Green County Well Water Monitoring 6-Year Summary

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November 2025

Table of Contents

Executive Summary

Groundwater is the principal water supply for Green County municipalities, industries, and rural residents. While municipal water supplies are regularly monitored and required to meet drinking water standards, private well owners must make decisions regarding when and what to test for and how to proceed if there is a problem. In order to: 1) understand changes in well water quality over time, 2) effectively target management, and 3) focus public health outreach efforts related to groundwater and private well owners, Green County undertook steps to initiate a long-term well monitoring project.

In July 2019, Green County began collaborating with the University of Wisconsin--Stevens Point & University of Wisconsin – Madison, Division of Extension's Center for Watershed Science and Education to test a subset of Green County private wells as part of a 5-year initiative to better understand trends in well water quality. Following the initial 5-year period, the Green County Board voted to extend the project by an additional 2 years. The following county departments are assisting with the project: Extension Green County, Green County Health Department, Green County Land & Water Conservation Department, Green County Land Information Office, and Green County Land Use & Zoning Department.

Criteria were developed and used to select a network of wells that are representative of Green County's diverse soils, geology, land-use, and well construction. A total of 348 participants successfully submitted samples for Year 1, 323 samples were analyzed in Year 2, and 307 samples were analyzed in Year 3 of the project, 294 samples in Year 4, 279 samples in Year 5, and 260 in Year 6. All samples were analyzed for nitrate-nitrogen, chloride, pH, alkalinity, total hardness, and conductivity at the state-certified Water and Environmental Analysis Lab.

With the most recent year of data, Green County's groundwater can generally be characterized as slightly basic (mean pH = 8.1), hard water (mean = 343 mg/L as $CaCO_3$), with high alkalinity (mean = 298 mg/L as $CaCO_3$). These aesthetic characteristics of the water are largely influenced by the geologic materials groundwater is stored and transported in; lower values of pH, alkalinity, and total hardness are sometimes found in wells near the Sugar River where wells may be shallower and access the sand/gravel aquifer versus bedrock.

Nitrate is a common health-related contaminant found in Green County's groundwater (mean = 5.6 mg/L nitrate-nitrogen). Nineteen percent of wells tested were greater than the 10 mg/L drinking water standard; approximately 75% of wells tested measured greater than 2 mg/L, which provides evidence that land-use activities are impacting water quality in much of the county. Over the six-year period increasing nitrate has been observed in 12% of wells, 9% showed evidence of decreasing nitrate, and 78% of wells showed no discernable trend. A predictive model was developed to highlight areas at greater risk of elevated groundwater nitrate.

Chloride provides additional insight into the effects of land-use on water quality. Background levels of chloride in groundwater are typically less than 10 mg/L; levels observed in 35% of wells. The mean chloride concentration in Green County was 20.5 mg/L. While most individual wells did not detect chloride trends (87%), increases were observed in 7% of wells while decreases were observed in 6% of wells.

This study provides an ongoing assessment of well water quality in Green County. The project has one additional year of data that will be collected which will add to our understanding of how groundwater quality changes over time and allow for ongoing assessment of land-use impacts to groundwater quality.

Project Background

On May 8, 2018, the Green County Board voted to accept the Green County Livestock Facility Study Group's recommendations for consideration. As a result of the recommendations from the Green County Livestock Facility Study Group, Green County started a five-year groundwater quality trend data project, with 2020 being the first year of testing. It is one of the first counties in Wisconsin (and nationally) to use this process. This study is an opportunity to learn more about groundwater in Green County. The multiyear process was specifically designed to get accurate data in order to better understand water quality in Green County.

Previously, little information was available for understanding how groundwater quality has changed over time in Green County. Establishing a network of private well owners to perform annual testing over an extended multi-year period is helping to inform residents and local leaders whether groundwater quality is getting better, worse, or staying the same. Ultimately, the goal is to use the information to make data-driven decisions for the management of groundwater quality in Green County.

Following the initial five years of data collection, the Green County Board voted to extend the project by an additional two years. This report highlights Year 6 and the previous five years of data.

Initial Well Selection and Recruitment

A total of 778 wells were selected as part of the initial recruitment (Figure 1). This assumed a response rate of approximately 35%. Wells were selected utilizing a variety of datasets that included the Wisconsin Parcel Data Layer, Well Construction Records, Center for Watershed Science and Education Well Water Data, and others.

For the initial recruitment list, an attempt was made to locate at least one well-owner per section with a Wisconsin Unique Well Number that could be matched to a landowner from the parcel data layer. All things being equal, preference was given to those landowners that participated in previous Extension well testing efforts. Most wells on the list have well depth, well casing, and water table information. Of the landowners that were contacted, 114 submitted a previous sample through Extension programming. Recruitment materials consisted of a recruitment 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. Recruitment materials were mailed in early November 2019.

A total of 388 landowners indicated their willingness to participate in the well monitoring program (Figure 2). This is a success rate of 49.8%, higher than our initial estimate of 35%. Anticipating a drop in participation over the 5-year period, we attempted to sample all 388 wells in hopes that we still have a minimum of 240 well samples by the end of the final year of the project. Each year kits are mailed to all participants from the previous year.

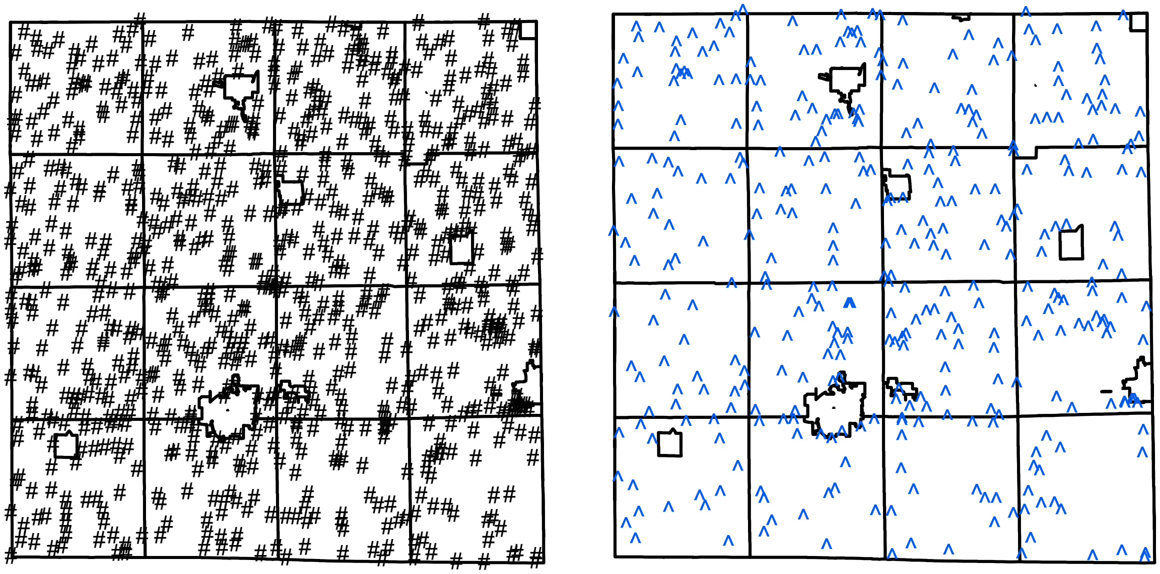


Figure 1. Black symbols represent 770 well parcels that were mailed recruitment materials. The blue symbols indicate the location of well parcels (388 / 49.8%) that indicated an interest in participating.

