
2.1 – 5.0	79	10%
5.1 – 10.0	129	16%
10.1 – 20.0	57	7%
Greater than 20.0	2	<1%

Figure 10. Mean nitrate-nitrogen by municipality.

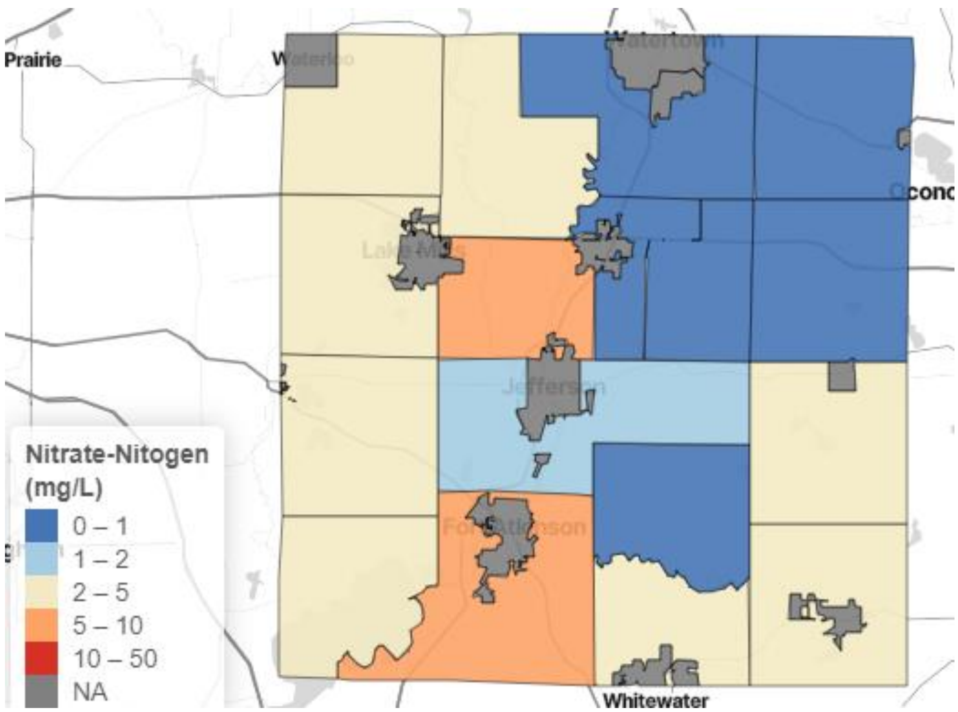


Figure 11. Boxplots of nitrate-nitrogen by town.

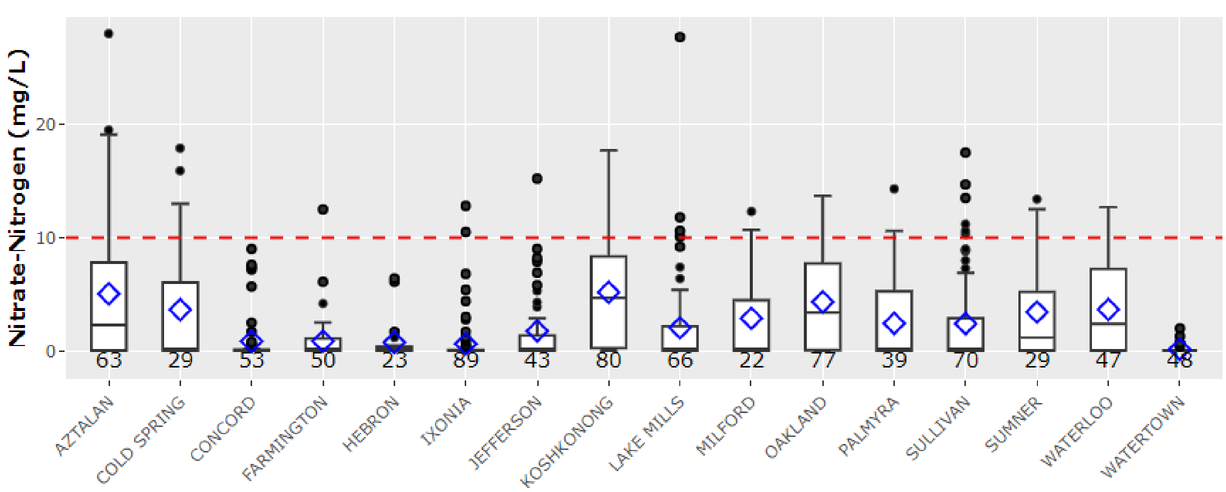


Figure 12. Boxplots of nitrate-nitrogen concentration by casing depth (ft) below the water table. Average and median nitrate-nitrogen concentrations generally decreased as the depth below the water table increased. Red dashed line indicates the 10 mg/L drinking water standard.

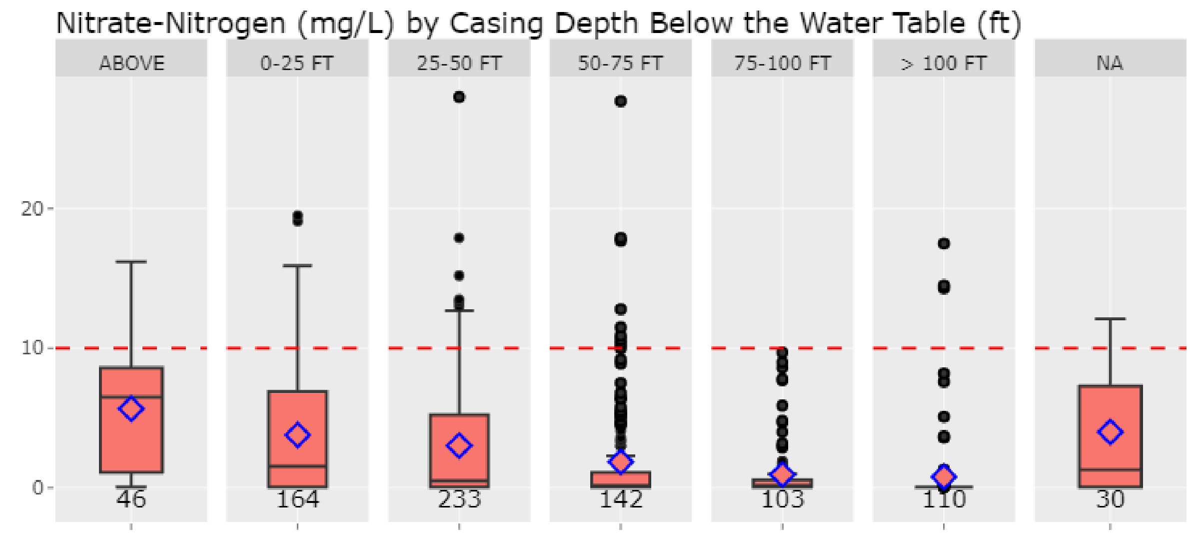
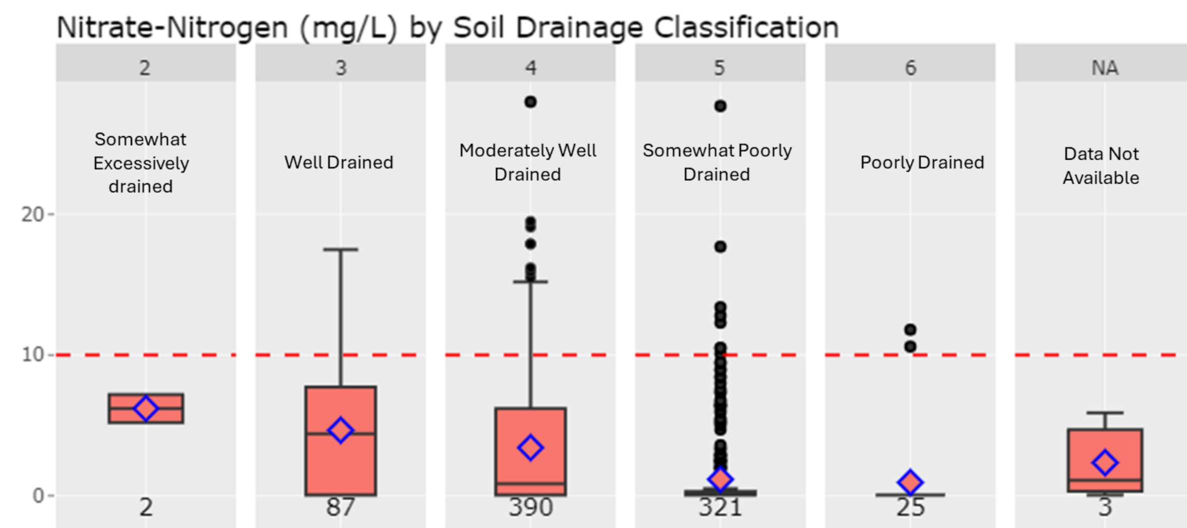


Figure 13. Boxplots of nitrate-nitrogen concentration by soil drainage classification. Mean and median nitrate-nitrogen concentration decreases as the ability of the soil to drain decreases. Red dashed line indicates the 10 mg/L drinking water standard.



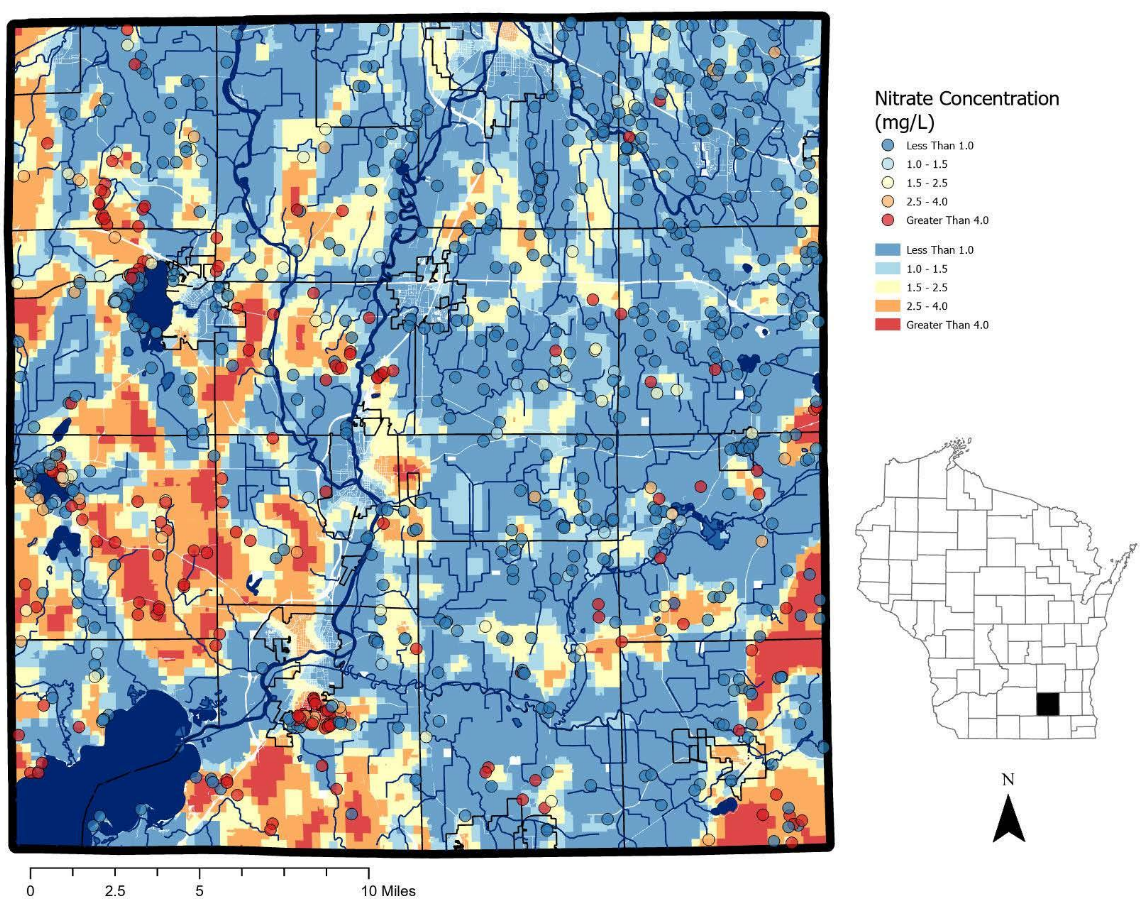
A OLS regression model of nitrate (Appendix X) indicated that soil drainage in the vicinity of the well had the strongest overall influence ($p<0.001$) on nitrate, followed by percent agricultural activity within a 500 m buffer ($p = 0.006$), septic system density ($p=0.007$), and percent forest cover within 500 m buffer ($p=0.15$). Whereas increases in the percent of agricultural land cover and number of septic systems were associated with increased nitrate-nitrogen concentrations, more forest land cover had a decreasing impact on nitrate predicted by the model (Appendix J). Overall the model was able to explain 19.8% of the variability in nitrate-nitrogen concentrations.

Land cover and soil drainage information within a 500-meter buffer of each parcel centroid was determined. The multiple linear regression model was then applied to the data from each parcel. Figure 14 shows the results of that model applied to individual parcels as a map of predicted nitrate-nitrogen concentration. The model has generally good agreement with areas that well water samples were elevated and areas where nitrate-nitrogen was generally low.

Nitrate is dependent on a variety of factors which include land-use, soils, geology, well depth, casing depth, etc. Even under similar land cover categories, the land cover data used for this analysis cannot determine the degree to which management may differ between owners. For example, sources and rates of nitrogen may differ, cover crops may be used on some fields and not others, or types of crops planted may have changed since 2017 when the Wiscland data layer was published.

As a result, predicting high nitrate risk does not mean wells in those areas are guaranteed to have elevated nitrate, but does suggest a greater likelihood of detecting nitrate at elevated levels and generally agrees well with the actual data (Figure 14). Predictive models like these can be used to inform county outreach strategies or prioritize areas for additional conservation management.

Figure 14. Predicted nitrate-nitrogen concentration by land parcel in Jefferson County. The measured nitrate-nitrogen concentrations of wells participating in 2023 countywide well water inventory are also included in the map.

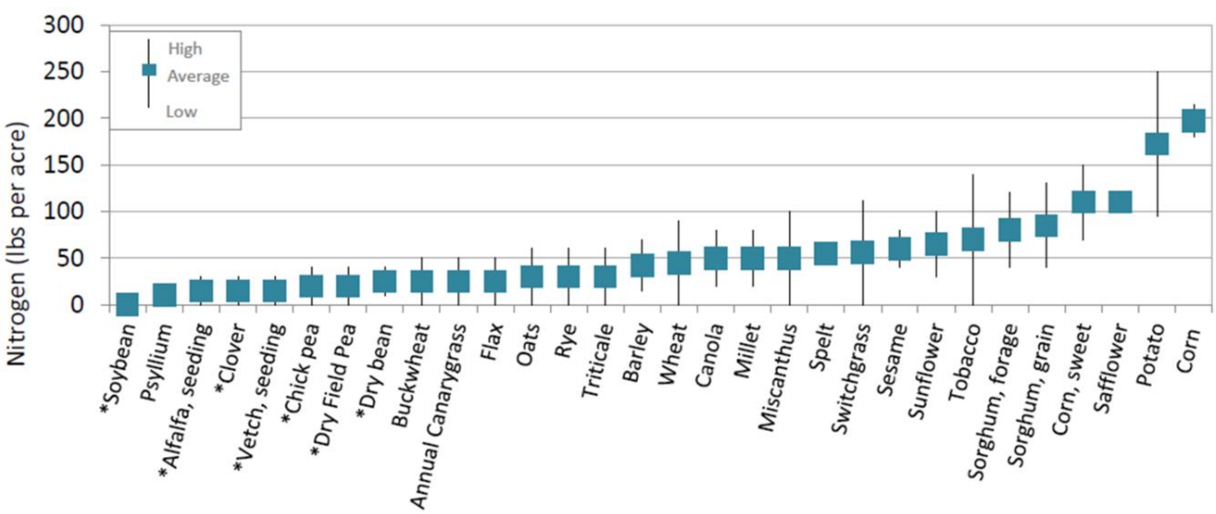


Agriculture and Nitrate

Agricultural activities are one of the factors that influence the amount of nitrate that gets into groundwater. While significant amounts of nitrogen are taken up by crops, not all of the nitrogen applied as fertilizer/manure is removed via the harvested portion of the plant. Heavy rains during the growing season can push nitrate past the reach of plant roots. Meanwhile, any nitrate left over in the soil at harvest time is likely to leach into groundwater with autumn rains and/or spring snow melt.

Nitrate leaching is largely a function of nitrogen fertilizer/manure inputs and the amount of nitrogen removed via harvested material. As a result, nitrate leaching estimates can be made when you know how much fertilizer was applied and the yield that was obtained on that field (Meisinger and Randall, 1991).

Figure 15. Nitrogen fertilizer recommendations (in pounds per acre) for various crops growing in Wisconsin. Asterisk (*) indicates legumes. (Source: Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin. A2809. Laboski and Peters, 2012. University of Wisconsin-Madison).



This budget approach often reveals that even fields with nutrient management plans are capable of leaching nitrate-nitrogen that is in excess of what is considered suitable for drinking water (i.e. 10 mg/L). Depending on the soil type and other factors, it's estimated that 20-50% of the nitrogen applied as fertilizer may leach past the root zone into groundwater (Shrethsa et al., 2023). Applying fertilizer at the right rate, time, source, place will maximize profitability and minimize excessive losses of nitrogen to groundwater; however additional practices are often necessary if looking to improve water quality in areas with susceptible soils and geology.

As the OLS model shows, soil drainage can also play a role in nitrate leaching. Poorly drained soils, particularly in the presence of organic matter, promote the conversion of nitrate into gaseous forms of nitrogen. These conditions reduce the amount that ends up leaching to groundwater.

Figure 16. Illustration of the relationship between crop type, the susceptibility of groundwater to contaminants such as nitrate, and the amount of nitrate that leaches under various scenarios. The plane represents the baseline level of nitrate leaching expected as the result of what are generally considered to be acceptable management practices.

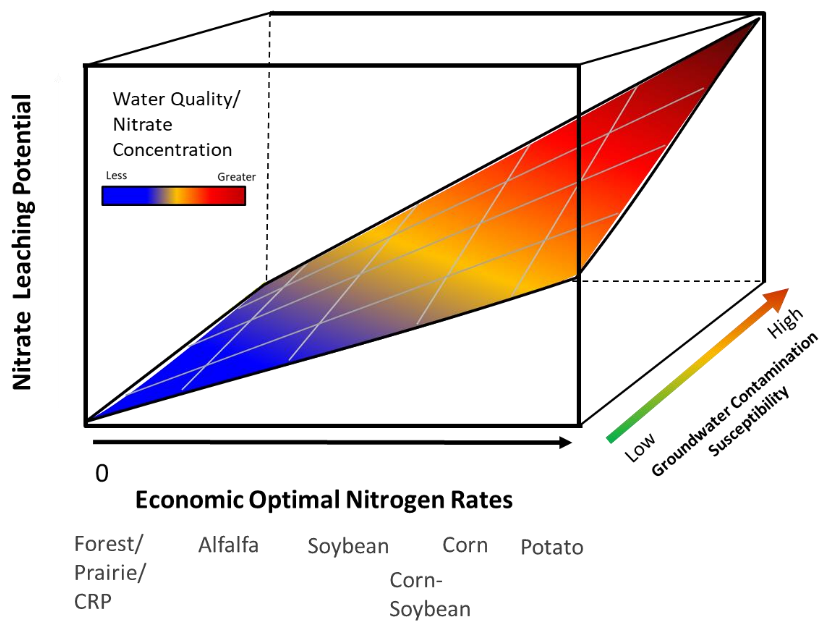
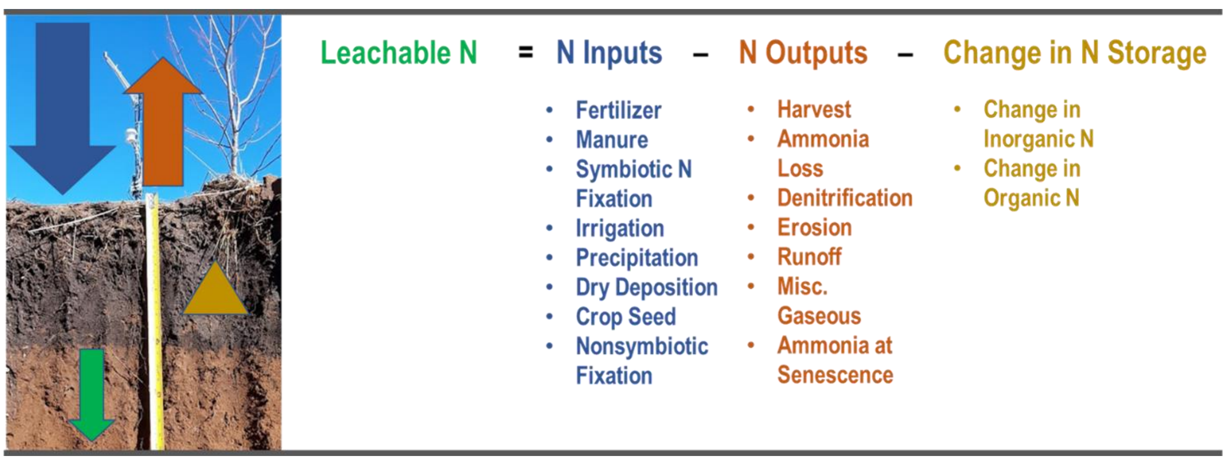


Figure 17. Potential leachable N (nitrate) can be calculated using a nitrogen budget approach. If various inputs are known and a reasonable estimate of yield can be made, estimating leachable nitrogen can be performed.