Year 6 - Well Sampling

Sampling kits were mailed in mid-October 2024 to the 279 participants that participated in Years 1-5. 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 they were not sure which faucet was untreated, 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.

A total of 260 samples were received by February 1, 2025 and analyzed for nitrate-nitrite-nitrogen*, chloride, alkalinity, pH, total hardness, and conductivity. Samples were analyzed by the Water and Environmental Analysis Laboratory, which is state-certified to perform the analyses of interest.
Available data from public water systems required to test for nitrite-nitrogen and nitrate-nitrogen show that the majority of nitrogen is in the nitrate form; for simplicity we will refer to it as nitrate-nitrogen in this report.

2019 (Year 1) – 348 well owners participated
2020 (Year 2) – 323 well owners participated
2021 (Year 3) – 307 well owners participated
2022 (Year 4) - 294 well owners participated
2023 (Year 5) - 279 well owners participated
2024 (Year 6) – 260 well owners participated

Participant Results

Analyses were completed and results mailed out to participants in early February 2025. Each participant received a copy of their individual test results along with an interpretive guide and is able to access their individual results on the project dashboard.

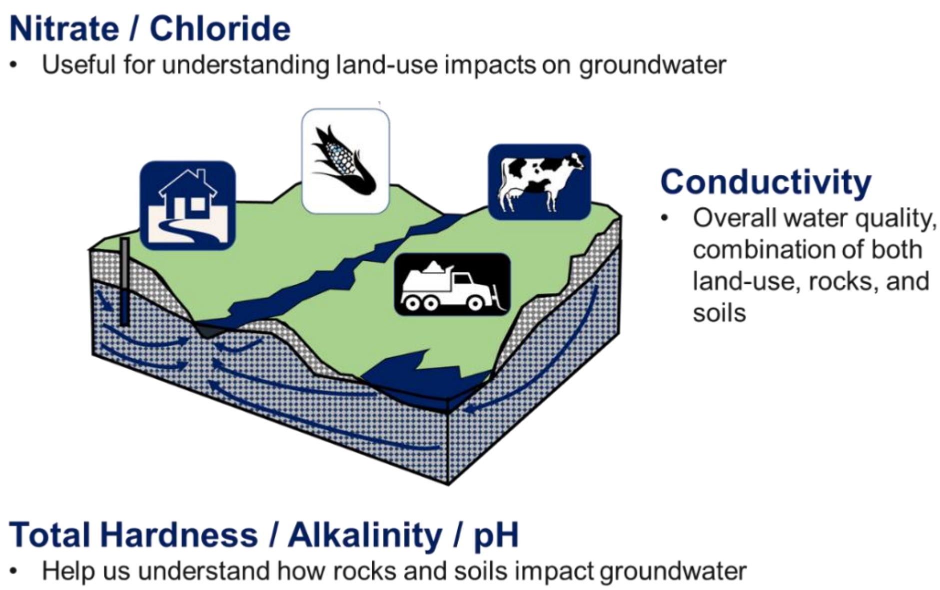
Project Results

The following information summarizes the Year 6 test results and provides an overview of each of the tests performed on the participating wells.

What did we test for?

Nitrate is an important test because it is a health-related contaminant. The other tests deal with other important characteristics of well water, such as how hard or corrosive it is. Nitrate and chloride can also be useful for understanding how land use is impacting groundwater. Meanwhile, hardness, alkalinity, pH, and conductivity tell us other important information such as how rocks and soil affect well water quality.

Figure 2. Each of the tests performed help us better understand influences on well water quality in Green County. (figure modified from Merritts et al., 2014)



Summary of Water Quality Results

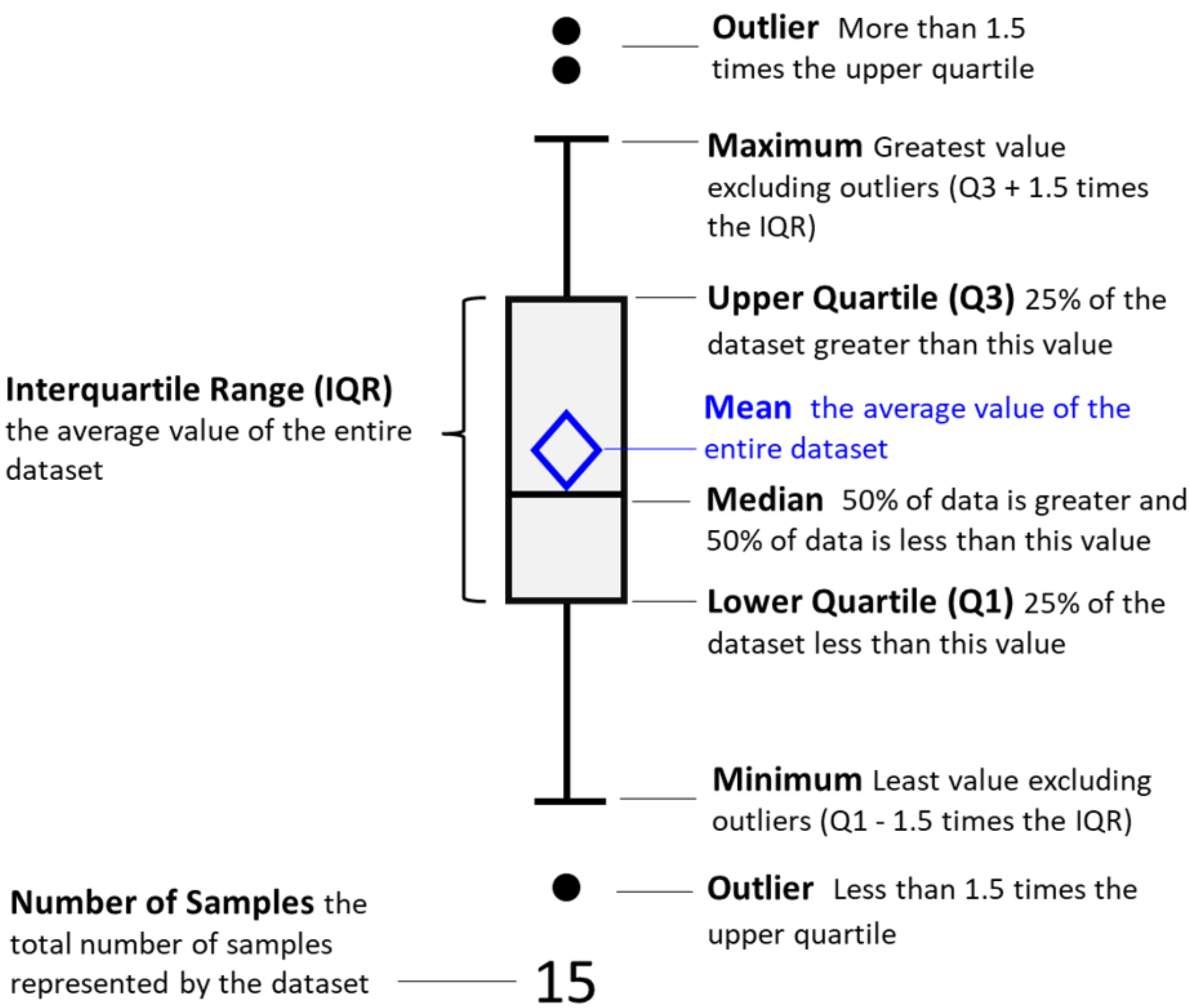
Table 1. Summary statistics for Year 6 (2024) of the Green County Well Water Monitoring Project.

	Total Hardness*	**Alkalinity**	**Conductivity**	**pH**	**Nitrate-Nitrogen**	**Chloride**
	mg/L as $CaCO_3$	**mg/L as $CaCO_3$**	**umhos/cm**		**mg/L**	**mg/L**
Minimum	47	37	228	6.72	<0.1	0.7
Mean	343	298	657	8.1	5.6	20.5
Median	349	306	658	8.16	5.1	14.9
Maximum	577	440	1248	8.67	23.3	192
# of samples	248	260	260	260	260	260

*Softened samples removed from summary statistics for Total Hardness.

Boxplots throughout the report summarize county-wide project results for analytes by year, by municipality, and by individual well over the 6-year period. Boxplots visually give us an idea of how the population of water quality samples is distributed and allows us to compare the countywide results from year to year or more easily observe differences between municipalities.

Figure 3. The diagram below shows how we can interpret the water quality data in the boxplots.



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 naturally occuring sources of these elements in rock and soils. The amount present in drinking water is generally not a significant source of these nutrients compared with a healthy diet. While there are no health standards associated with total hardness in water, too much or too little hardness can be associated with various aesthetic issues that can impact plumbing and other functions.

Results from the project suggest that Green County well water generally contains moderate amounts of hardness. Hardness values are such that water softeners are expected to be fairly common to treat against negative aesthetic effects associated with hardness. Lower values associated with soft water were most commonly detected in sand/gravel wells located near the Sugar River.

Why Test for Total Hardness

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 climate variability 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 mg/L 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, 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.

If you are experiencing problems with hard water: Consider a water softener. Water softeners remove calcium and magnesium and replace those elements with a different cation (usually sodium). Many people choose not to soften the cold-water kitchen tap used for drinking/cooking and the outdoor faucet used for yard watering. *Note: the water softening industry measures hardness in grains per gallon. 1 grain per gallon = 17.1 mg/L as $CaCO_3$*

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. Please note: total hardness values less than 50 would be rare for Green County. Water reported at less than 50 mg/L of total hardness likely represents softened or partially softened water.

If you are experiencing problems with soft water or corrosion of household plumbing: You may want to consider a water treatment device (called a neutralizer) designed to make water less corrosive. Newer homes with plastic plumbing generally don't need to be as concerned with corrosive water with respect to the plumbing.

Ideal:

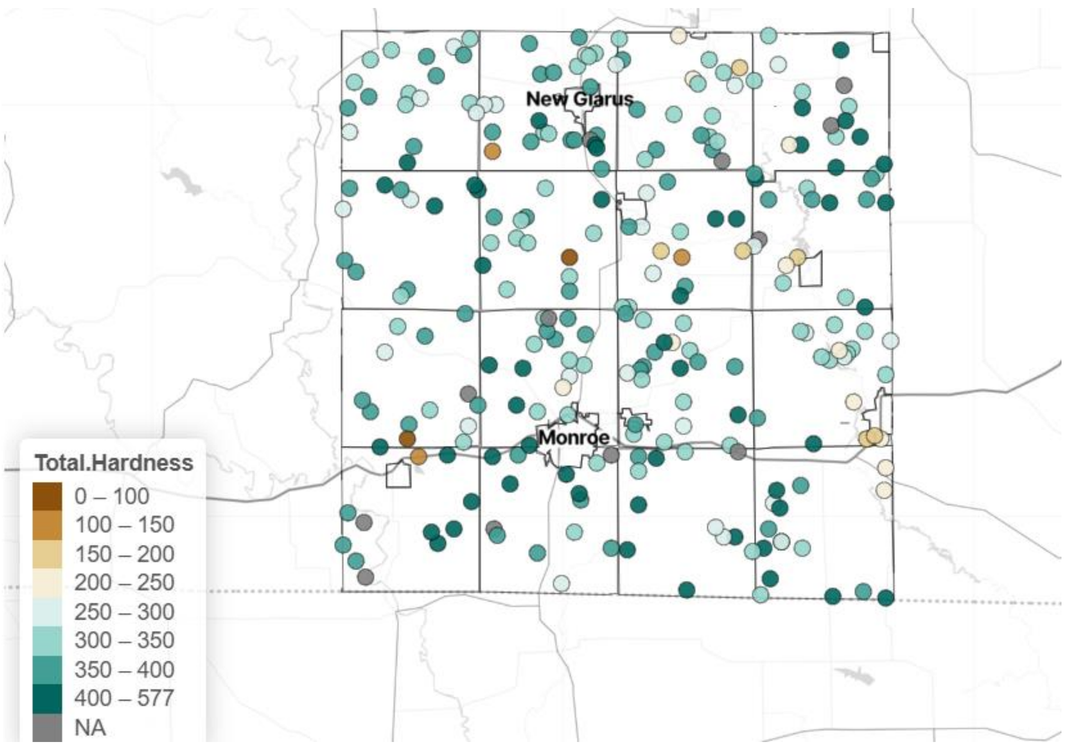
Water with total hardness between 150-200 mg/L is generally an ideal range of water hardness because there are enough ions to protect against corrosion, but not too many that they contribute to scale formation. While it is a personal preference, households with hardness in this range generally don't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

Sources of Total Hardness

Primarily dissolved carbonate minerals from soil and rock materials. When carbonate minerals dissolve, they increase the amount of calcium and magnesium ions in water.

Total Hardness Results

Figure 4. Total hardness results for Year 6 (2024) of the Green County Well Water Monitoring Project. (NA indicates softened or partially softened samples.