Minimizing nitrate leaching to groundwater fundamentally requires that we think about how best to maintain nitrogen in the top one to two feet of soil where plants are most likely to capture it. If nitrate in groundwater is an issue, improvements to groundwater quality below agricultural systems will only be observed when the following are achieved: 1) increasing yield with the same amount of nitrogen, 2) achieve the same yield with less nitrogen, 3) increase long-term soil organic matter levels which helps to store organic nitrogen in the soil and also increase water holding capacity, 4) temporary storage of nitrogen by cover crops that can be used to reduce nitrogen inputs to the next year's crop.

While significant nitrate can be lost during the growing season, particularly during wet years, leaching post-harvest through the following planting season may represent the majority of leaching losses during moderate to dry years (Masarik et al., 2014). Therefore, multiple strategies that reduce nitrogen fertilizer inputs, make nitrogen available when the plant needs it most, combined with additional activities that encourage active root systems or minimize decomposition during the fall and spring should all be explored.

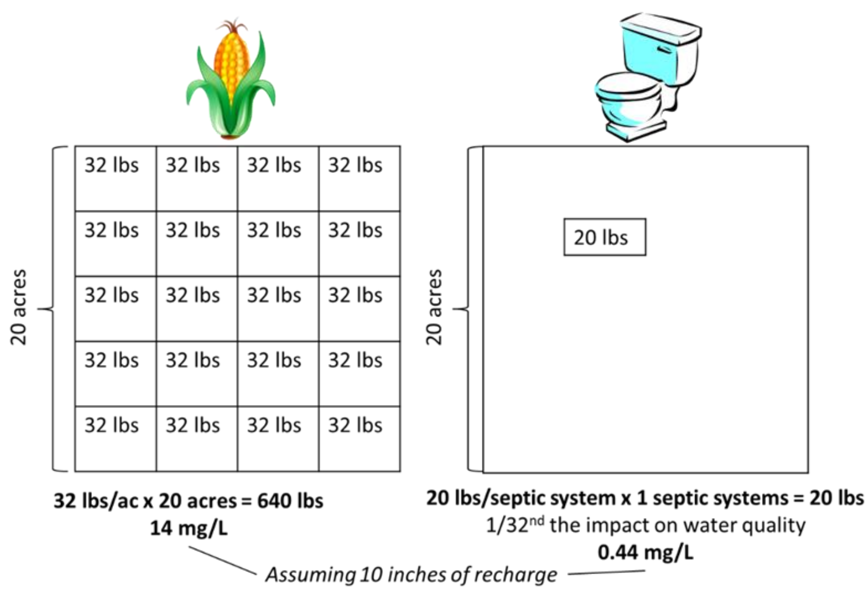
The following ideas are actionable activities that will help to reduce nitrate concentrations in groundwater and nearby wells:

- You may not need as much nitrogen fertilizer as you think, conduct your own on-farm rate trials to develop customized fertilizer response curves for your farm.
- Utilize conservation incentive programs to take marginal land or unprofitable parts of fields out of production.
- Diversify cropping systems to include less nitrogen intensive crops in the rotation (see Figure 15 for list of crops and nitrogen recommendations).
- Explore and experiment with the use of cover crops, intercropping, perennial cropping systems, or managed grazing to reduce nitrate losses to groundwater. Perennial cover, particularly diverse cover with multilayered root systems will have the greatest potential to reduce nitrate losses.

Septic systems and nitrate

Septic systems are designed to deactivate pathogens from wastewater and filter out other potential pollutants such as phosphorus, however other dissolved constituents like nitrate/chloride pass easily through drainfields into groundwater below. It is important to point out here that even properly functioning septic systems are contributors of nitrate to groundwater, although in traditional rural development the degree of influence is much less than agricultural systems.

Figure 18. Illustration of nitrogen leaching estimates for a twenty-acre agricultural field of corn (left) versus a twenty-acre parcel with one septic system drainfield for a 3 person household (right).



We can use a nitrogen budget approach to again understand why this might be the case. On average a septic system would be expected to leach between 16-20 pounds of nitrogen per year (EPA 625/R-00/008). If we compare this to an agricultural field that leaches 32 pounds per acre (Masarik, 2014) they may not seem that different. However, traditional rural development often has one septic system on a large parcel where the impact of nitrate leaching is offset by the rest of the property acreage (Figure 18). In some instances the impacts may be more evident; for instance if a well is directly downgradient of a septic drainfield or there are large numbers of drainfields in close proximity to one another.

When the density of septic systems in a small area increases, there is a greater potential for higher nitrate concentrations resulting from the increased nitrate loads to groundwater relative to the area. The smaller the lot size the greater potential impact that will result from septic systems in close proximity to one another, not only with respect to nitrate but also other compounds associated with household wastewater (ex. pharmaceuticals, personal care products, PFAS, etc.). For the example in Figure 18, we'd estimate that lot sizes of 0.6 acres in a 20 acre development with septic systems would essentially have the same impact as a 20 acre agricultural field leaching 32 lbs of nitrogen per acre. Portions of Jefferson County where subdivisions are served by private wells and septic systems on lot sizes of 2 acres or less, may be prone to elevated nitrate and other compounds as a result of development type and density.

Figure 19. (Right) Picture of subdivision with homes served by private wells and septic system drainfields. Groundwater flow direction is from upper-left to lower-right. Orange shapes illustrate hypothetical plumes paths downgradient of drainfields. Lawn fertilizers in excess of what the lawn is able to use may also represent a source of nitrate to groundwater in these settings.

Chloride

In most areas of Wisconsin, chloride concentrations are naturally low (usually less than 10 mg/L). Higher concentrations may serve as an indication that the groundwater supplied to your well has been impacted by various human activities. Sources of chloride include agricultural fertilizers (chloride is a companion ion of potash fertilizers), septic system effluent (particularly from households with water softeners), road salt, and manure/other biosolids. There is increasing concern over water quality impacts of chloride on groundwater and surface waters. Having baseline chloride concentrations in well water will allow for future testing to understand trends in chloride concentrations over time.

Interpreting Chloride Concentrations

Chloride is not toxic at typical concentrations found in groundwater. Unusually high concentrations of chloride (greater than 100 mg/L) are often associated with road salt and may be related to nearby parking lots or road culverts where meltwater from winter deicing activities often accumulates. Water with concentrations greater than 250 mg/L are likely to contain elevated sodium and are sometimes associated with a salty taste; high chloride levels are also more likely to be corrosive to certain metals.

Jefferson County Results

Natural or background levels of chloride (<10 mg/L) were observed in 23% of wells, 52% showed some slight impacts, 16% moderate impact, and 8% had evidence of significant impacts. High levels of chloride are often found adjacent to major roadways or near urban areas where road salting is more prevalent. The Towns of Sullivan and Koshkonong had the greatest mean chloride concentrations. Similar to nitrate, chloride levels generally decreased as the casing depth below the water table increased (Figure 23).

Figure 20. Chloride results for 2023 Jefferson County well testing.

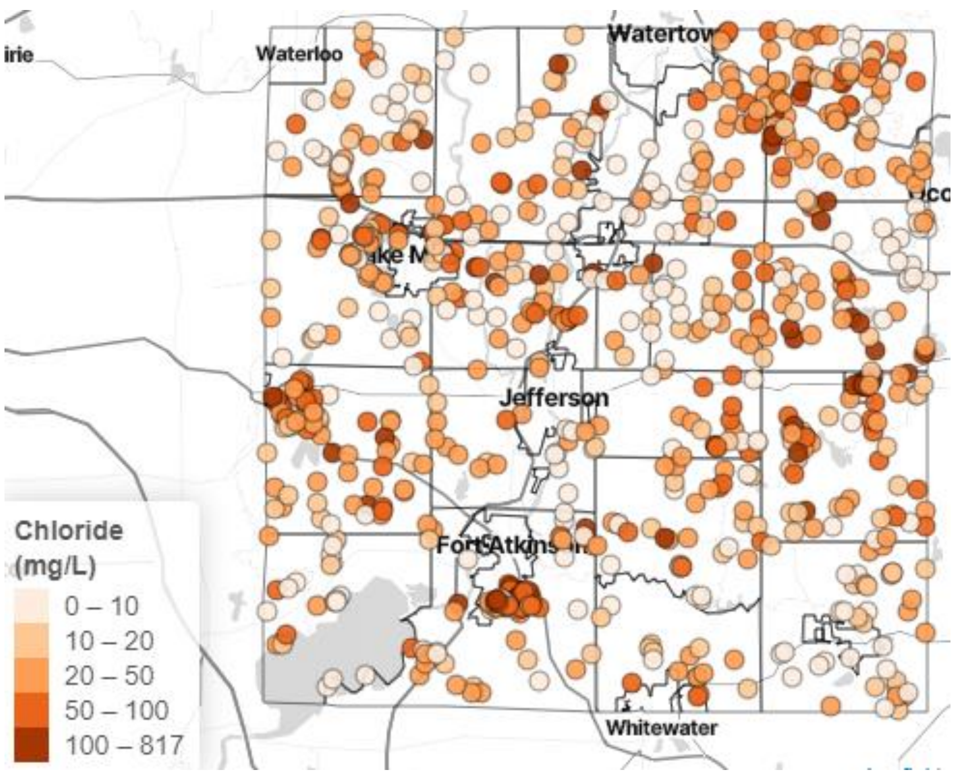


Table 4. Summary table of chloride for countywide test results.

Chloride (mg/L)	Number of Samples	Percent
Less than 10	192	23%
11 – 50	436	52%
51 – 100	137	16%
101 – 200	45	5%
Greater than 200	22	3%

Figure 21. Mean chloride concentration by town.

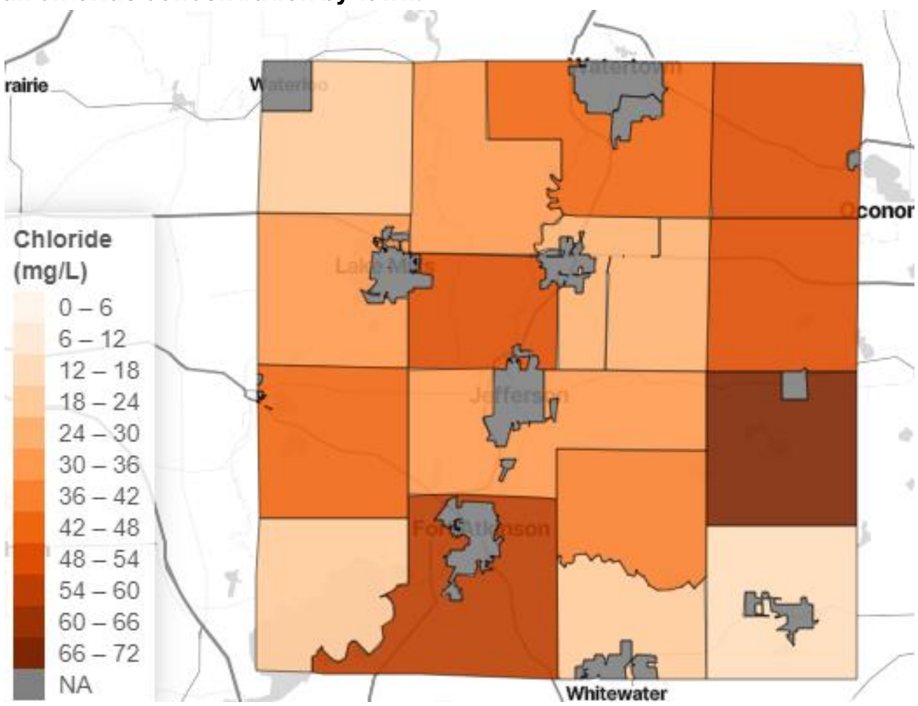


Figure 22. Boxplots of chloride by municipality.

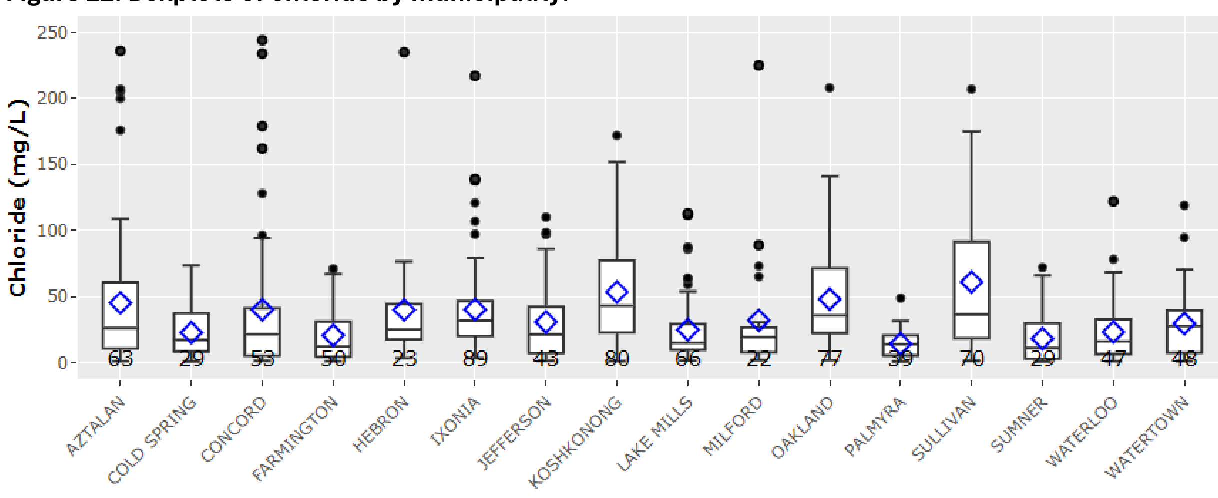


Figure 23. Boxplots of chloride by casing depth below the water table.

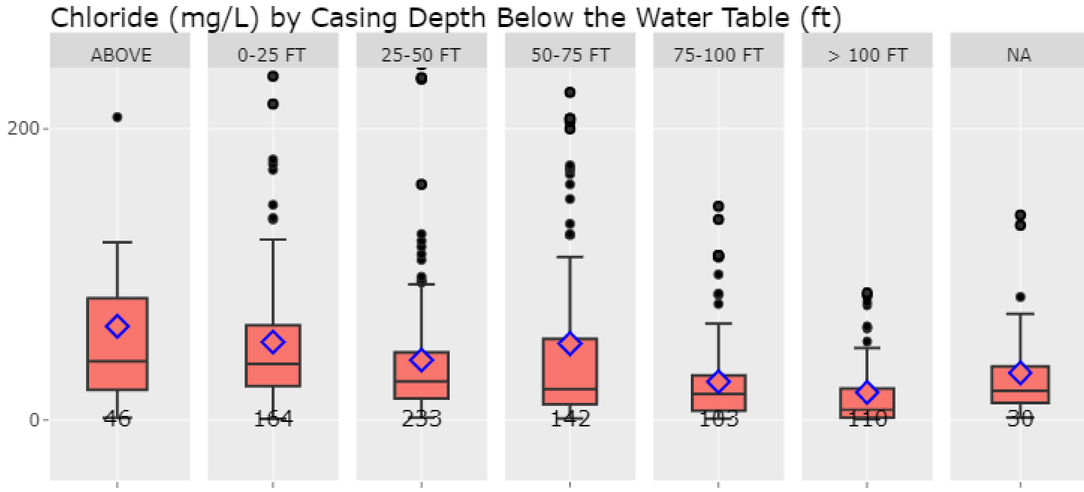
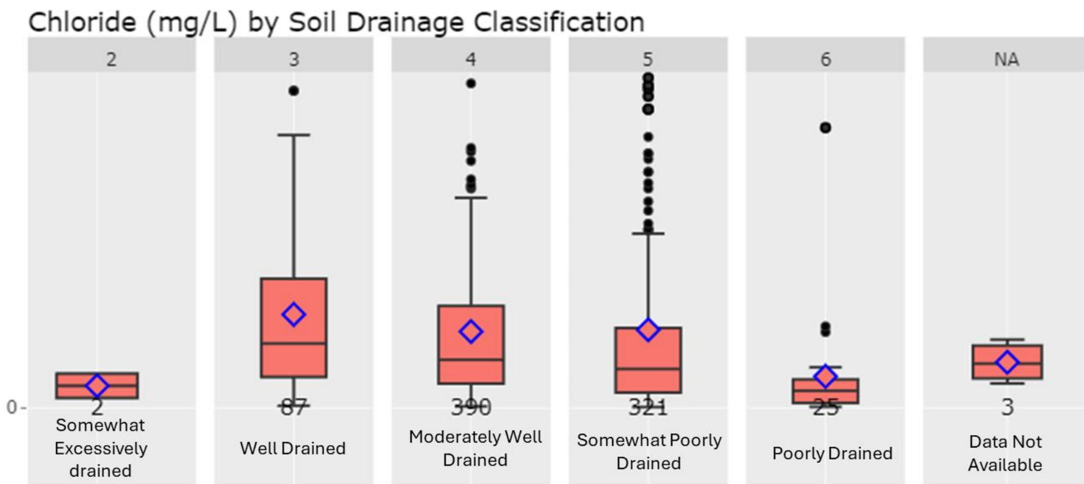


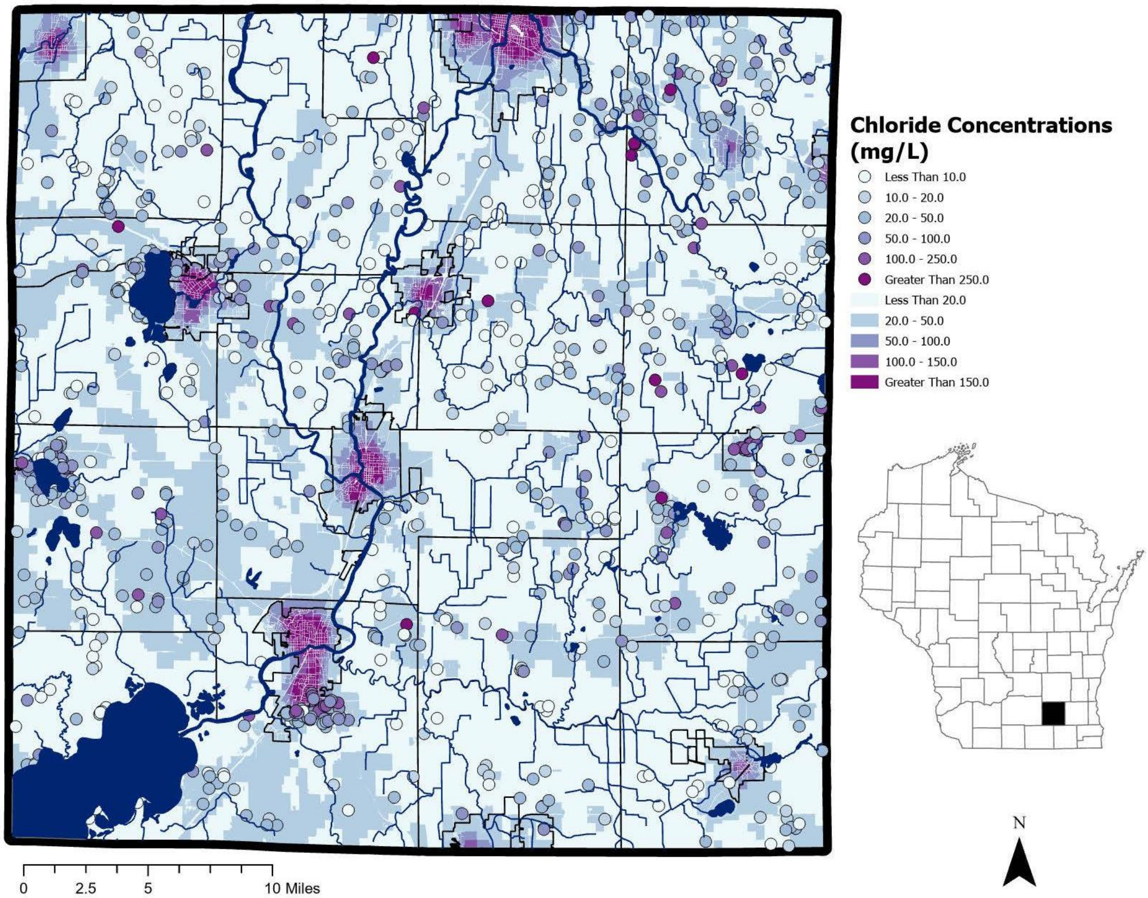
Figure 24. Boxplots of chloride by soil drainage classification.



A OLS regression model of chloride (Appendix J) indicated that percent of urban land cover within a 500 m buffer of the well had the strongest overall influence ($p<0.001$) on chloride, followed by soil drainage in the vicinity of the well ($p = 0.003$), and lastly agricultural land cover within a 500 m buffer ($p=0.094$). Overall the model was able to explain 11% of the variability in chloride concentrations.

The multiple linear regression model was then applied to the data from each parcel. Figure 25 shows the results of that model applied to individual parcels as a map of predicted chloride concentration. Predicted chloride levels did not always agree with the actual well water data, however it does highlight the role of urban areas and overall influence that road salt activities play in contributing to elevated chloride in groundwater.