Total Hardness (mg/L CaCO3)	# Samples	Percent
Less than 50	1	<1%
51 – 100	1	<1%
101 – 200	10	4%
201 – 300	40	16%
301 – 400	144	58%
Greater than 400	52	21%

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

Figure 5. Boxplots of countywide total hardness for Year 1 (2019), Year 2 (2020), Year 3 (2021), Year 4 (2022), Year 5 (2023), and Year 6 (2024) of the project. Data Includes only wells sampled in each of the 6 years. Levels greater than 200 mg/L indicated by the dashed purple line are considered hard water, while levels less than 150 mg/L indicated by the dashed green line are considered soft water.

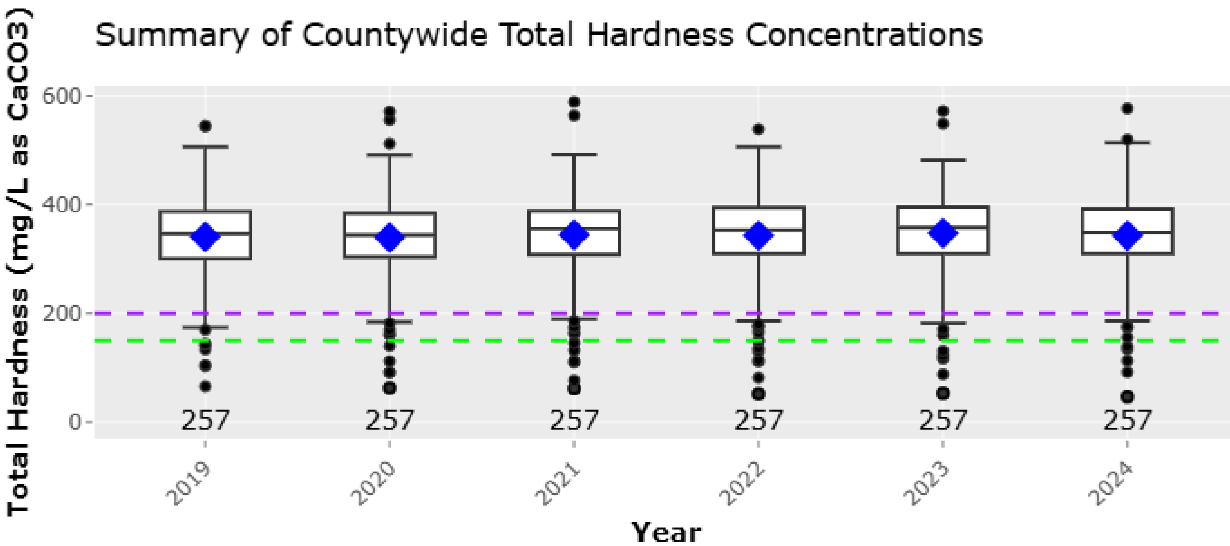
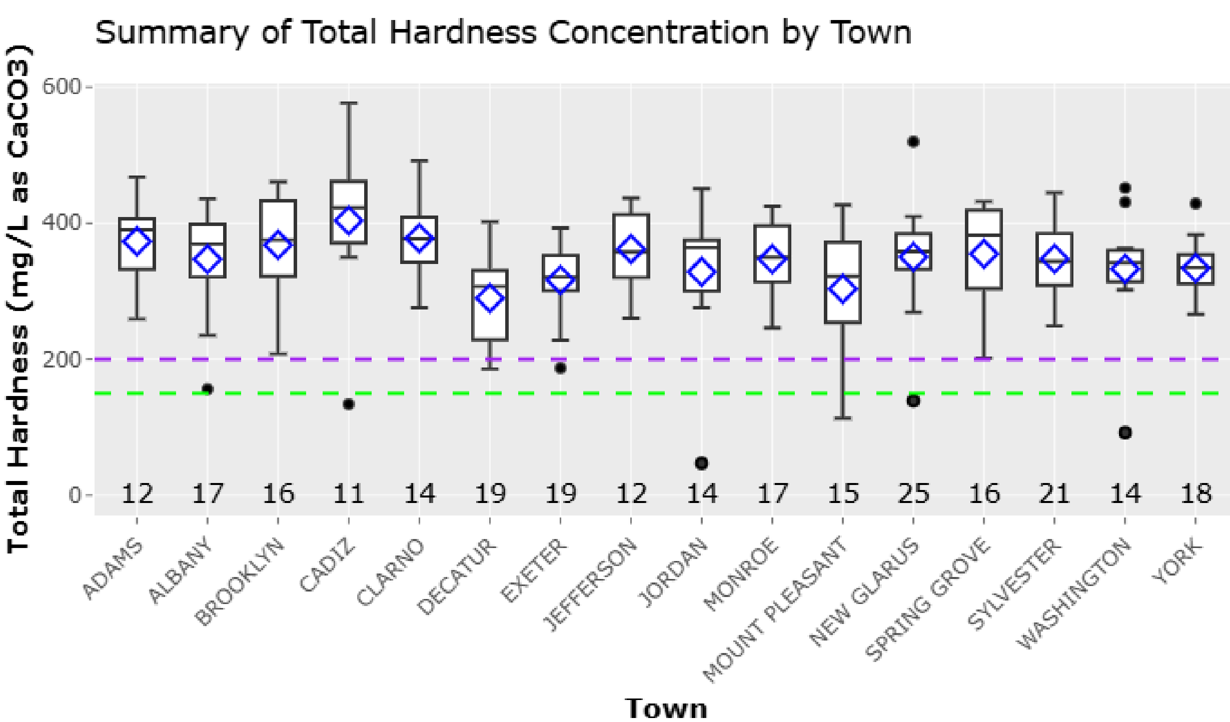


Figure 6. Boxplots of total hardness by town for Year 6 (2024).



Alkalinity

Alkalinity measures the ability of water to neutralize acids. Alkalinity is associated with carbonate minerals and is commonly found in areas where groundwater is stored or transported in carbonate rock, which occur in parts of Green County and help explain alkalinity variations throughout the county. Well water in Green County was generally found to contain moderate to high amounts of alkalinity. Lower values occurred in sand/gravel wells near the Sugar River.

Why Test for Alkalinity

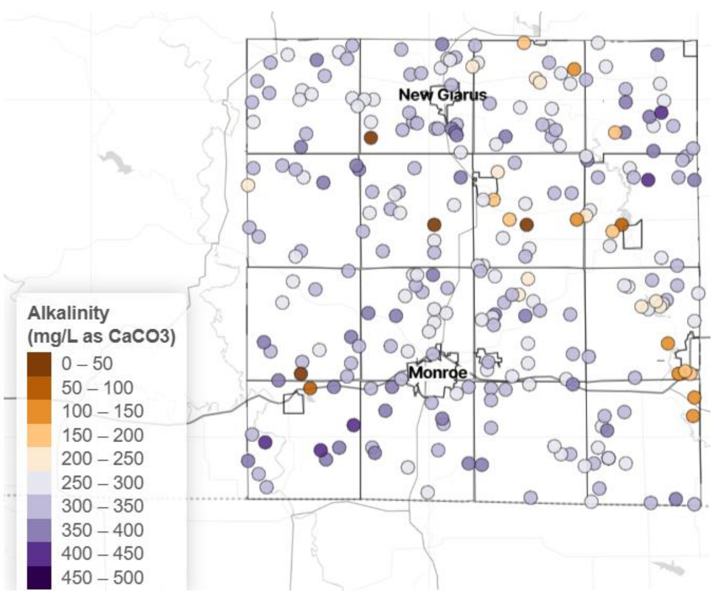
Because alkalinity is related to the rocks and soils that water flows through on its way to a well, we would expect alkalinity concentrations to be relatively stable from year to year. Any changes observed in alkalinity concentrations may help us better understand the influence of climate variability on well water quality from year to year or make sense of broader water quality results from Green County. Particularly in wells that are uninfluenced by human activity, alkalinity concentrations may help us better understand which aquifers wells may be 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 water has passed through a water softener. If alkalinity is significantly less than total hardness, it could be related to elevated levels of chloride or nitrate..

Alkalinity Results

Figure 7. Alkalinity results for Year 6 (2024) of the Green County Well Water Monitoring Project.



Alkalinity (mg/L CaCO3)	# Samples	Percent
Less than 50	4	2%
51 – 100	2	<1%
101 – 200	14	5%
201 – 300	98	38%
301 – 400	137	53%
Greater than 400	5	2%

Figure 8. Boxplots of countywide alkalinity for Year 1 (2019), Year 2 (2020), Year 3 (2021), Year 4 (2022), Year 5 (2023), and Year 6 (2024) of the project. Includes only wells that sampled in all 6 years.

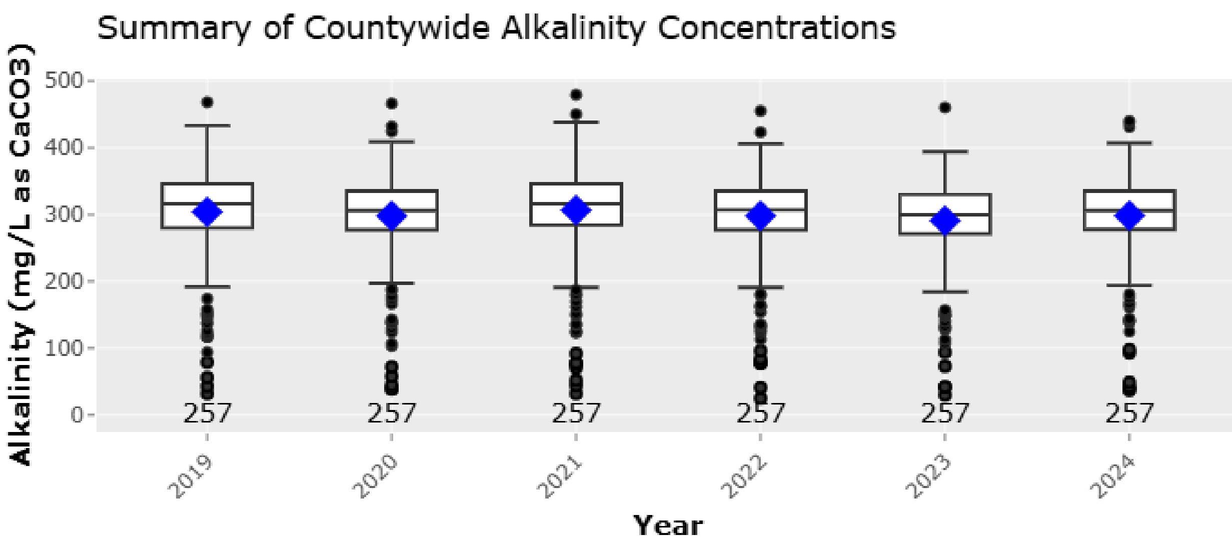
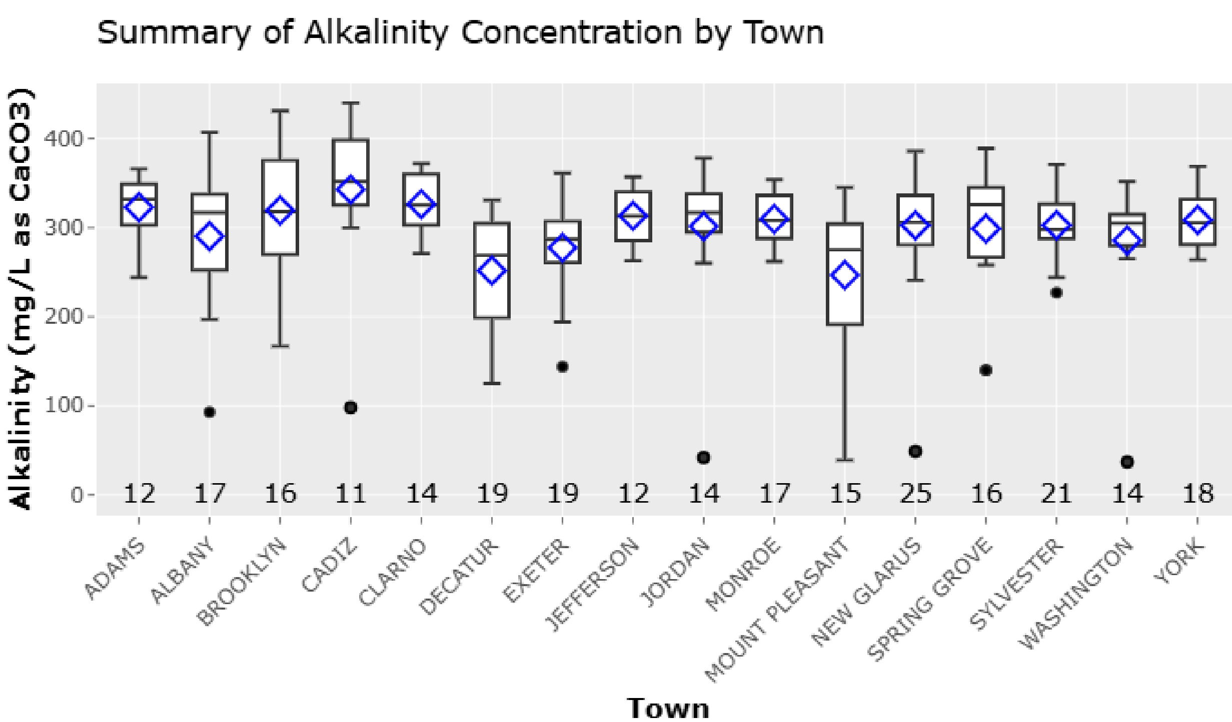


Figure 9. Boxplots of alkalinity by town for Year 6 (2024).



Conductivity

Conductivity measures the amount of dissolved substances (or ions) in water; but does not give an indication of which ions 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.