Figure 25. Map of predicted chloride concentration by parcel created using statistical model of chloride for 2023 Jefferson County well water results.



Total Hardness

The total hardness test measures the amount of calcium and mangnesium in water. Calcium and magnesium are essential nutrients, which generally come from natural sources of these elements in rock and soils (i.e. carbonate rocks). The amount present in drinking water is generally not a significant source of these nutrients compared with a healthy diet. There are no health standards associated with total hardness in your water, however; too much or too little hardness can be associated with various aesthetic issues that can impact plumbing and other functions.

Because total hardness is related to the rocks and soils that water flows through on its way to a well, we would expect total hardness concentrations to be fairly stable from year to year. Any changes observed in total hardness concentrations may help us better understand the influence of weather variability during the year on well water quality on an individual well. Because hardness concentrations have been shown to increase when nitrate and/or chloride increase, the total hardness test is a good complement to other tests.

Interpreting Total Hardness Concentrations

Hard Water: Water with a total hardness value greater than 200 mgL is considered hard water. Hard water can cause lime buildup (scaling) in pipes and water heaters. Elements responsible for water hardness can also react with soap decreasing its cleaning ability, can cause buildup of soap scum, and/or graying of white laundry over time. Some people that use hard water for showering may notice problems with dry skin.

Soft Water: Water with a total hardness concentration less than 150 mg/L is considered soft. Water with too little hardness is often associated with corrosive water, which can be problematic for households with copper plumbing or other metal components of a plumbing system.

Ideal: Water with total hardness between 150-200 mg/L is generally an ideal range of water hardness because there are enough ions to protect against corrosion, but not too many that they contribute to scale formation. While it is a personal preference, households with hardness in this range generally don't require additional treatment.

Jefferson County Results

Mean total hardness levels were 415 mg/L as $CaCO_3$, when accounting for softned samples. Essentially all wells that participated have water that has moderate to high total hardness. Results show Jefferson County well water generally contains higher levels of hardness than what is typically found in other parts of Wisconsin. Northeastern Jefferson County contained some of the highest concentrations of total hardness, likely related to the geology that wells encounter and the higher amounts of calcium and magnesium containined in those specific rock units. Soft water was not typical, as a result, most households in Jefferson County likely have water softeners or other treatment to treat for the amount of hardness measured in well water.

Figure 26. Total hardness well water quality results for 2023

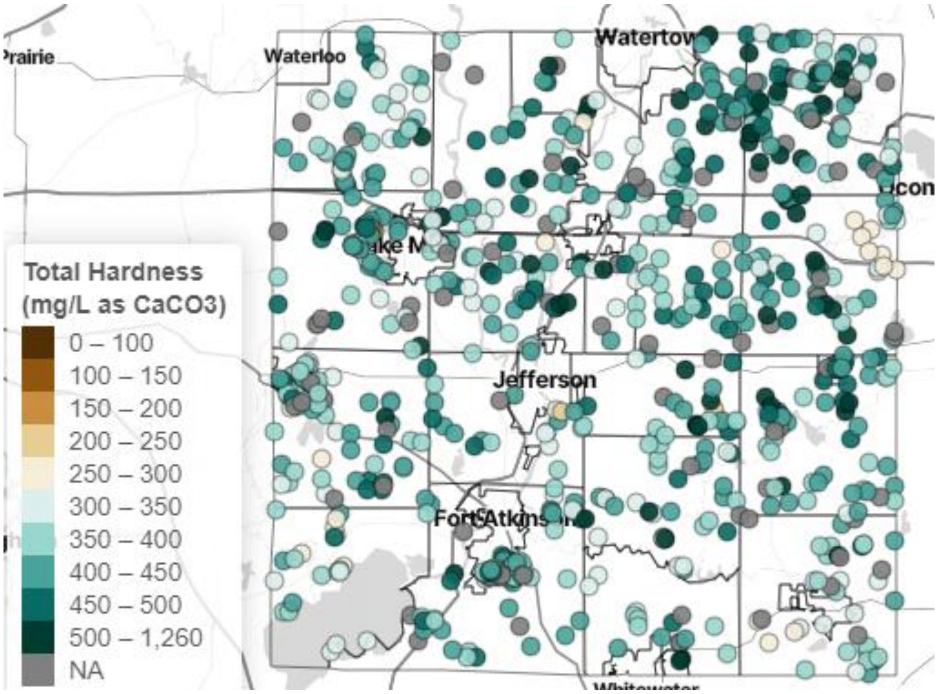


Table 5. Summary table of total hardness for countywide test results.

Total Hardness (mg/L CaCO3)	Number of Samples	Percent
Less than 50*	98	12%
51 – 100	1	<1%
101 – 200	1	<1%
201 – 300	27	3%
301 – 400	296	36%
Greater than 400	409	49%

*Samples with less than 50 mg/L are likely softened or partially softened

Figure 27. Mean total hardness by town.

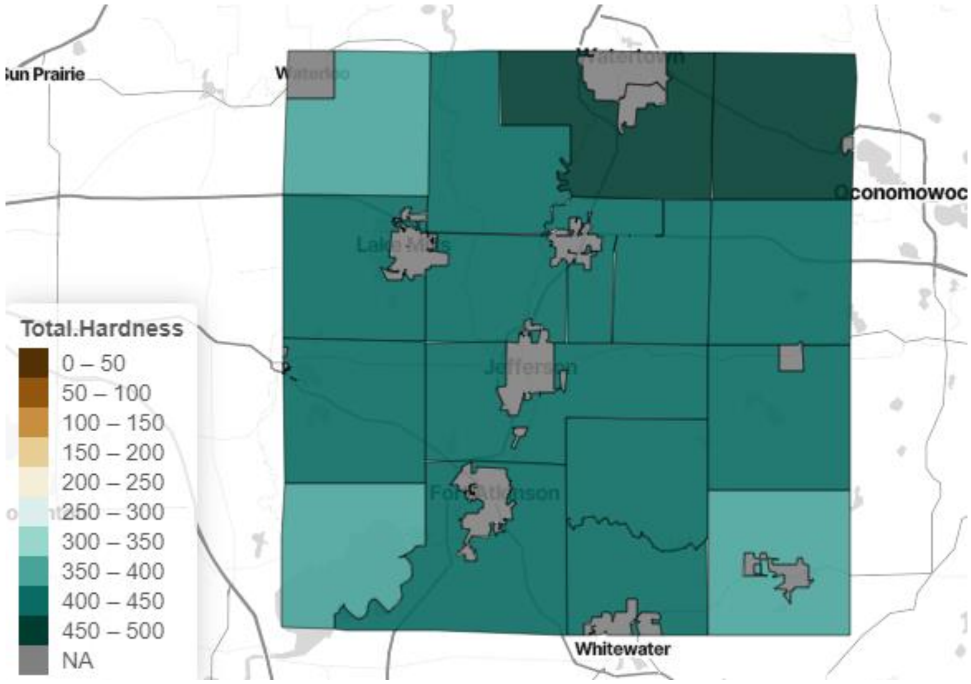
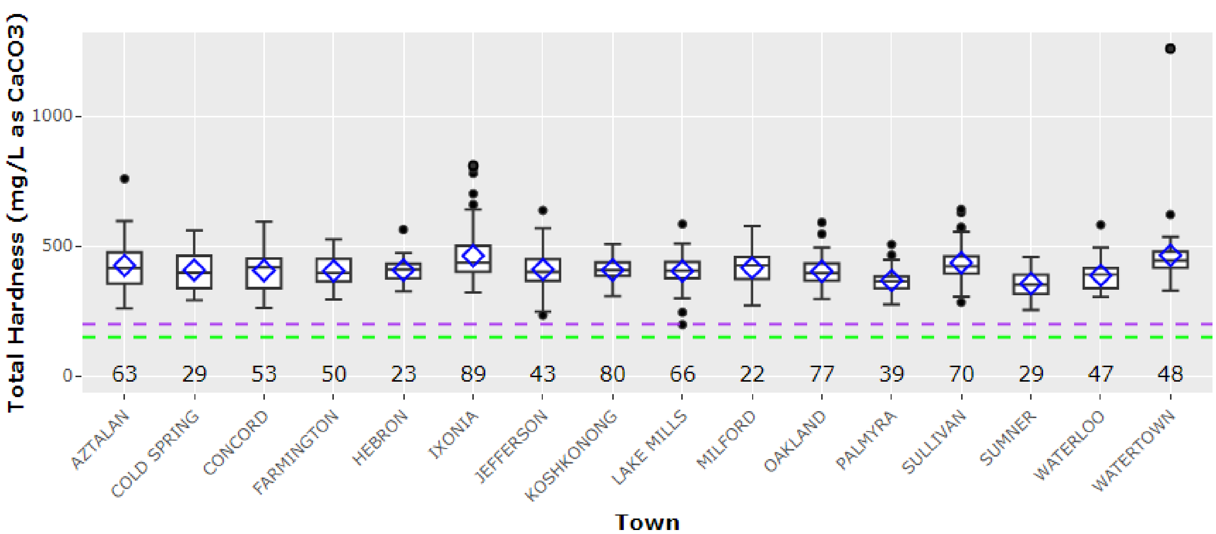


Figure 28. Boxplots of total hardness by town. Dashed purple line indicates threshold for hard water (>200 mg/L as $CaCO_3$), while green dashed line indicates threshold for soft water (<150 mg/L as $CaCO_3$).



Alkalinity

Alkalinity is a measure of water's ability to neutralize acids. Alkalinity is associated with carbonate minerals and is commonly found in areas where groundwater is stored or transported in carbonate aquifers. Because they both originate from carbonate rocks, lower values of alkalinity are generally associated with those areas which measure lower total hardness values.

Alkalinity is the result of dissolution of carbonate from the rocks and soils that water flows through on its way to a well. Generally, alkalinity concentrations are relatively stable from year to year. Changes observed in alkalinity concentrations may help determine the influence of climate variability on well water quality from year to year, or help with interpretation of broader water quality results from Jefferson County. Particularly in wells that are uninfluenced by human activity, alkalinity concentrations may help us better understand which aquifers wells are accessing groundwater from.

Interpreting Alkalinity Concentrations

There are no health concerns associated with having alkalinity in water. Alkalinity should be roughly 75-100% of the total hardness value in an unsoftened sample. Water with low levels of alkalinity (less than 150 mg/L) is more likely to be corrosive. High alkalinity water (greater than 200 mg/L), may contribute to scale formation. If total hardness is half or less than the alkalinity result, it likely indicates that your water has passed through a water softener. If alkalinity is significantly less than total hardness, it might be related to elevated levels of chloride or nitrate in a water sample.

Figure 29. Alkalinity well water quality results for 2023.

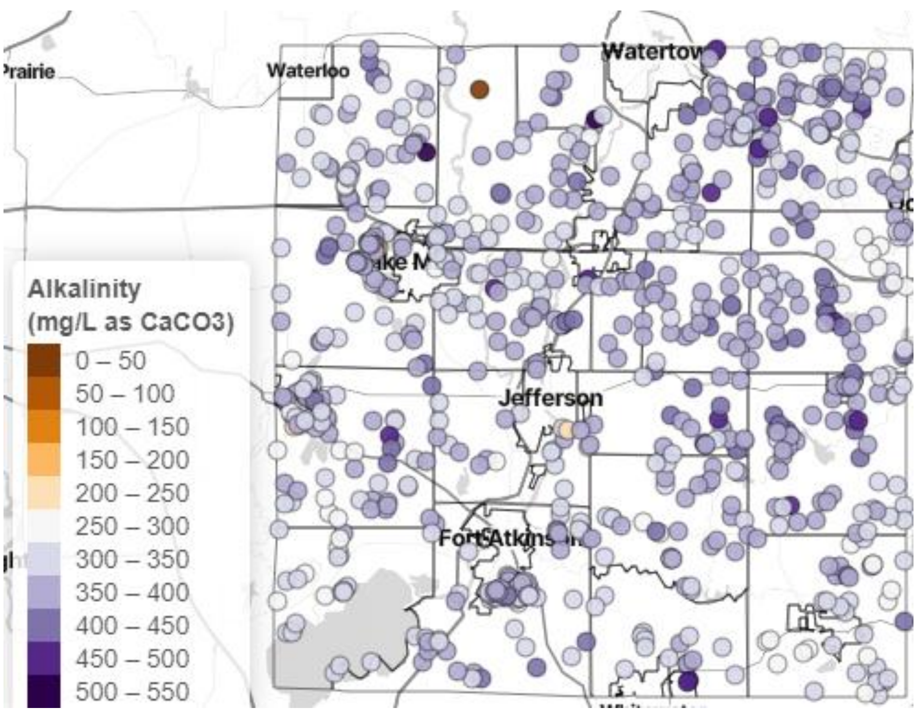


Table 6. Summary table of alkalinity for countywide test results.

Alkalinity (mg/L $CaCO_3$)	Number of Samples	Percent
Less than 50	1	<1%
51 – 100	0	0%
101 – 200	1	<1%
201 – 300	54	6%
301 – 400	682	82%
Greater than 400	94	11%

Figure 30. Mean alkalinity concentration by town.

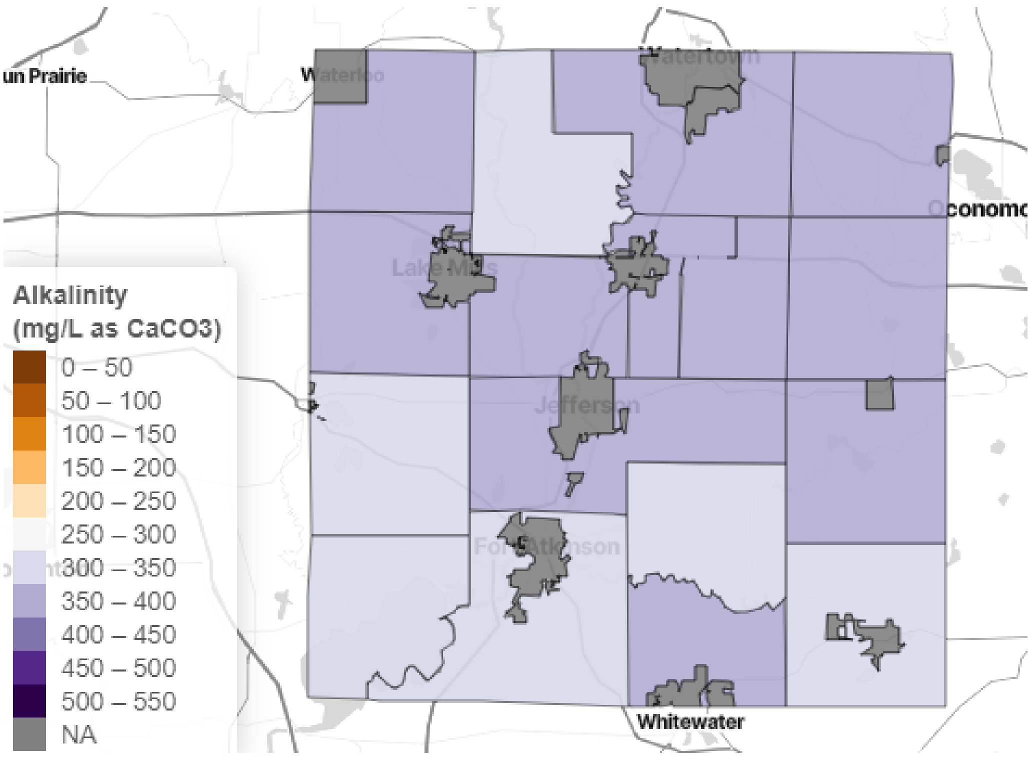
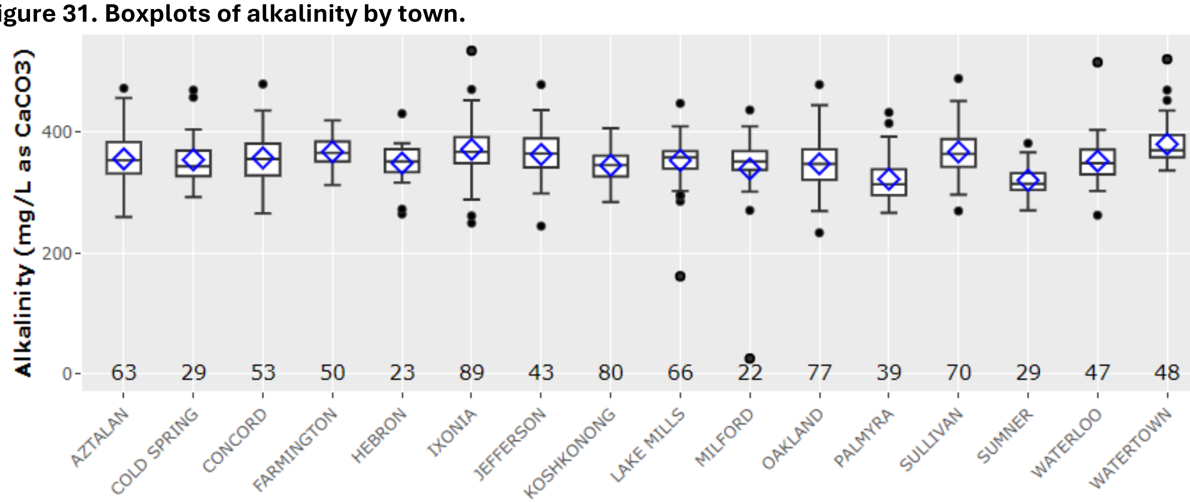


Figure 31. Boxplots of alkalinity by town.



Conductivity

Conductivity measures the amount of dissolved substances (or ions) in water; but does not give an indication of which minerals are present. Conductivity is a measure of both naturally occurring ions such as calcium, magnesium, and alkalinity; as well as ions that are often associated with human influences such as nitrate and chloride. Changes in conductivity over time may indicate changes in your overall water quality.

Conductivity is relatively easy to measure and sensors for conductivity are reliable. Information learned from changes in conductivity during this project may be useful for designing future monitoring strategies for Jefferson County or individual households to inexpensively track sudden changes in water quality on their own. A sudden drop in conductivity may indicate rapid recharge from rain or snow melt. Conversely, gradual increases in conductivity, may be the result of increasing chloride or nitrate levels that should be investigated with additional testing.

Acceptable results:

There is no health standard associated with conductivity. A normal conductivity value measured in µmhos/cm is roughly twice the total hardness as mg/L $CaCO_3$ in unsoftened water samples. If conductivity is significantly greater than twice the hardness, it may indicate the presence of other human-influenced or naturally occurring ions such as chloride, nitrate, or sulfate.

Figure 32. Conductivity results for 2023 Jefferson County well sampling.

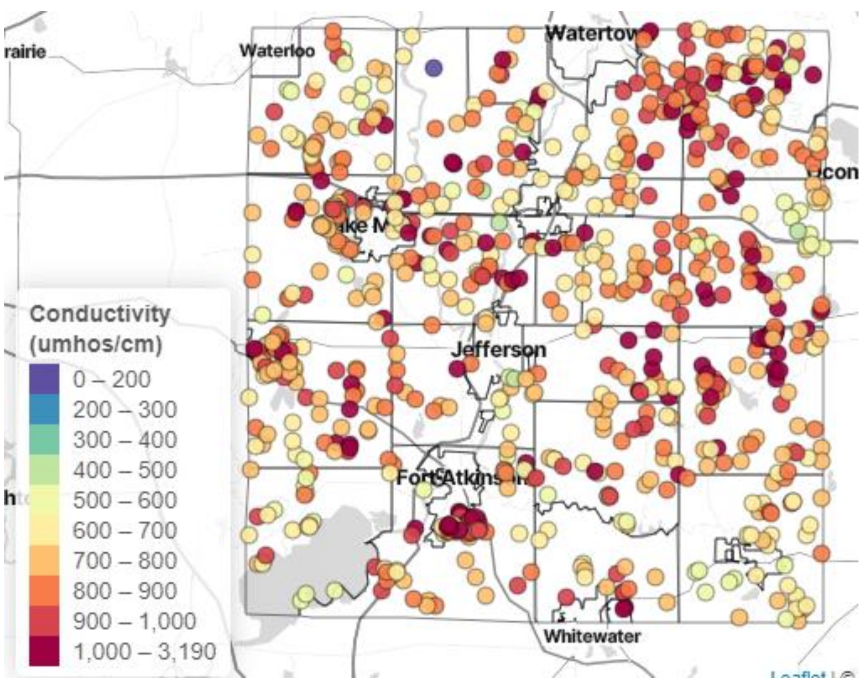


Table 7. Summary table of conductivity for countywide test results.

Conductivity (µmhos/cm)	Number of Samples	Percent
101 – 250	1	<1%
251 – 500	6	<1%
501 – 750	290	35%
751 – 1000	414	50%
Greater than 1000	121	15%

Figure 33. Mean conductivity by town.