Why Test for Conductivity

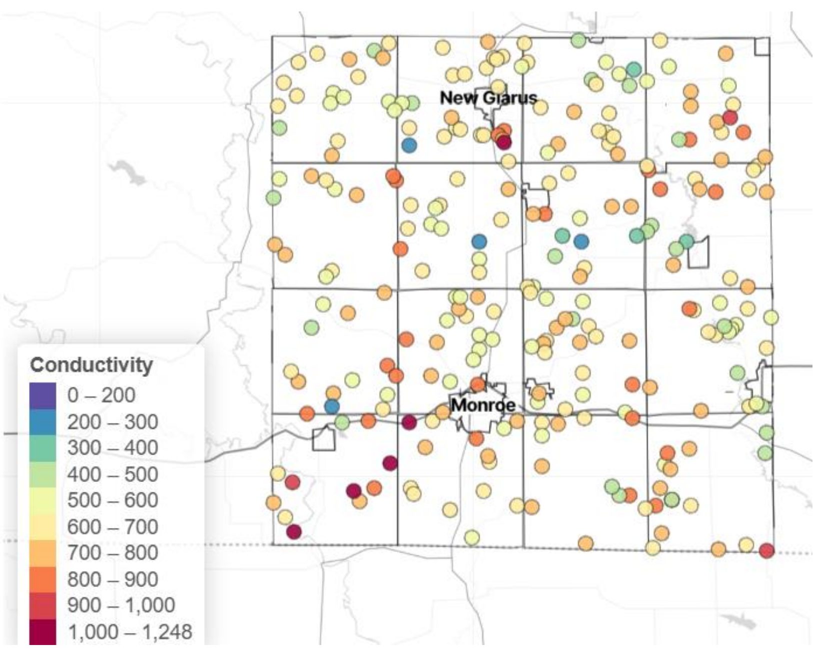
Conductivity is relatively easy to measure and conductivity sensors available for purchase by the layperson are reliable. Information learned from changes in conductivity during this project may be useful for designing future monitoring strategies for Green County or even individual households to inexpensively track changes in well water quality continuously on their own.

Acceptable results:

There is no health standard associated with conductivity. A normal conductivity value measured in umhos/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.

Conductivity Results

Figure 10. Conductivity results for Year 6 (2024) of the Green County Well Water Monitoring Project.



Conductivity (umhos/cm)	Number of Samples	Percent
Less than 100	0	0%
101 – 250	2	<1%
251 – 500	30	12%
501 – 750	172	66%
751 – 1000	51	20%
Greater than 1000	5	2%

Figure 11. Boxplots of countywide conductivity for Year 1 (2019), Year 2 (2020), Year 3 (2021), Year 4 (2022), Year 5 (2023), and Year 6 (2024) of the project. Includes only wells that sampled in all 6 years.

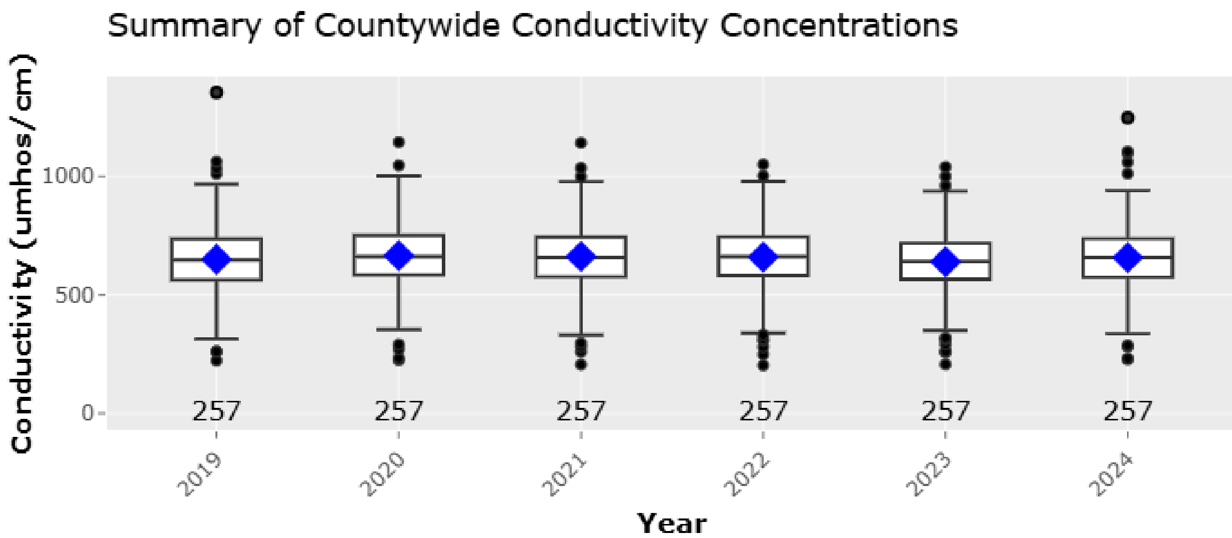
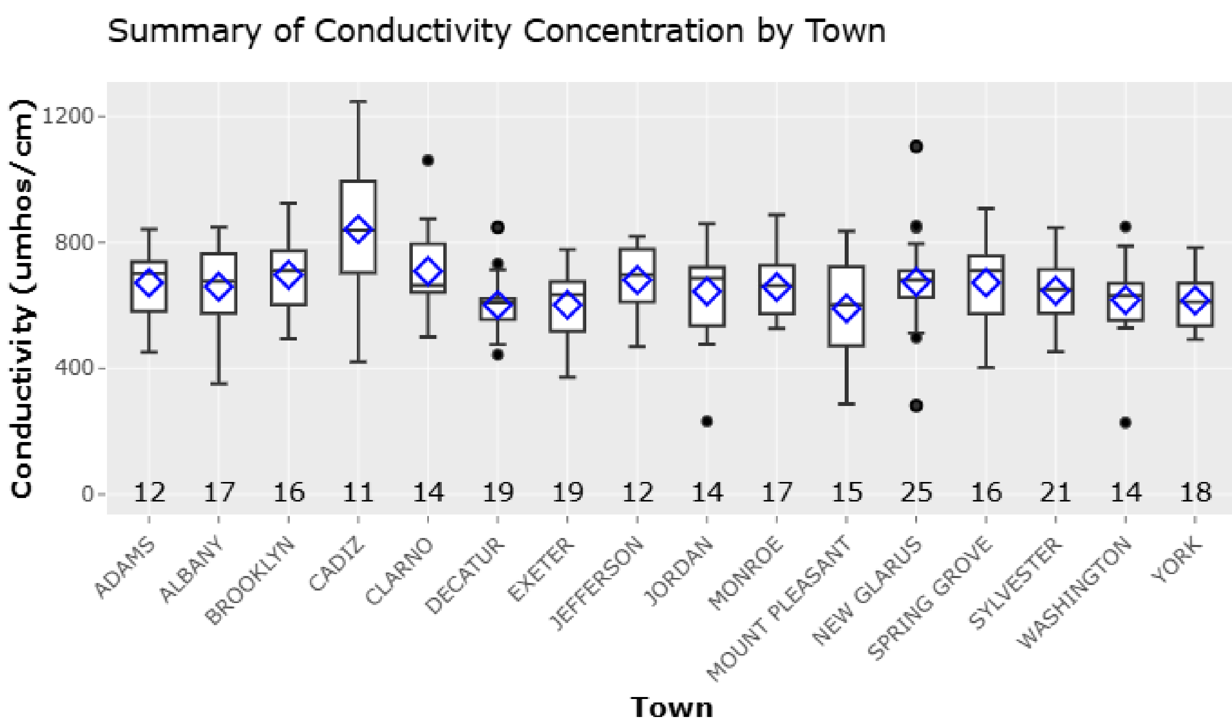


Figure 12. Boxplots of conductivity by town for Year 6 (2024).



pH

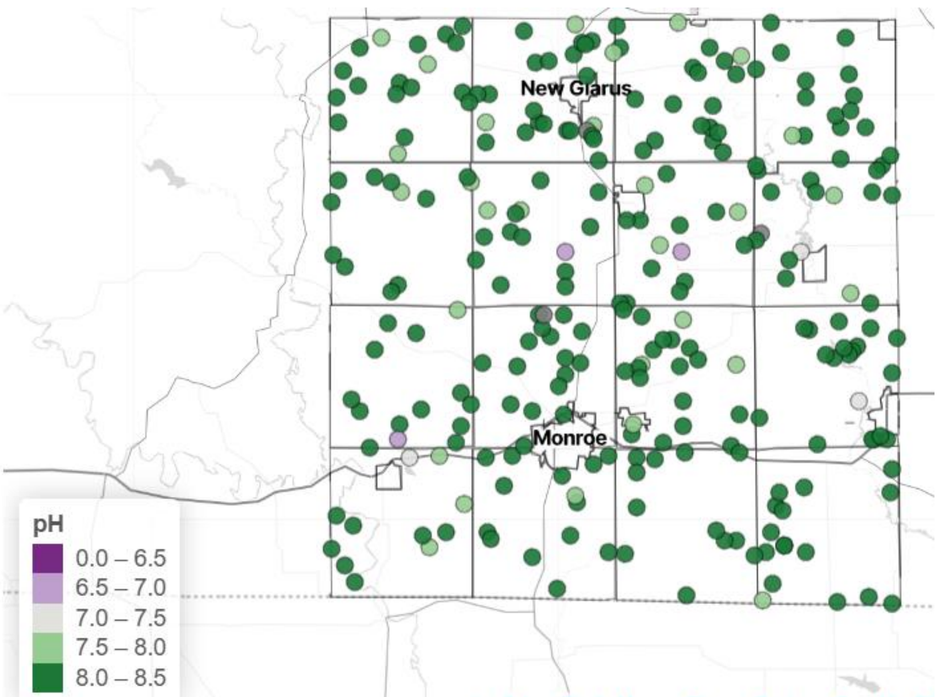
The pH test measures the concentration of hydrogen ions in a solution. The concentration of hydrogen determines if a solution is acidic or basic. The lower the pH, the more corrosive water will be. The pH of well water in Green County is basic, with 87% of wells indicating a pH between 8 and9.

Acceptable results:
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.

Sources: Low values are most often caused by lack of carbonate minerals in the aquifer.

pH Results

Figure 13. The pH results for Year 6 (2024) of the Green County Well Water Monitoring Project.



pH	Number of Samples	Percent
Less than 5.00	0	0%
5.01 - 6.00	0	0%
6.01 – 7.00	3	1%
7.01 – 8.00	35	14%
8.01 – 9.00	222	85%
More than 9.01	0	0%

Figure 14. Boxplots of countywide conductivity for Year 1 (2019), Year 2 (2020), Year 3 (2021), Year 4 (2022), Year 5 (2023), and Year 6 (2024) of the project. Includes only wells that sampled in all 6 years.

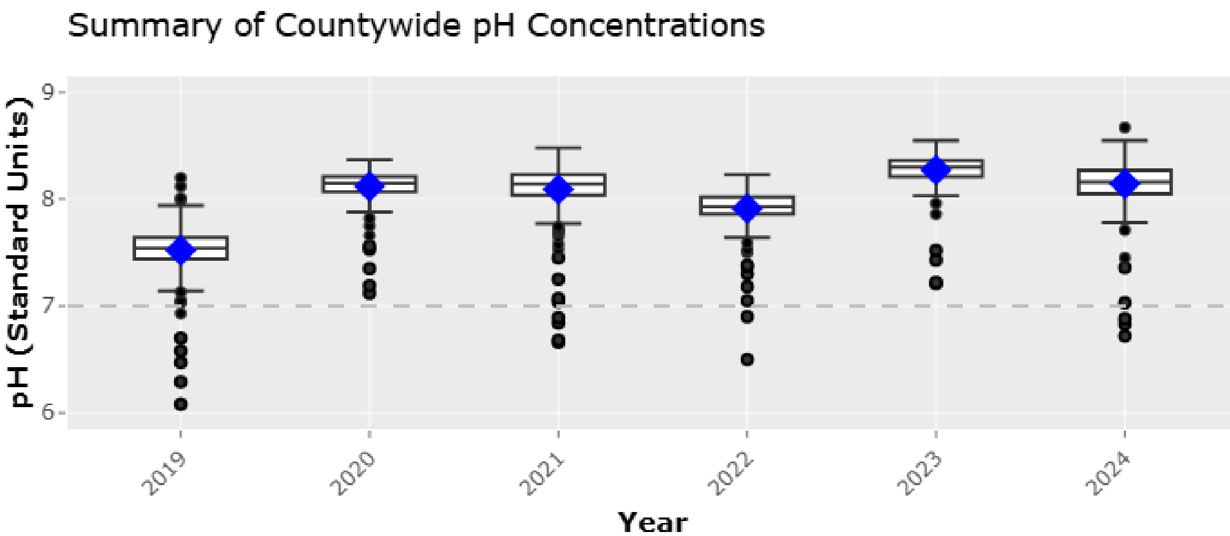
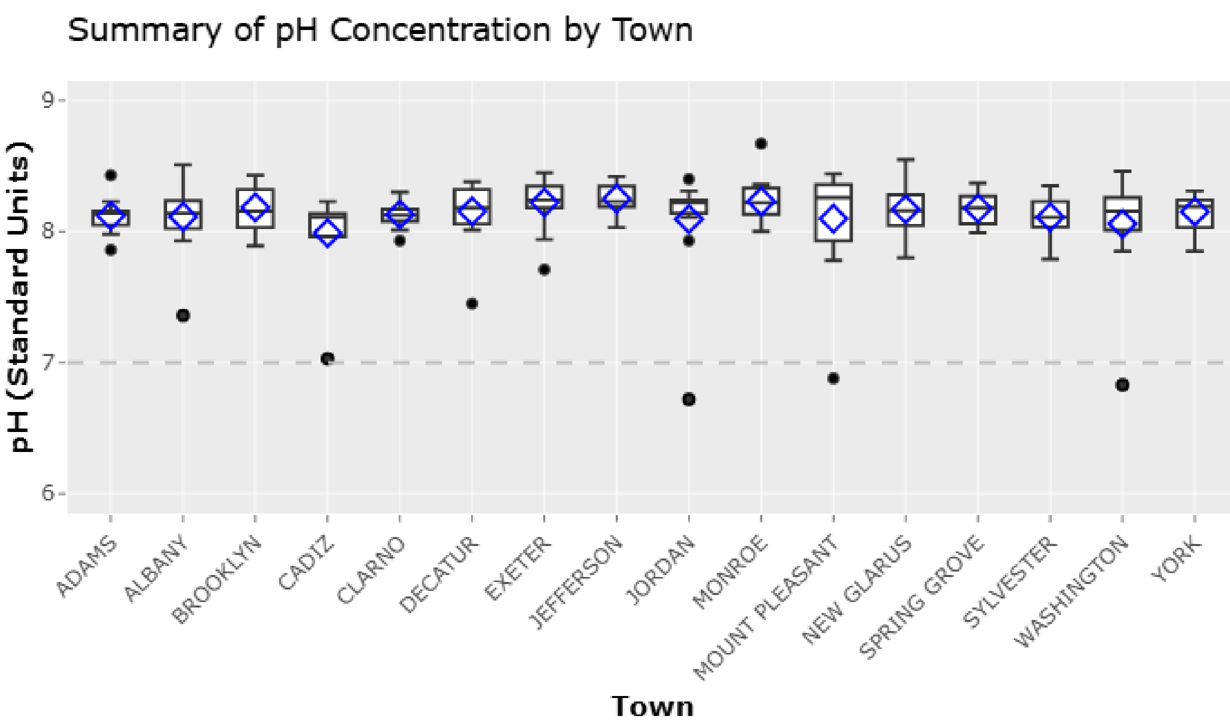