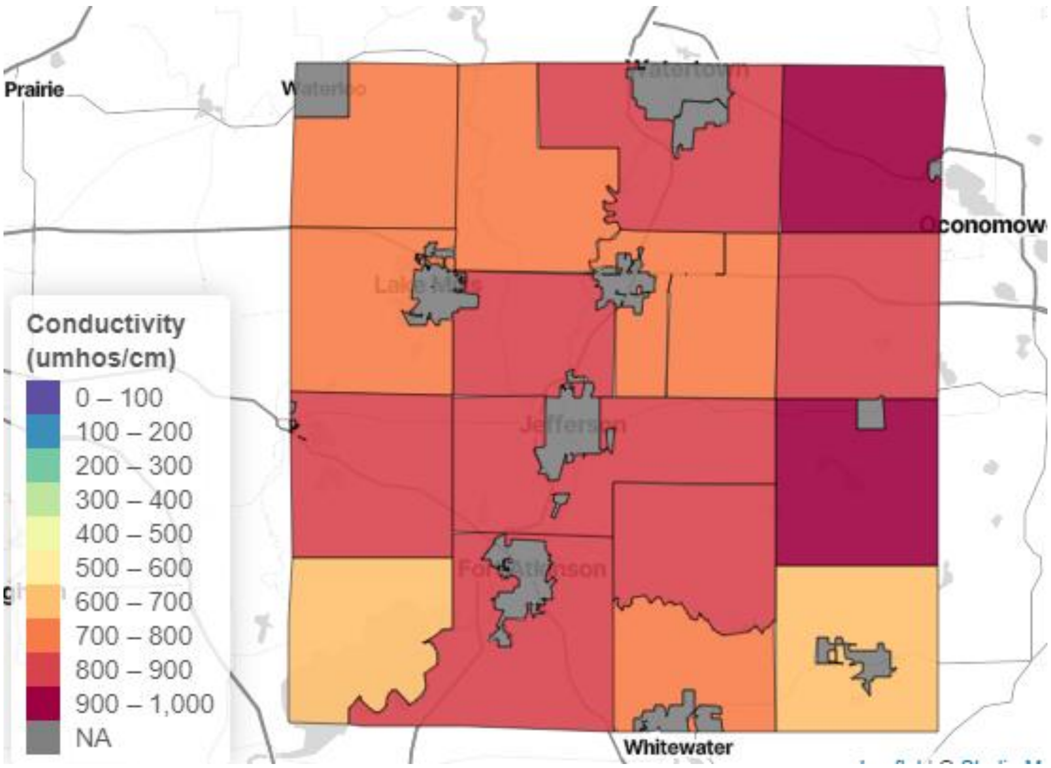
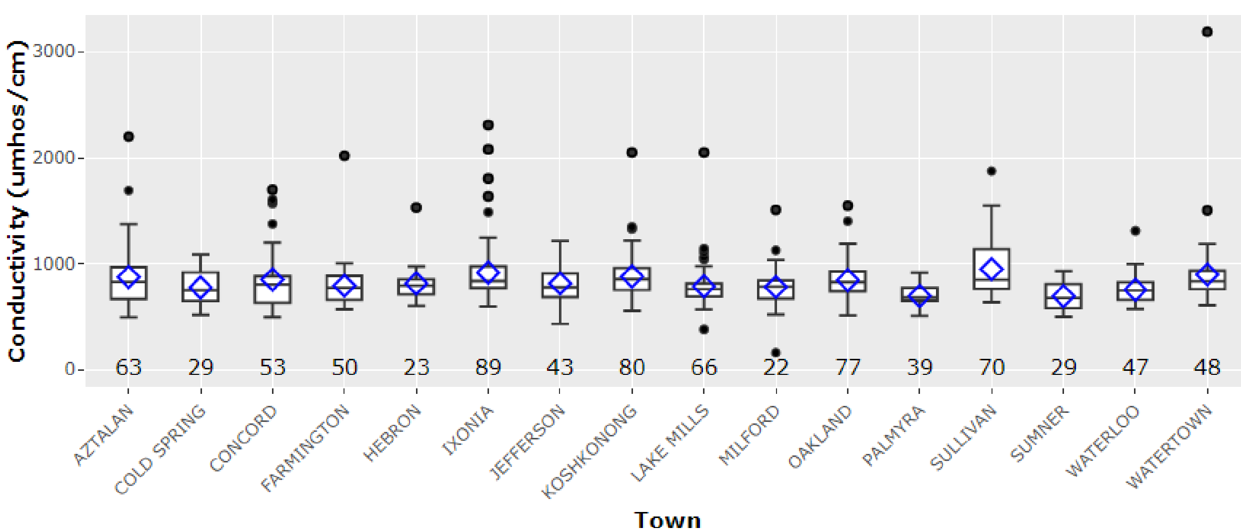


Figure 34. Boxplots of conductivity by town.



pH

The pH test measures the concentration of hydrogen ions in a solution. The concentration of hydrogen determines if a solution is acidic or basic. The lower the pH, the more corrosive water will be. The pH reported here is likely higher than what would be measured straight out of the well. This is because dissolved carbon dioxide is released into the atmosphere as groundwater is exposed to the air. Dissolved carbon dioxide creates a weak acid known as carbonic acid which reduces pH. The difference between field pH (pH of water directly out of the well) and lab pH (the value reported here), is generally on the order of 0.3 to 0.5 pH units.

There is no health standard for pH but corrosive water (pH less than 7) is more likely to contain elevated levels of copper or lead if these materials are in your household plumbing. Typical groundwater pH values in Wisconsin range from 6.0 to 9.0.

Elevated levels are usually the result of carbonate minerals which help raise the pH and also buffer against changes in pH. Conversely, low values of pH are most often caused by lack of carbonate minerals in the aquifer. Low pH combined with low mineral content makes water aggressive or corrosive, particularly to metal plumbing components.

Jefferson County Results

The pH of well water in Jefferson County would be considered basic and was found to be fairly uniform countywide. The pH is largely a function of the soils and geology that groundwater flows through and is typical for this region.

Figure 35. The pH of samples from samples of the 2023 Jefferson County well water testing.

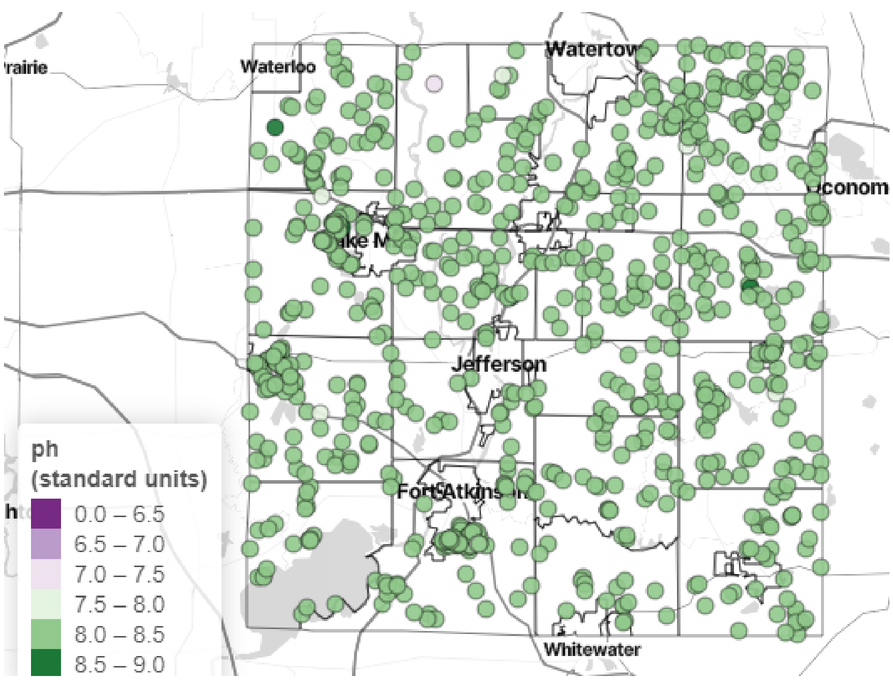


Table 8. Summary table of pH for countywide test results.

pH	Number of Samples	Percent
7.01 – 8.00	17	2%
8.01 – 9.00	815	98%

Figure 36. pH levels by town.

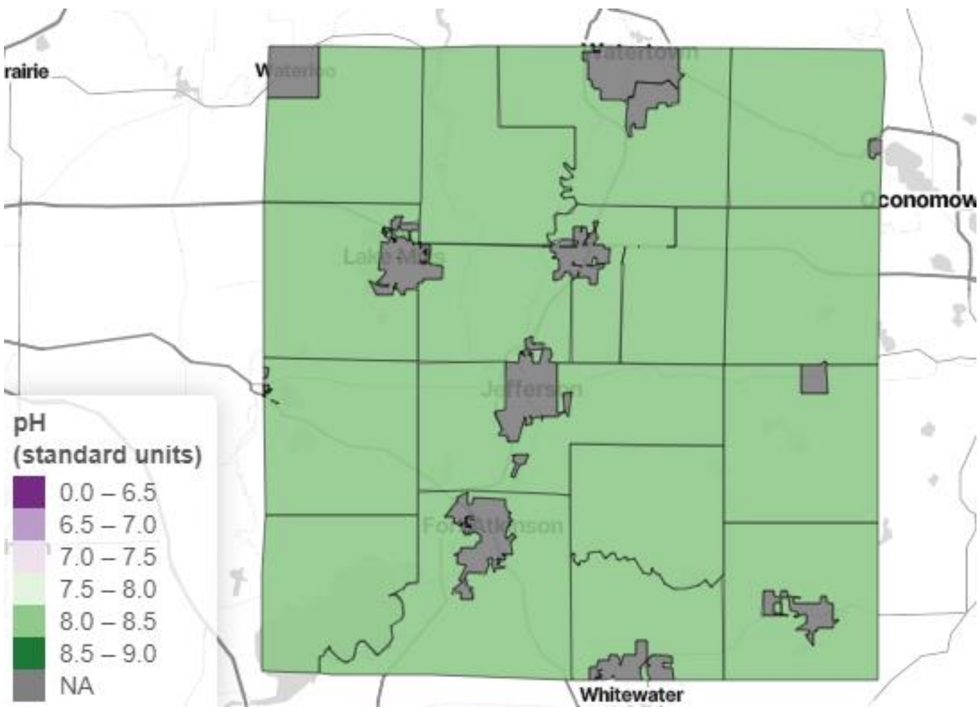
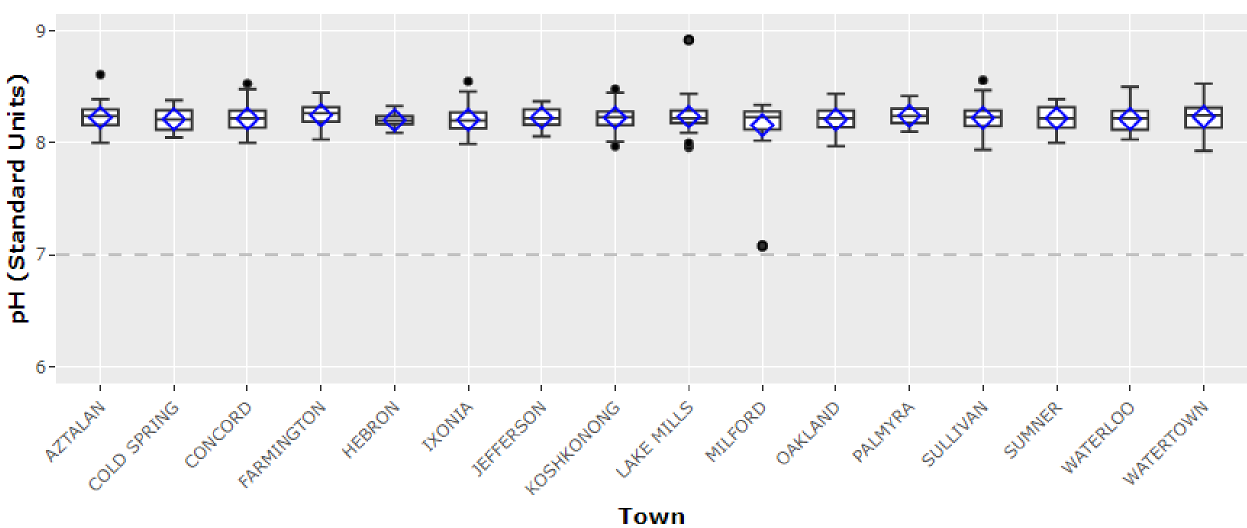


Figure 37. Boxplots of pH by town. Grey dashed line represents neutral pH.



Arsenic

Arsenic is a naturally occurring element that can be found at levels of concern when groundwater dissolves arsenic containing mineral deposits in the soil and bedrock of some aquifers. There is a health-based drinking water standard of 0.010 mg/L. Long-term exposure to arsenic greater than 0.010 mg/L in drinking water can increase the likelihood of cancer (ex. skin, liver, kidney, bladder).

Treatment may be effective for reducing arsenic in drinking water. Reverse osmosis and distillation are point-of-use devices that are capable of treating arsenic. Point of use devices treat enough water for drinking and cooking needs. Any treatment system installed to remove a health-related contaminant should verify through testing that the device is removing contaminant at sufficient levels to be considered safe.

Jefferson County Results

Approximately one in four wells participating in the countywide study had detectable levels of arsenic. Seven percent contained levels greater than the safe drinking water standard of 0.010 mg/L, this is higher than the Wisconsin average of approximately 3% of private wells statewide. The towns of Ixonia, Watertown, Farmington, and Jefferson had the greatest average concentration of arsenic. While every private well should be tested for arsenic at least once, these results suggest an even greater emphasis on this recommendation for Jefferson County. If a well detects measurable arsenic routine testing is encouraged until you can determine whether concentrations are stable and not changing. If levels ever exceed 0.010 mg/L water treatment or other options should be explored to reduce exposure to arsenic in drinking water.

More detailed information on the geology in the towns of Ixonia and Watertown could be beneficial for understanding more about sources of arsenic in that part of Jefferson County.

Figure 38. Arsenic results for 2023 Jefferson County well samples.

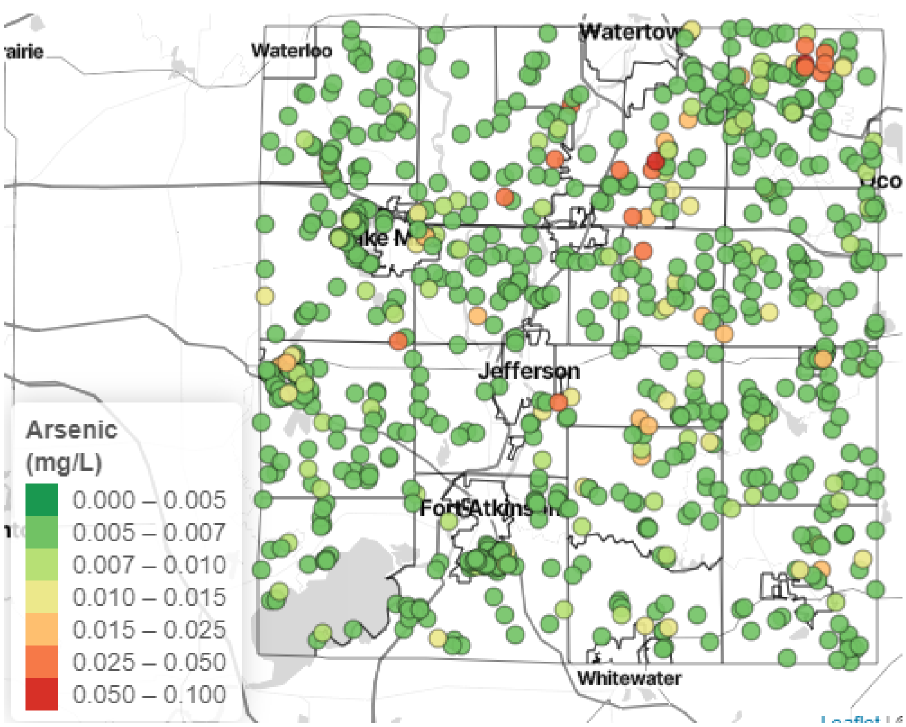


Table 9. Summary of countywide arsenic concentrations.

Arsenic (mg/L)	Number of Samples	Percent
None detected	608	73%
Less than 0.010	166	20%
0.011 – 0.050	55	7%
0.051 – 0.100	3	<1%

Figure 39. Mean arsenic concentration by town.

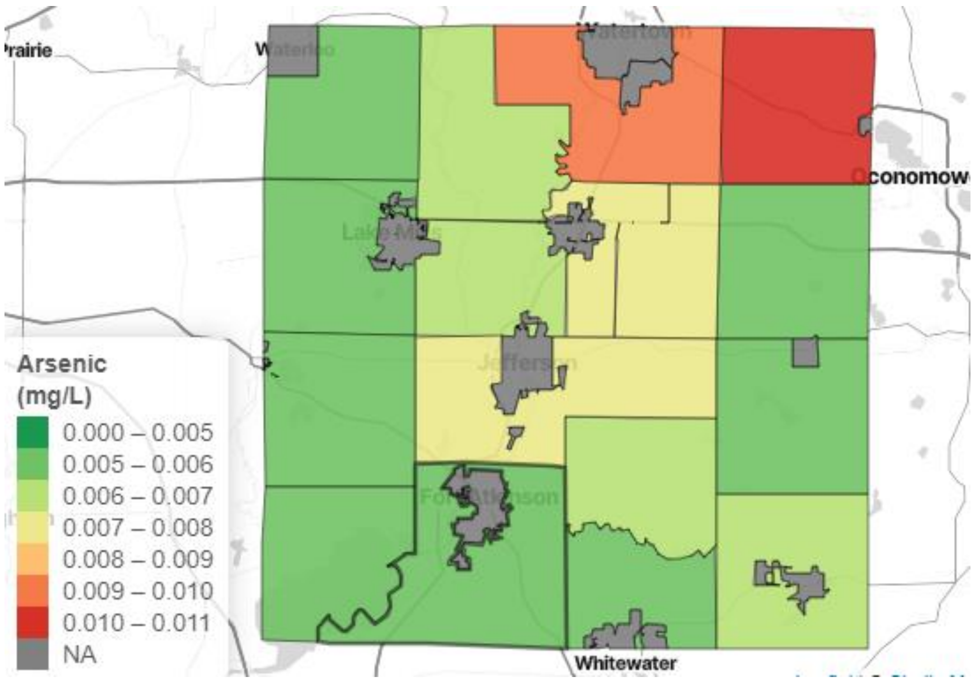
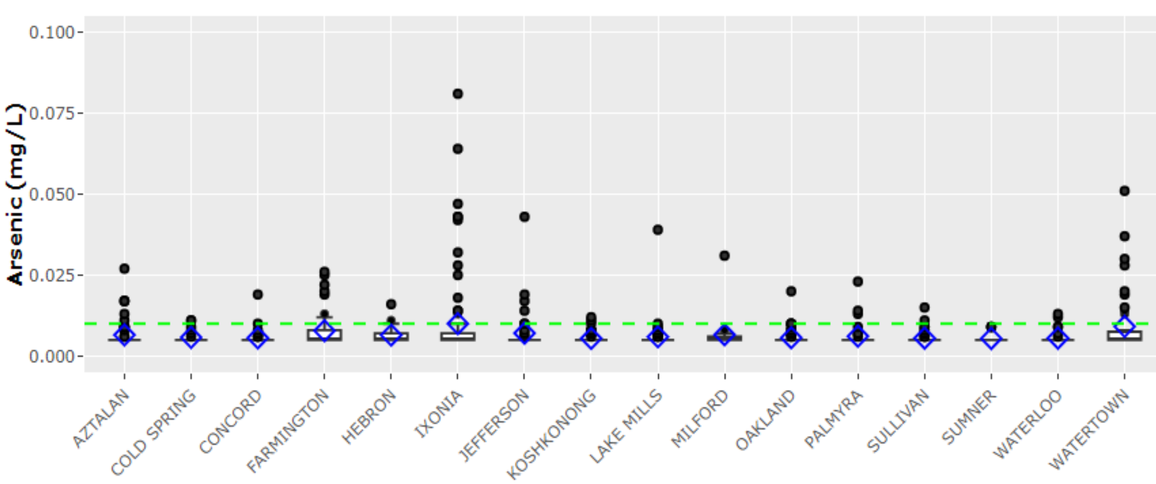


Figure 40. Boxplots of arsenic by town. Dashed green line indicates arsenic drinking water standard of 0.010 mg/L.



Calcium

Calcium is naturally occurring in groundwater from the dissolution of calcium from dolomite and limestone rock formations. There are no health concerns associated with calcium. Calcium is essential for a variety of human health functions, although the amount obtained through drinking water is generally small compared to intake through food consumption. Along with magnesium, calcium contributes to hard water. Hard water can cause scale buildup and other issues and is removed through the water softening process. Calcium results are similar to hardness and alkalinity because they are all related to the same geologic sources.

Figure 41. Calcium results for 2023, wells with less than 10 mg/L calcium are likely softened samples.

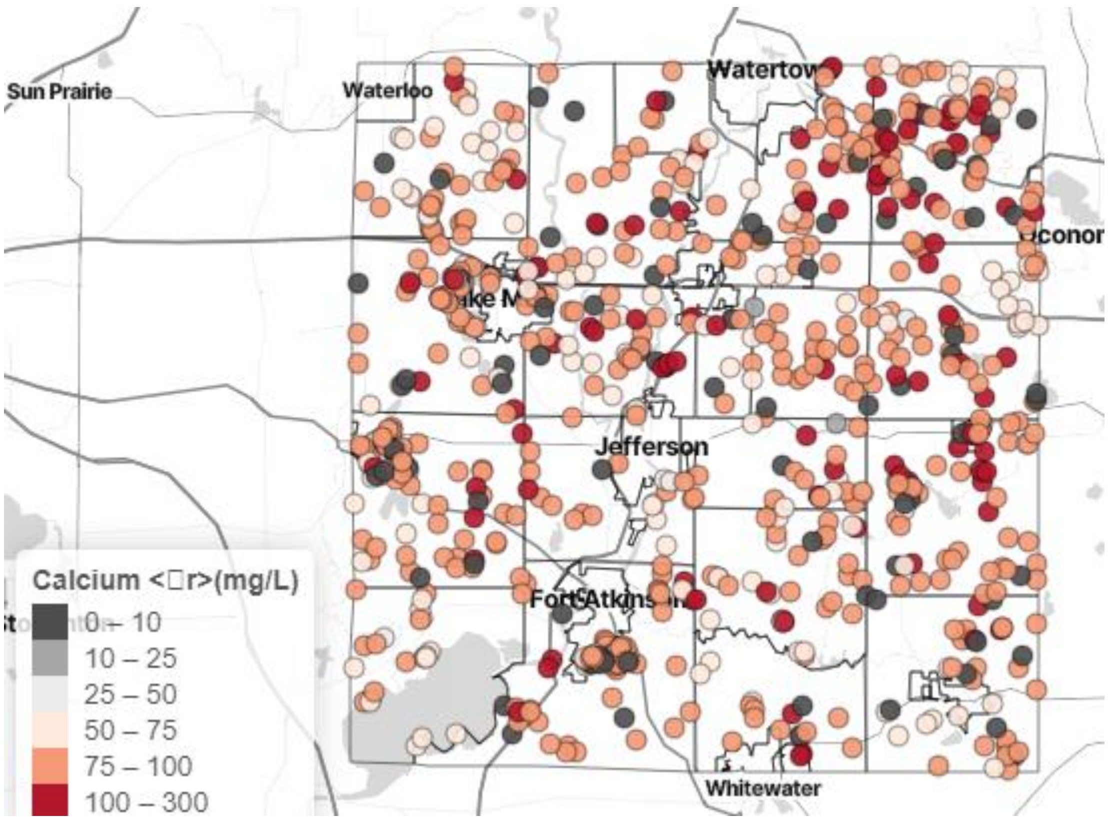


Table 10. Summary table of calcium for countywide test results.

Calcium (mg/L)	Number of Samples	Percent
None detected	1	<1%
Less than 25	101	12%
26 – 50	4	<1%
51 – 75	141	17%
76 – 100	471	57%
Greater than 101	114	14%

Magnesium

Magnesium is naturally occurring in groundwater from the dissolution of magnesium from dolomite rock formations. There are no health concerns associated with magnesium. Magnesium is essential for a variety of human health functions, although the amount obtained through drinking water is generally small compared to intake through food consumption. Along with calcium, magnesium contributes to hard water. Hard water can cause scale buildup and other issues and is removed through the water softening process. Magnesium results are similar to hardness and alkalinity because they are all related to the same geologic sources.

Figure 42. Magnesium results by individual well, wells with less than 10 mg/L magnesium are likely softened.

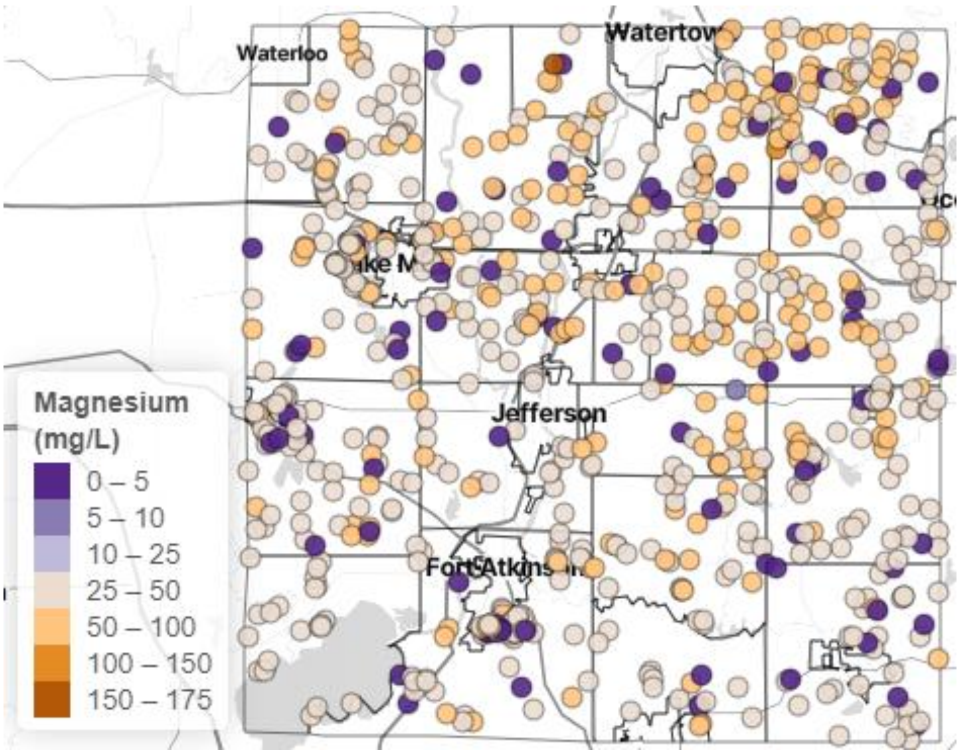


Table 11. Summary of magnesium results.

Magnesium (mg/L)	Number of Samples	Percent
None detected	0	<1%
Less than 20	96	12%
21-40	116	14%
41 – 60	559	67%
61 – 80	49	6%
Greater than 81	8	<1%

Iron

Iron is a common element found in minerals, rocks, and soil. It is naturally occurring in groundwater. Levels of iron greater than 0.300 mg/L have a greater tendency to cause taste problems and discoloration of water and/or staining (reddish-brown) of fixtures and sometimes clothing washed in it. There are no health concerns associated with iron for levels typically found in drinking water. Knowing the amount of iron in water can be useful when pursuing treatment. Small amounts of iron can generally be removed effectively by water softeners. Larger concentrations of iron (greater than 3 mg/L) may require special iron treatment.

Figure 43. Iron concentrations of wells sampled in the 2023 Jefferson County Well Water Inventory.

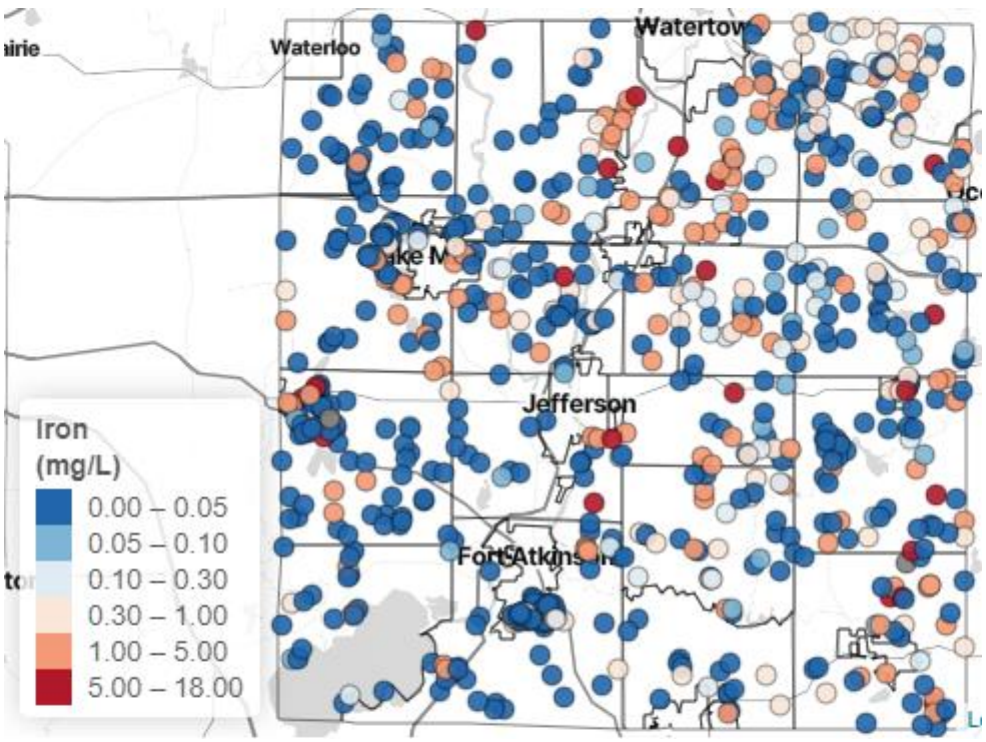


Table 12. Summary of iron results.

Iron (mg/L)	Number of Samples	Percent
None detected	304	37%
Less than 0.300	279	34%
0.301 – 1.000	89	11%
1.001 – 2.000	60	7%
2.001 – 5.000	74	9%
Greater than 5.001	26	3%

Figure 44. Map of mean iron concentration by town.

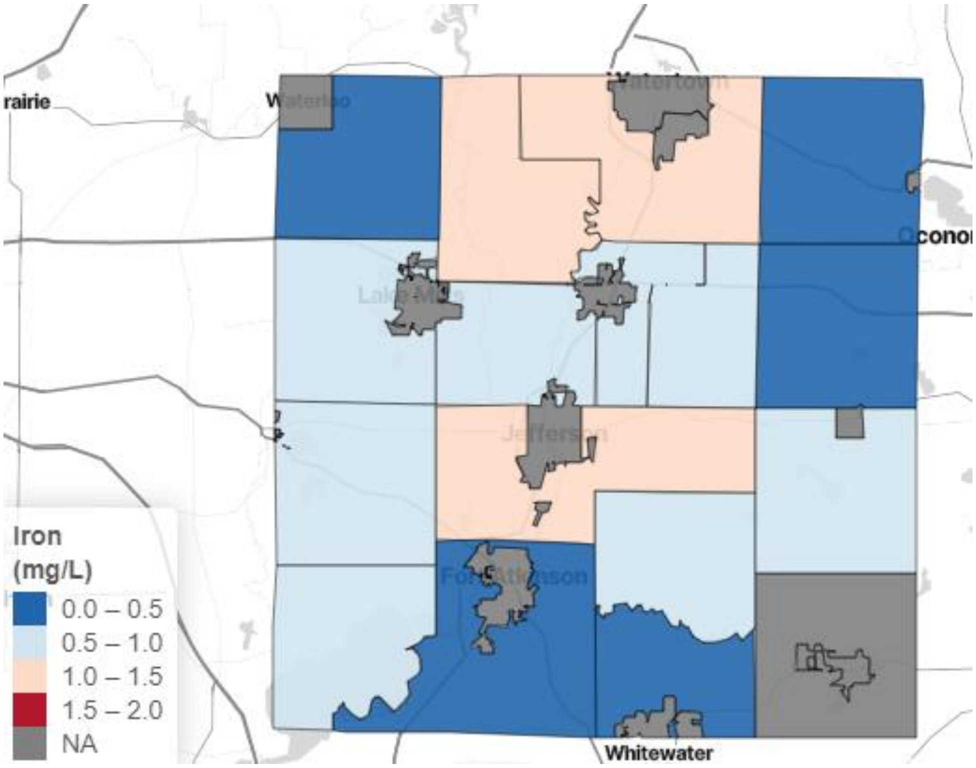
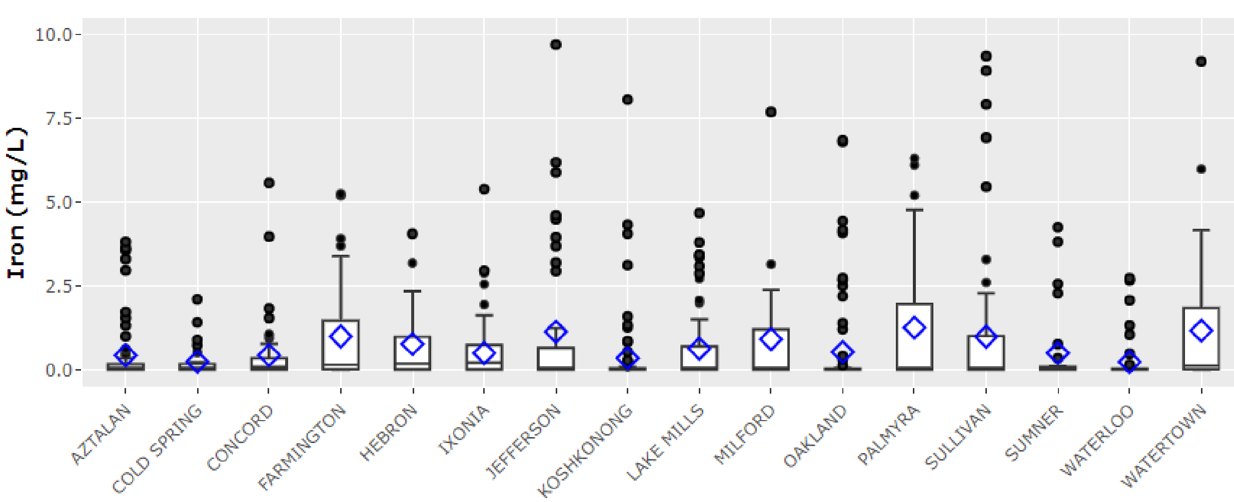


Figure 45. Box plot of iron by town.



Manganese

Manganese is a common element found in minerals, rocks and soil as a result it is naturally occurring in groundwater. Aesthetic concerns such as black staining or the formation of black precipitates is likely to occur when levels are greater than 0.050 mg/L. It is more likely to be found in areas where groundwater is low in oxygen because these conditions make manganese more soluble. Low oxygen groundwater conditions occur frequently in areas with organic sediments and significant wetlands.

Manganese levels greater than 0.300 mg/L in drinking water can increase the risk of health complications from long term consumption of water at those levels. Some studies suggest manganese can have effects on learning and behavior in children. It is also suspected to cause harm to the nervous system. Infants and people who have a liver disease are most at risk. Small amounts of manganese can sometimes be removed effectively by water softeners. Larger concentrations of manganese may require special treatment such as an oxidation unit. If treating drinking water, it is recommended to test after treatment to ensure it is reducing manganese below health advisory levels.

Figure 46. Manganese concentrations of wells sampled in the 2023 Jefferson County Well Inventory.

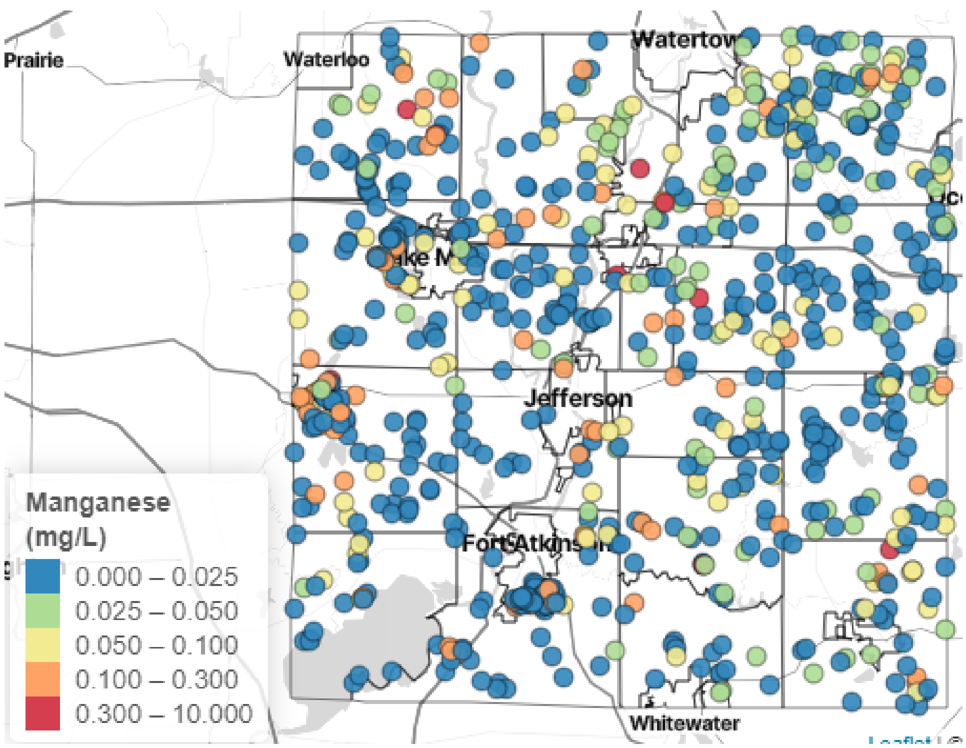


Table 13. Table of countywide manganese results.

Manganese (mg/L)	Number of Samples	Percent
None detected	301	36%
Less than 0.050	341	41%
0.051 – 0.3000	181	22%
0.301 – 0.500	4	<1%
0.501 – 1.000	4	<1%
Greater than 1.001	1	<1%

Figure 47. Mean manganese concentration by town.

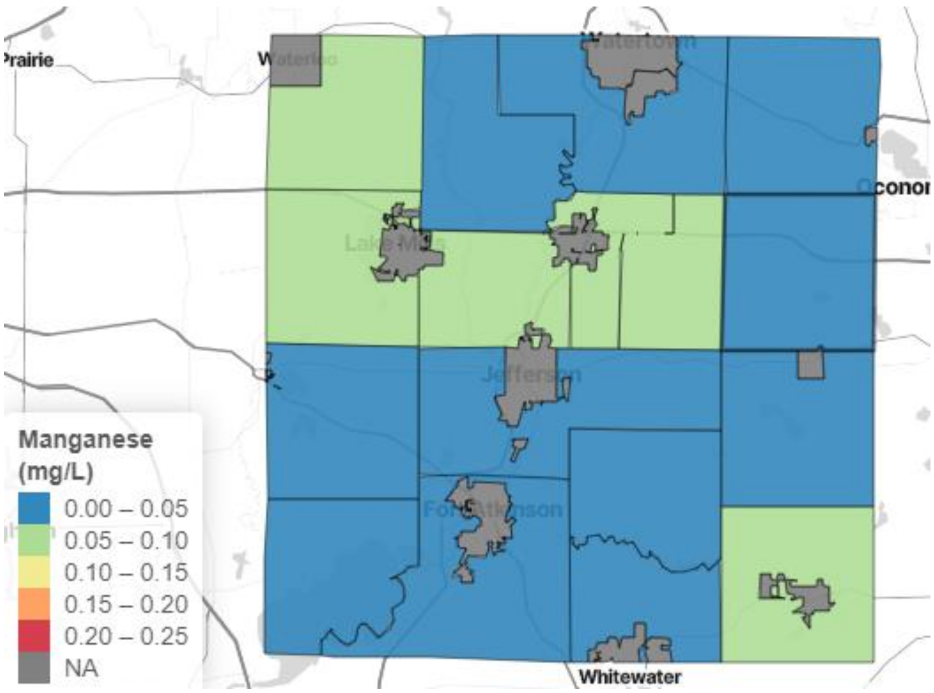
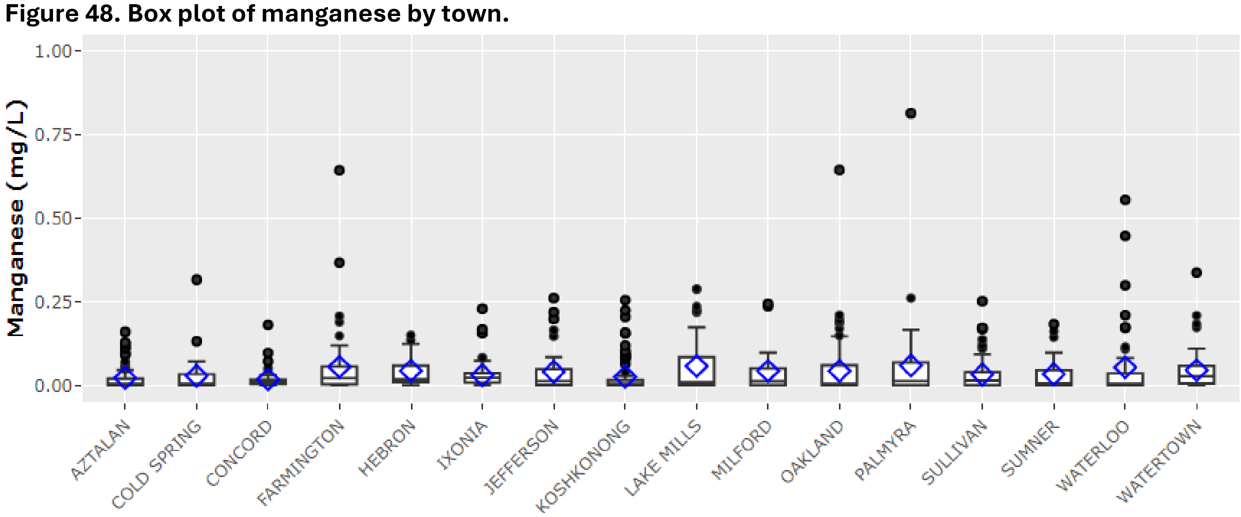


Figure 48. Box plot of manganese by town.



Phosphorus

Phosphorus is an essential nutrient for plants. Phosphorus applied as fertilizer or found in animal manure is commonly applied as an amendment to crops and is used to increase productivity of agricultural systems. However, too much phosphorus in freshwater systems can contribute to eutrophication (excessive aquatic plant/algae growth) in lakes and rivers. While phosphorus generally binds to soil, both particulate phosphorus and dissolved phosphorus are common pollutants from agricultural runoff. Phosphorus standards vary by water body type, however in Jefferson County they range from 0.02 mg/L (20 µg/L) to 0.075 mg/L (75 µg/L) depending on the lake and either 0.075 mg/L (75 µg/L) or 0.100 mg/L (100 µg/L) for rivers. There are no health concerns associated with phosphorus at levels typically found in groundwater and is not a routine test for private well owners to have performed.

Phosphorus in Jefferson County

Phosphorus in groundwater is less studied and data collected here provides some insight into typical levels in Jefferson County groundwater. With a mean concentration of 0.012 mg/L and median concentration of <0.005 mg/L, the vast majority of wells showed phosphorus levels below levels of environmental concern. While phosphorus contributions from surface waters remain an ongoing challenge throughout Wisconsin, there is little evidence that there is significant migration of phosphorus from the land surface into Jefferson County groundwater.

Figure 49. Individual phosphorus results for participating wells.

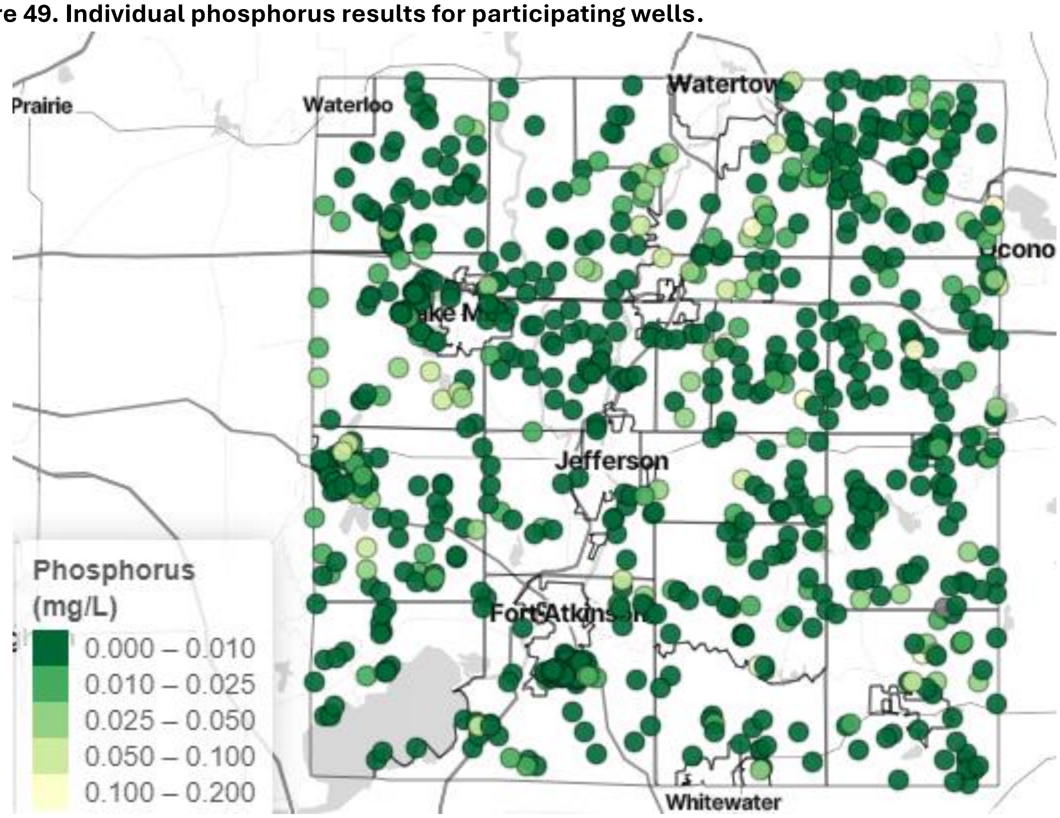
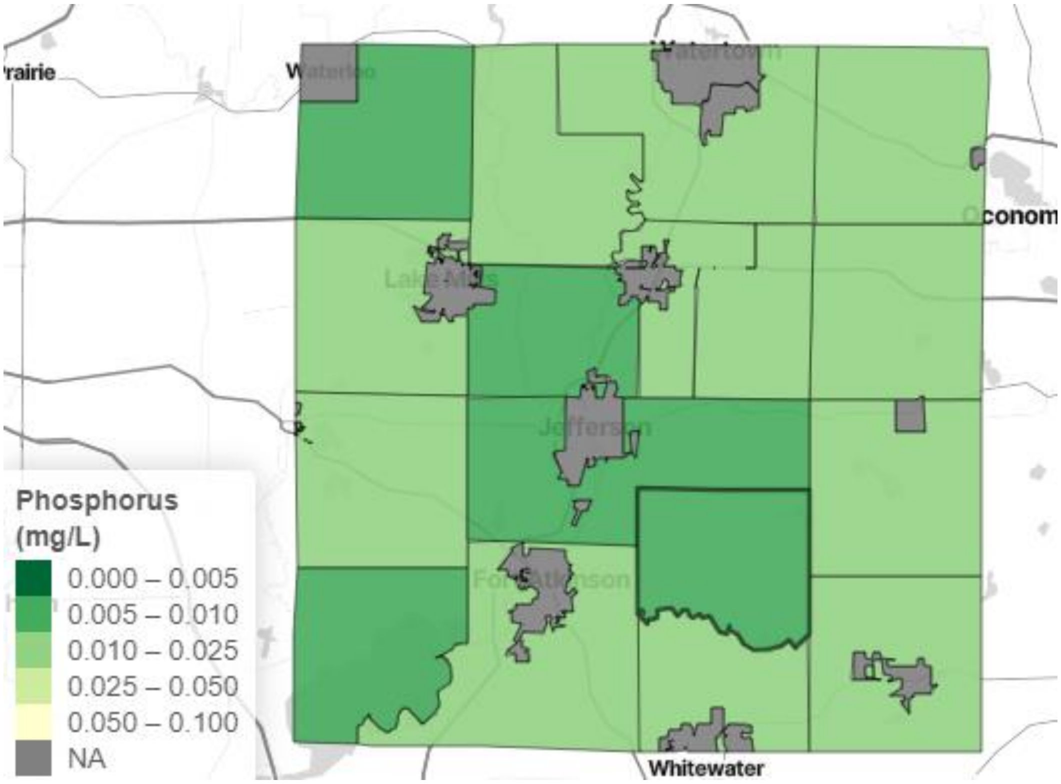


Figure 50. Mean phosphorus result by town.



Sulfate

Sulfate is naturally occurring in groundwater in some parts of Wisconsin due to sulfide minerals present in various geologic formations, including some of those found in Jefferson County. Sulfate concentrations over 250 mg/L may give water an off taste and cause diarrhea in people not accustomed to consuming water containing sulfate. Sulfate over 500 mg/L may lower milk production and butterfat production in dairy cows.

Jefferson County Results

Sulfate levels were generally greater in the northeastern portion of Jefferson County and is likely related to naturally occurring sulfide minerals present in the various bedrock layers encountered by wells in that region. Concentrations of sulfate were generally higher than what is observed in much of Wisconsin, but were not high enough to be relevant to health. The highest sulfate concentration measured in Jefferson County was 243 mg/L.

Figure 51. Sulfate concentration by individual well.

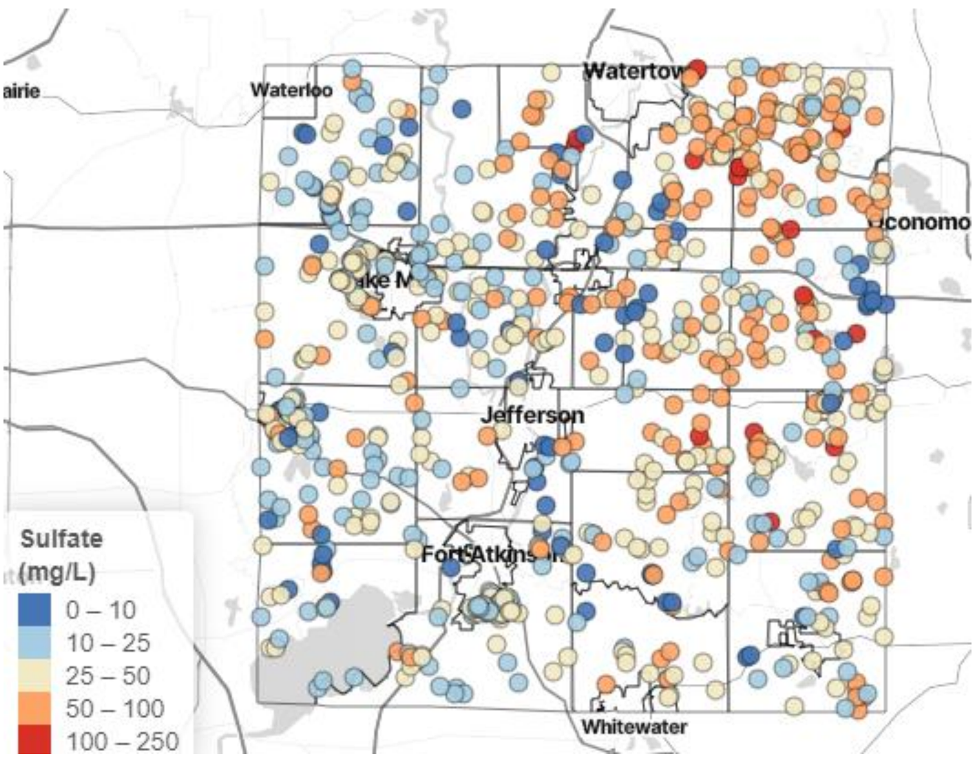


Table 14. Summary of countywide sulfate results.

Sulfate (mg/L)	Number of Samples	Percent
Less than 25	267	32%
26 – 50	349	42%
51 – 75	170	20%
76 – 100	28	3%
Greater than 101	18	2%

Figure 52. Mean sulfate concentration by town.

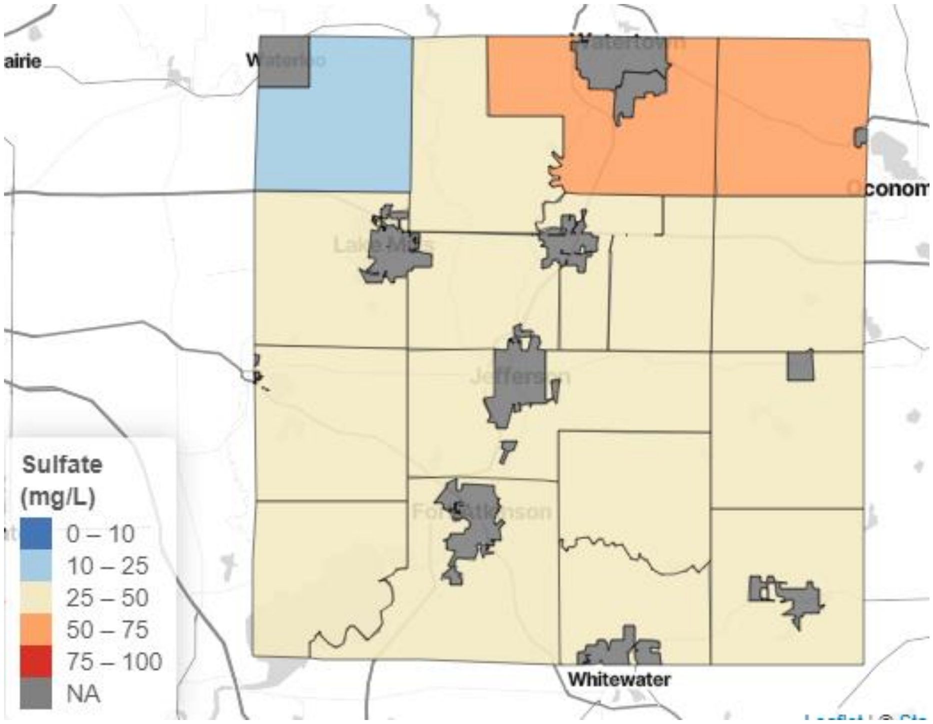
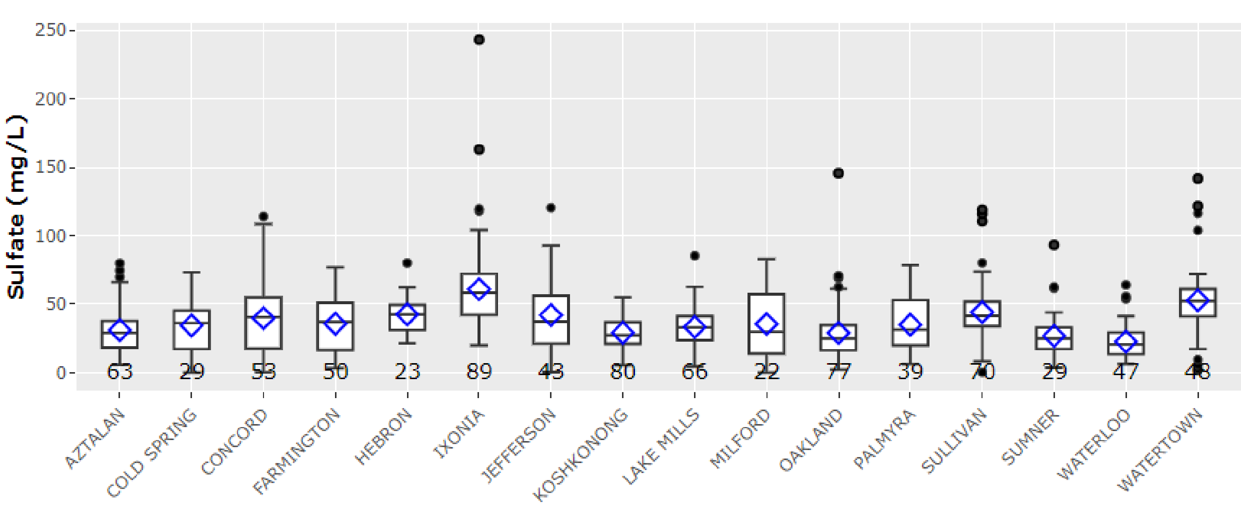


Figure 53. Box plot for sulfate by town.



Sodium

Natural levels of sodium are generally less than 10 mg/L in Wisconsin groundwater, except in some areas of eastern Wisconsin where bedrock can be the source of sodium. Sodium can also be elevated from the use of water softeners (which exchange sodium for calcium and magnesium), road salting, or septic effluent.

Sodium is associated with increased blood pressure in susceptible populations. The USEPA and American Health Associated recommend less than 20 mg/L in drinking water for those individuals on a physician described no salt diet.

Jefferson County Results
Approximately 12% of samples are elevated because of the softening process. When accounting for those wells that are artificially elevated because of the softening process, there are still significant numbers of wells with elevated sodium concentrations that are from natural sources or potentially indicative of land-use impacts such as road salt.

There is strong correlation of chloride to sodium (r=0.88); as a result, road salt and septic system influences are likely explanations for the elevated levels. Wells located just south of Fort Atkinson, where many households with private wells are located within close proximity of one another is one area in particular where the use of septic systems (many of which are likely using water softeners) combined with the use of road salt, Is a potential explanation for elevated sodium.

Figure 54. Map of sodium levels for each participating well.

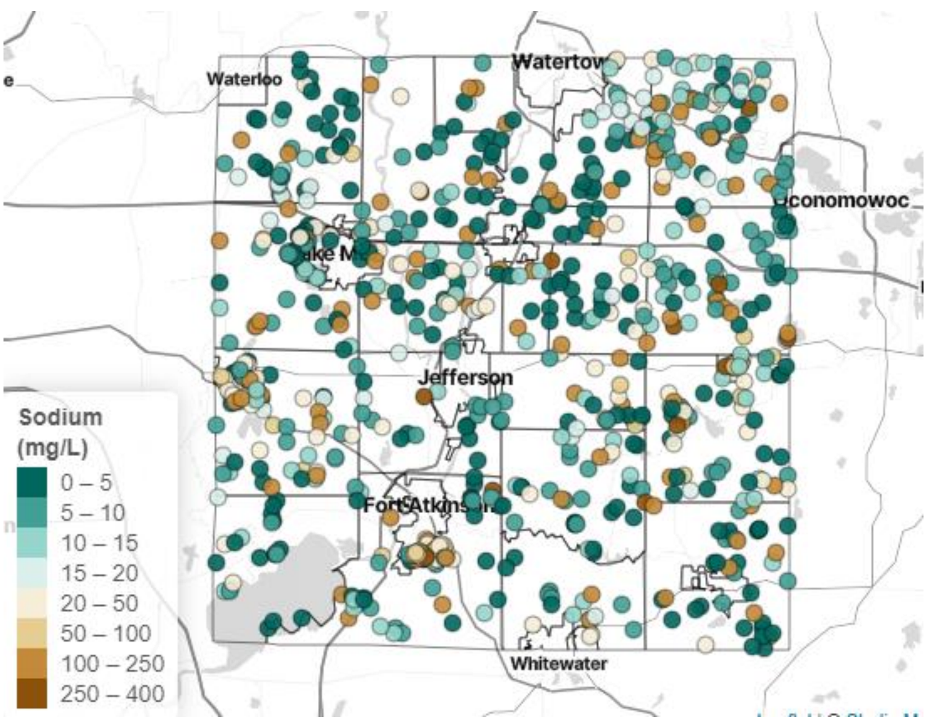
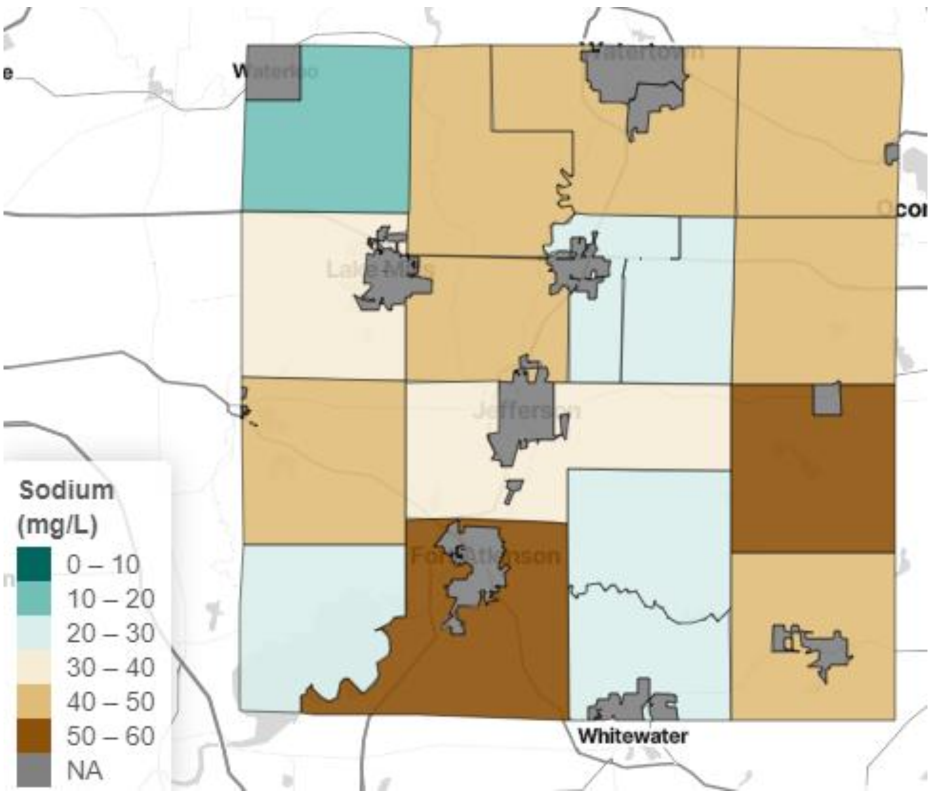


Table 15. Summary of countywide sodium results.

Sodium (mg/L)	Number of Samples	Percent
Less than 25	595	72%
26 – 50	74	9%
51 – 75	34	4%
76 – 100	9	1%
Greater than 101	120	14%

Figure 55. Mean sodium concentration by town.



Potassium

Potassium is naturally occurring but is normally less than 5 mg/L in Wisconsin groundwater. Potassium is essential for a variety of human health functions, although the amount obtained through drinking water is generally small compared to intake through food consumption. Elevated potassium levels are the result of softened water for those using potassium chloride as a softener salt.

Figure 56. Potassium levels of individual well samples.

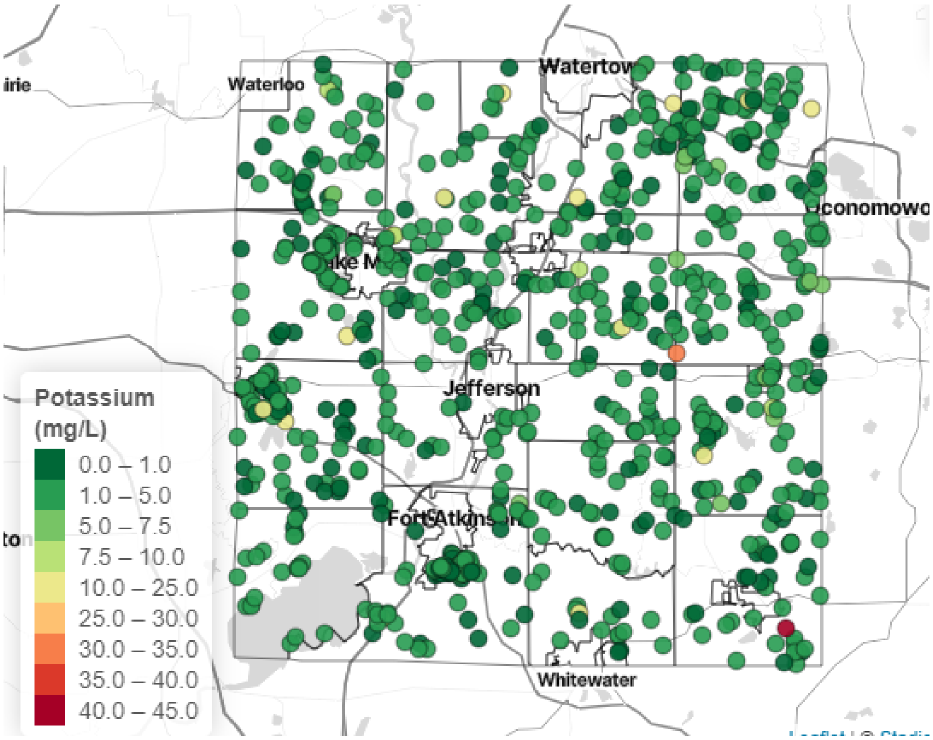


Table 16. Summary of countywide potassium results.

Potassium (mg/L)	Number of Samples	Percent
None detected	3	<1%
Less than 20	824	99%
21 – 40	3	<1%
41 – 60	2	<1%

Conclusions and Recommendations

This report summarizes the Jefferson County well water sampling conducted in 2023. A total of 828 private wells were analyzed for fifteen common well water quality parameters of interest to drinking water and environmental quality monitoring efforts. The wells selected were intended to be a representation of the diverse land cover, soils, and geology that influence groundwater quality accessed by the rural residents and communities of Jefferson County. Participation was voluntary; all participants received a copy of their individual results along with interpretive information.

The results of this work provide baseline data on the extent and geographic occurrence of both natural and human-induced contaminants. In addition, this work provides an overall assessment of well water quality in Jefferson County at a point in time. Outcomes of these efforts include the identification of factors responsible for well water quality, characterizing the spatial extent and occurrence of various chemical parameters, identifying avenues for potential investigations, and providing a solid foundation for future studies on groundwater quality changes or trends.

Regarding recommendations for well water testing, rural residences served by private wells are encouraged to test annually for common water quality parameters such as nitrate and bacteria. Given the prevalence of arsenic in Jefferson County, all private well owners should be encouraged to test for arsenic at least once, and more frequently if levels are elevated. Chloride and conductivity are also good indicators of changes in water quality and provide valuable insight into trends when monitored routinely. If water treatment is being used to reduce levels of health-related contaminants, water testing should also be performed annually for contaminants of concern to evaluate treatment effectiveness and ensure adequate removal efficiency.

Common barriers to well water testing include not knowing what to sample and not knowing where to submit samples. While well testing is ultimately the responsibility of individual landowners, Jefferson County may assist in these efforts by:

- Devoting staff time to organizing or facilitating convenient local well water testing opportunities to remove common barriers of testing.
- If funding exists, subsidizing the cost of testing could also be an option to strategically collect more detailed spatial data and/or explore testing of emerging contaminants.
- One of the project deliverables included a parcel level nitrate and chloride risk potential dataset. This information could be utilized to prioritize testing efforts in areas of greatest risk for contamination or utilize subsidized testing in those areas most likely to be impacted.

Other counties have initiated trend monitoring programs for assessment of nitrate and chloride trends. The results presented here represent an initial baseline that could be used as a starting point for analysis of trends or pursuit of contaminants of emerging concern. If interested in trends, testing a subset of the 828 wells annually could provide valuable information on whether Jefferson County groundwater quality is getting better, worse, or staying the same with respect to common water quality parameters such as nitrate and chloride. If interested in pursuing testing for an expanded list of compounds, elevated nitrate and chloride serve as an indicator of land-use impacts. Data from this work could be used to select wells for which additional testing for emerging compounds such as PFAS and or pesticides would be most beneficial (i.e. prioritizing testing of wells that are known to be impacted by land use). While grants and funding may be available to support limited testing of emerging contaminants, it is important to be strategic with resources. When resources are not available and/or the risk of detecting certain contaminants is low, homeowners interested in pursuing additional testing may need to be directed to alternative testing options.

Geology influences certain aspects of well water quality including but not limited to arsenic, manganese, and other aesthetic concerns such as iron and hardness. Jefferson County has a greater occurrence of arsenic than what is typically seen statewide. Arsenic in Wisconsin is generally associated with geologic influence; and collecting more detailed geologic data in the Towns of Ixonia and Watertown could potentially inform well construction methods to avoid layers prone to arsenic. Consultation with Wisconsin Geologic and Natural History Survey who performed Quaternary and bedrock mapping of Jefferson County could help with understanding the extent of arsenic and associations of geology with other elements.

Other major factors that affect groundwater quality in Jefferson County include land uses such as agricultural practices and development density. Forest, prairie, and wetlands continue to diminish but are long known to have proven groundwater quality benefits; maintaining what remains of landscape diversity by protecting existing natural areas should be a priority.

When it comes to improving groundwater quality in agricultural areas, many farm fields would benefit from additional conservation practices.

- If funding or staffing is limited, focusing implementation on those areas identified as having a greater risk for nitrate contamination should be prioritized.
- Where not already implemented, the following conservation practices will have benefits to groundwater quality, however some will have greater impacts than others.
    - Highest impact practices include conservation reserve program, prairie establishment, managed grazing, planting of perennial vegetation, restoring wetlands.
    - Medium impact practices include cover crops, taking underperforming portions of the field out of production, diversifying crop rotations to include lower nitrogen demanding crops.
    - Although the following would be considered low-impact compared to those previously mentioned, these do have benefits and are more easily adopted and should be encouraged on every farm: participation in nitrogen optimization programs to establish on farm economic optimal nitrogen fertilizer recommendations, not applying fall nitrogen, applying manure to actively growing crop, split application of nitrogen fertilizer, and crediting of nitrogen from irrigation water (where applicable).

Expansion of roads, parking lots, housing, and other development also will impact water quality in Jefferson County. Lawns, road salting activities, and septic system density are factors known to influence the quality of groundwater supplied to private wells. The following recommendations apply to areas near low, medium, or high development density:

- In new/existing subdivisions:
    - Consider community sewer and water to avoid impacts of adjacent septic systems on nearby private wells.
    - Encourage testing for additional health related parameters such as PFAS which have shown an association with this type of land-use.

- Homeowners should be encouraged to minimize fertilizer and pesticide use to limit the potential of these chemicals impacting neighboring wells and/or minimize lawns to maintain as much natural landscaping as possible.
- Work to educate homeowners and contractors on best practices for winter road salting.

The results summarized in this report provide an overview of typical well water quality and spatial variability. It is not a replacement for individual well water testing but does highlight relationships to land use and geology which can be used to guide future testing and management efforts in Jefferson County. While the wells tested are a small number of all private wells in the county, the Center remains committed to helping utilize this information to the benefit of all Jefferson County residents.

References

DATCP (2017). Agricultural Chemicals in Wisconsin's Groundwater. Madison, WI, Wisconsin Department of Agriculture, Trade, and Consumer Protection,. **ARM-PUB-264.indd**.

Ives, Libby R.W., and Rawling, J.E. III. 2022. Quaternary geology of Jefferson County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 118, 34.p., 1 plate, scale 1:100,000, https://doi.org/10.54915/minc7835.

Laboski, C. A. M. and J. B. Peters (2012). Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin, University of Wisconsin - Extension, Cooperative Extension. **A2809:** 92.

Masarik, K. C., et al. (2014). "Long-Term Drainage and Nitrate Leaching below Well-Drained Continuous Corn Agroecosystems and a Prairie." Journal of Environmental Protection **05**(04): 240-254.

Meisinger, J. J. and G. W. Randall (1991). Estimating Nitrogen Budgets for Soil-Crop Systems. Managing Nitrogen for Groundwater Quality and Farm Profitability**:** 85-124.

Mudrey, M.G. Jr., B.A. Brown and J.K. Greenberg, Bedrock Geologic Map of Wisconsin. Wisconsin Geologic and Natural History Survey. State Map 18-Digital Information, Version 1.0, 2007.

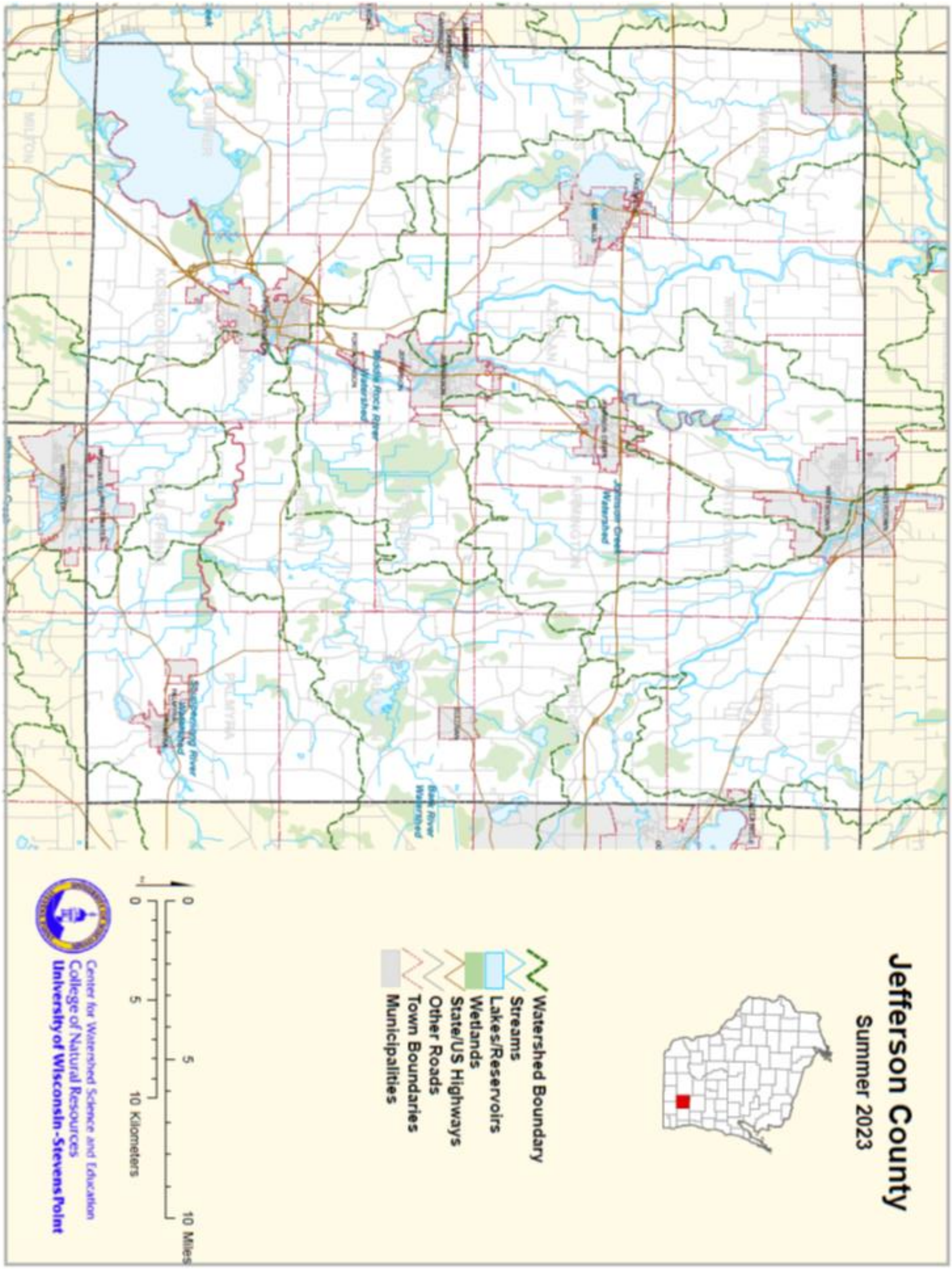
Schmidt, R.R., 1987. Groundwater contamination susceptibility map and evaluation: Wisconsin Department of Natural Resources, Wisconsin's Groundwater Management Plan Report 5, PUBL-WR-177-87, 27 p.

Shrestha, D., et al. (2023). "Nitrate losses from Midwest US agroecosystems: Impacts of varied management and precipitation." Journal of Soil and Water Conservation **78**(2): 141-153.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic Database (SSURGO).

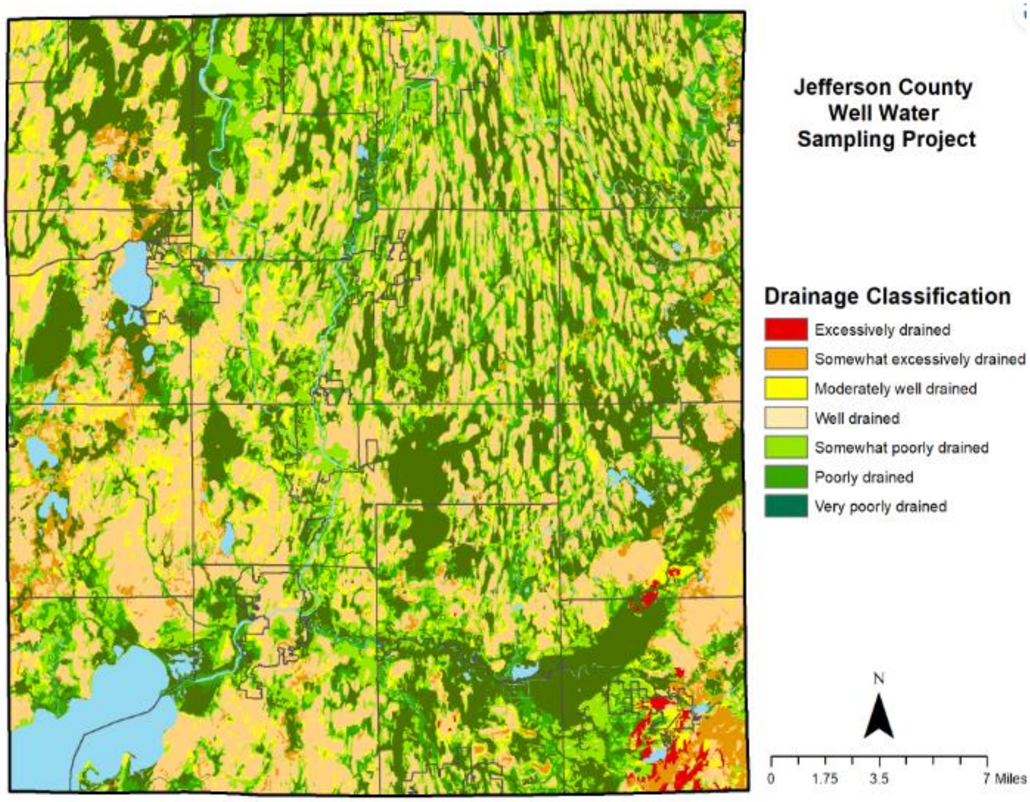
Stewart, E.K. 2024. Bedrock Geology of Jefferson County, Wisconsin 1:100,000 Scale, Wisconsin Geological and Natural History Survey. M511.

Appendix A

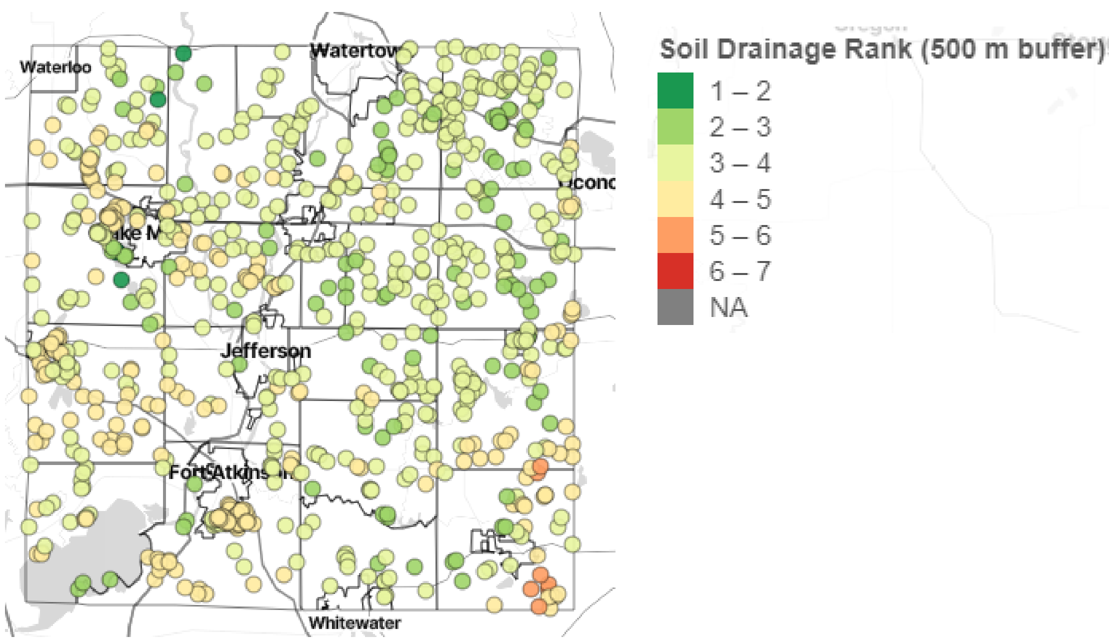

Jefferson County
Summer 2023
Watershed Boundary
Streams
Lakes/Reservoirs
Wetlands
State/US Highways
Other Roads
Town Boundaries
Municipalities
0 5 10 Miles
0 5 10 Kilometers
Center for Watershed Science and Education
College of Natural Resources
University of Wisconsin-Stevens Point

Appendix B

(Top) Map of soil drainage used to calculate weighted drainage rank. (Bottom) Soil drainage rank is a weighted average of soil drainage classification using the area of each drainage classification within a 500 m buffer of the well multiplied by a number (1 very poorly drained to 7 for Excessively drained) and divided by the total area of the 500 meter buffer.



Source: Soil Survey Staff, natural Resources Conservation Service, United States Department of Agriculture.
Soil Survey Geographic (SSURGO) Database

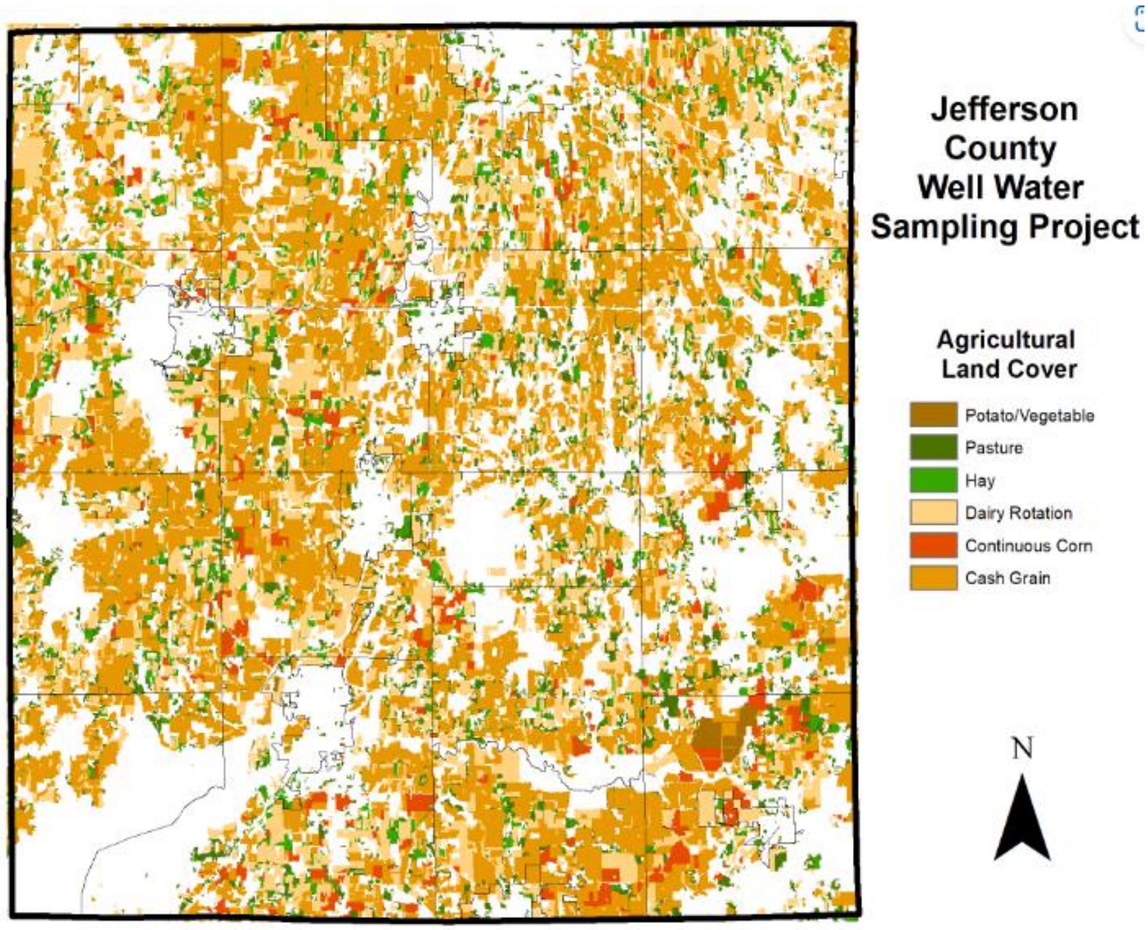


Soil drainage rank description

- (7) Excessively drained - Water is removed very rapidly. The soils are often coarse-textured and have very high hydraulic conductivity.
- (6) Somewhat excessively drained - Water is removed from the soil rapidly. Internal free water occurrence is very rare or very deep. The soils are commonly coarse-textured and have high saturated hydraulic conductivity.
- (5) Well drained - Water is removed from the soil readily but not rapidly. Internal free water occurrence is deep or very deep; annual duration is not specified. Water is available to plants throughout most of the growing season in humid regions. Wetness does not inhibit growth of roots for significant periods during most growing seasons. The soils are mainly free of redoximorphic features that are associated with wetness.
- (4) Moderately well drained - Water is removed from the soil somewhat slowly during some periods of the year. Internal free water occurrence is moderately deep and transitory through permanent. The soils are wet for only a short time within the rooting depth during the growing season, but long enough that most crops that prefer well-drained soils (i.e. corn, soybean, wheat etc.) are affected. They commonly have a moderately low or lower saturated hydraulic conductivity in a layer within the upper 1 m, periodically receive high rainfall, or both.
- (3) Somewhat poorly drained - Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The occurrence of internal free water commonly is shallow to moderately deep and transitory to permanent. Wetness markedly restricts the growth crops that prefer moist, well drained soils (i.e. corn, soybean, wheat etc.), unless artificial drainage is provided. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high-water table, additional water from seepage, or nearly continuous rainfall.
- (2) Poorly drained - Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods. The occurrence of internal free water is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season so that most crops cannot be grown, unless the soil is artificially drained. The soil, however, is not continuously wet directly below plow-depth. Free water at shallow depth is usually present. This water table is commonly the result of low or very low saturated hydraulic conductivity of nearly continuous rainfall, or of a combination of these.
- (1) Very poorly drained - Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water is very shallow and persistent or permanent. Unless the soil is artificially drained, most crops that prefer well drained soil (i.e. corn, soybean, wheat etc.) cannot be grown. The soils are commonly level or depressed and frequently ponded. If rainfall is high or nearly continuous, slope gradients may be greater.

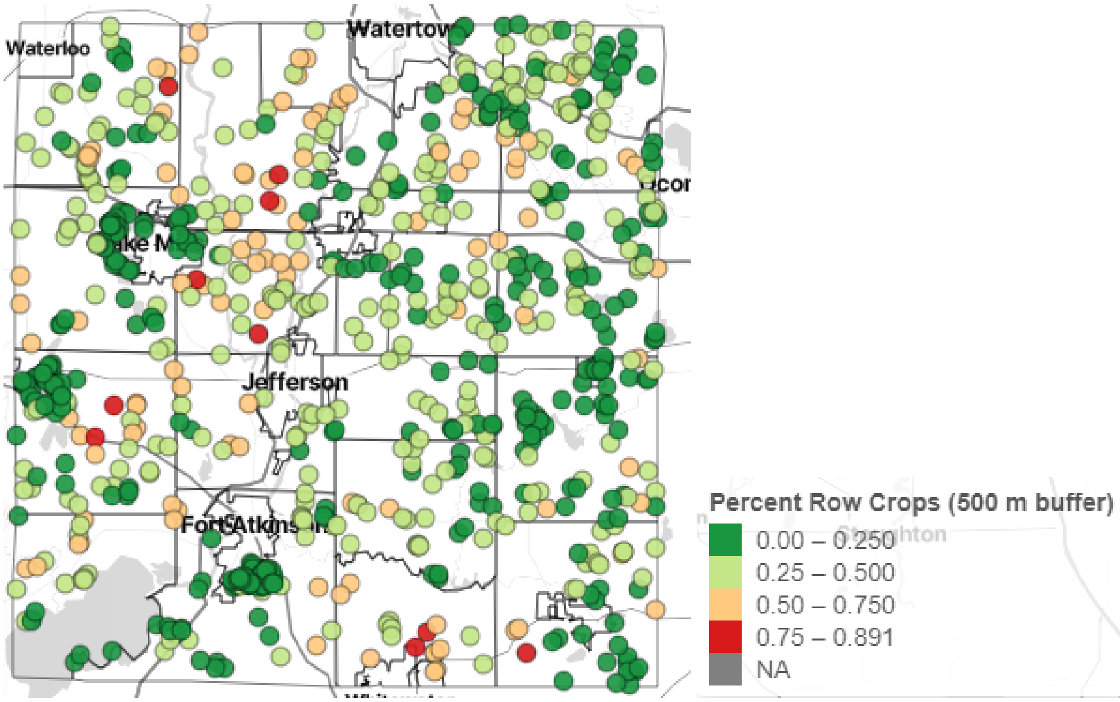
Appendix C

Agricultural land cover of Jefferson County was summarized within a 500 meter buffer of each well. The percentage of agricultural land was used in the ordinary least squares regression model for determination and prediction of nitrate risk.



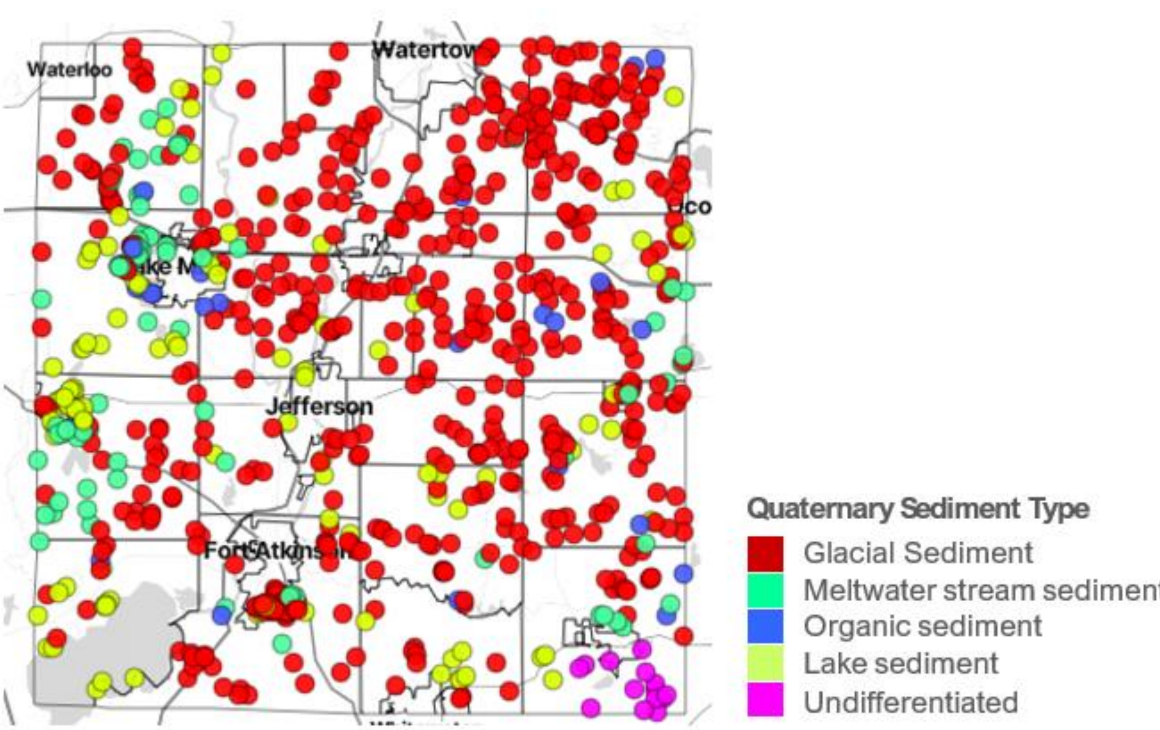
Appendix D

Percent row crops within a 500 meter buffer of each participating well.



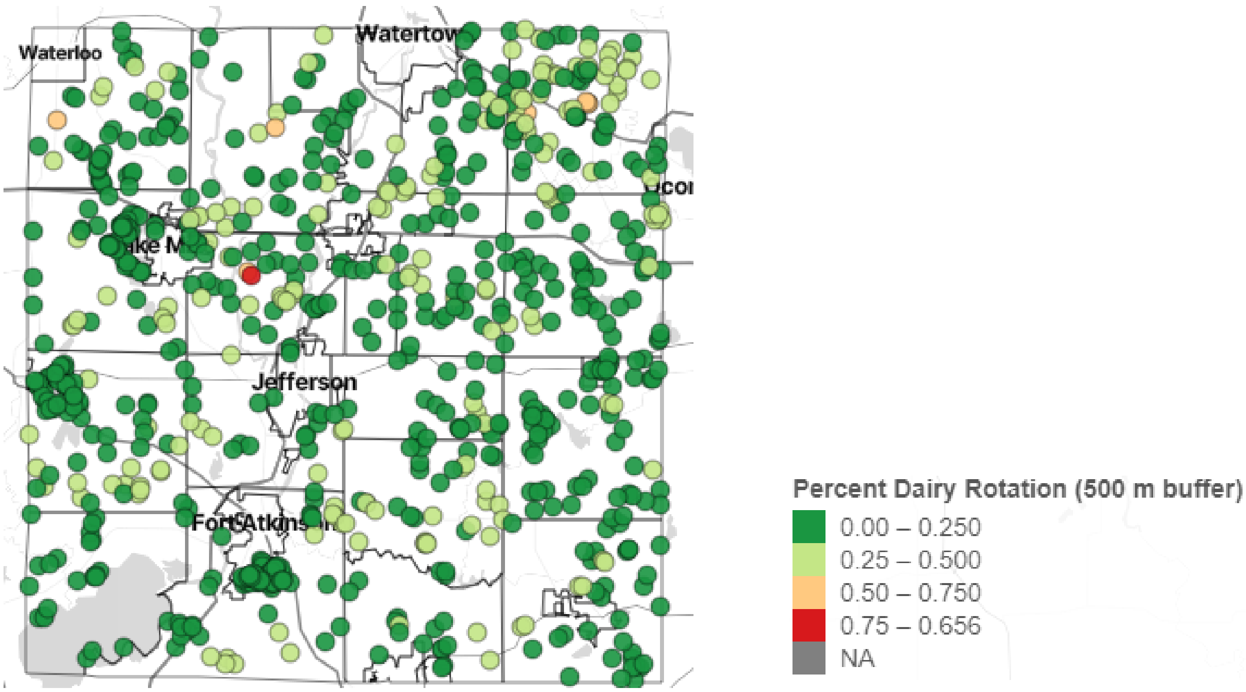
Appendix E

The Quaternary sediment classification at the well location.



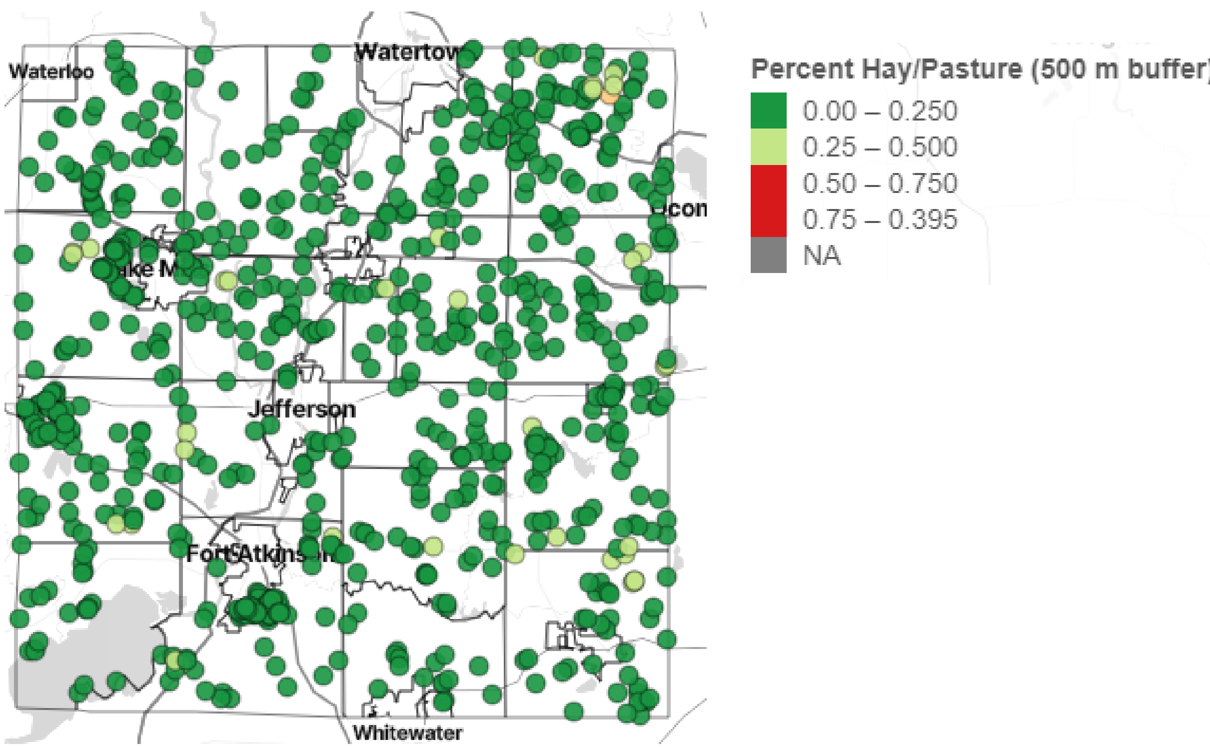
Appendix F

The percent dairy rotation within a 500 meter buffer of each participating well. Dairy rotation in Wiscland 2.0 layer is defined as land having corn grain, corn silage, and alfalfa in a rotation.



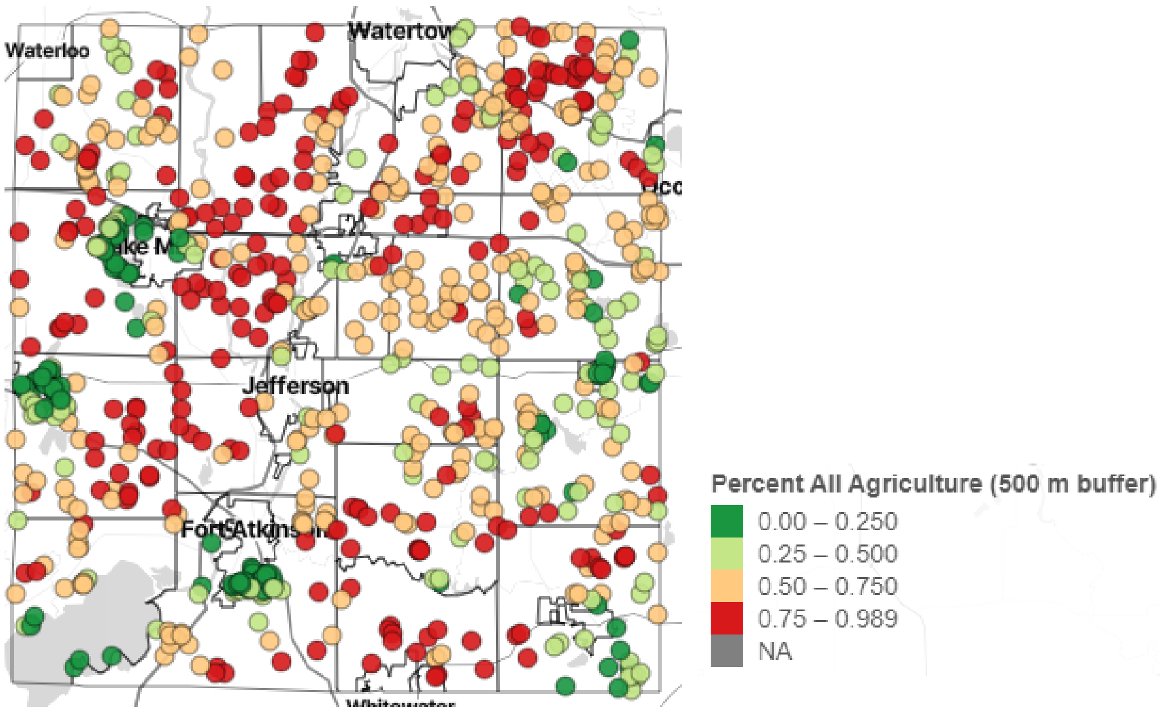
Appendix G

The percent hay/pasture in a 500 meter buffer from participating wells.



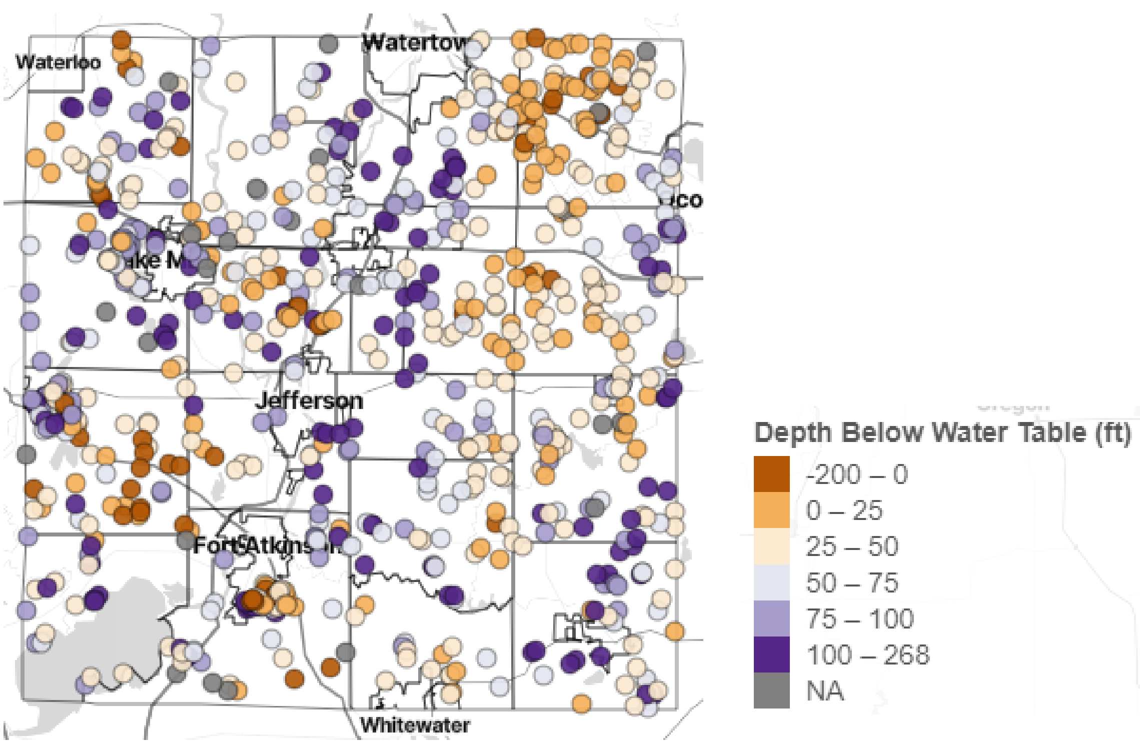
Appendix H

Percent of all agriculture in a 500 meter buffer of participating wells.



Appendix I

Casing below the water table in feet



Appendix J

Output of ordinary least squares regression models for nitrate. Analysis was performed using square root transformed nitrate-nitrogen concentrations.

```
Call:
lm(formula = NITRATE_SQRT ~ AG_PERC + FOREST_PERC + SEPTIC_COUNT_NORMALIZED +
    weighted.rank, data = df)

Residuals:
    Min      1Q  Median      3Q     Max
-1.9273 -0.7214 -0.2604  0.6217  4.1139

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)             -2.00146    0.24218  -8.264 5.64e-16 ***
AG_PERC                  0.51327    0.18547   2.767  0.00578 **
FOREST_PERC             -0.71301    0.49353  -1.445  0.14893
SEPTIC_COUNT_NORMALIZED  0.62437    0.22934   2.722  0.00662 **
weighted.rank            0.79406    0.07078  11.218  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.019 on 818 degrees of freedom
  (5 observations deleted due to missingness)
Multiple R-squared:  0.1978,	Adjusted R-squared:  0.1939
F-statistic: 50.43 on 4 and 818 DF,  p-value: < 2.2e-16
```

Output of ordinary least squares regression models for chloride. Analysis was performed using log transformed chloride concentrations.

```
Call:
lm(formula = LOG_CHLORIDE ~ AG_PERC + URBAN_PERC + weighted.rank,
    data = df)

Residuals:
     Min       1Q   Median       3Q      Max
-1.46164 -0.27399  0.06219  0.32458  1.63275

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    0.81044    0.11859   6.834 1.61e-11 ***
AG_PERC        0.16076    0.09593   1.676  0.09416 .
URBAN_PERC     1.05315    0.14235   7.398 3.41e-13 ***
weighted.rank  0.08800    0.02954   2.979  0.00298 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5143 on 822 degrees of freedom
  (2 observations deleted due to missingness)
Multiple R-squared:  0.1093,	Adjusted R-squared:  0.106
F-statistic: 33.62 on 3 and 822 DF,  p-value: < 2.2e-16
```