Figure 15. Boxplots of pH by town for Year 6 (2024).



Chloride

In most areas of Wisconsin, chloride concentrations are naturally low (usually less than 15 mg/L). Higher concentrations may serve as an indication that the groundwater supplied to your well has been impacted by various human activities. Forty-nine percent of wells tested as part of the Green County Well Water Monitoring Project suggest (through elevated chloride) that land-use has impacted the well water quality.

Why Test for Chloride

Chloride is a test that allows us to understand the influence of human activities on well water quality. Measuring chloride concentrations in well water will also allow us to better understand whether well water quality is getting better, worse, or staying the same with respect to certain land-uses (see Sources).

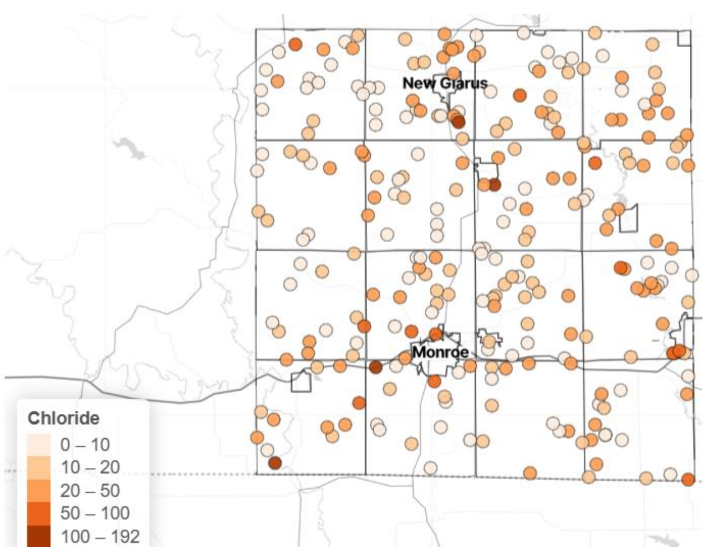
Interpreting Chloride Concentrations

Chloride is not toxic at typical concentrations found in groundwater. Unusually high concentrations of chloride (greater than 150 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; water is also more likely to be corrosive to certain metals.

Sources of Chloride

- Agricultural Fertilizers (chloride is a companion ion of potash fertilizers
- Manure and other biosolids
- Septic Systems
- Road Salt

Chloride Results



Chloride (mg/L)	Number of Samples	Percent
Less than 10 mg/L	92	35%
11 – 50	151	58%
51 – 100	13	5%
101 – 200	4	2%
Greater than 200	0	0

Figure 16. Chloride results for Year 6 (2024) of the Green County Well Water Monitoring Project.

Figure 17. Boxplots of countywide chloride for Year 1 (2019), Year 2 (2020), Year 3 (2021), Year 4 (2022), Year 5 (2023), and Year 6 (2024) of the project. Includes only wells that sampled in all 6 years.

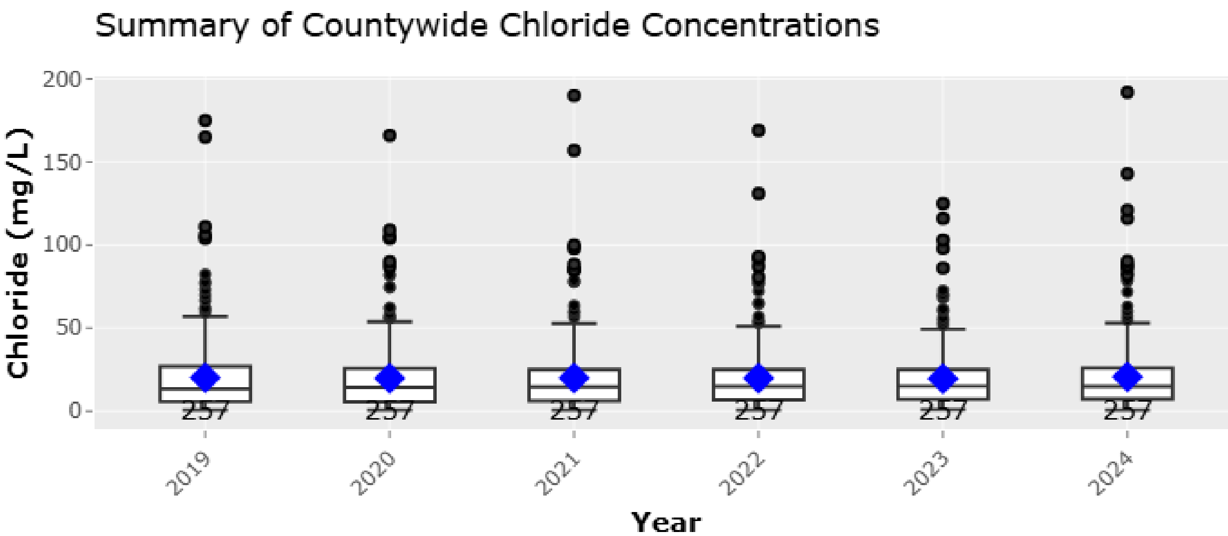
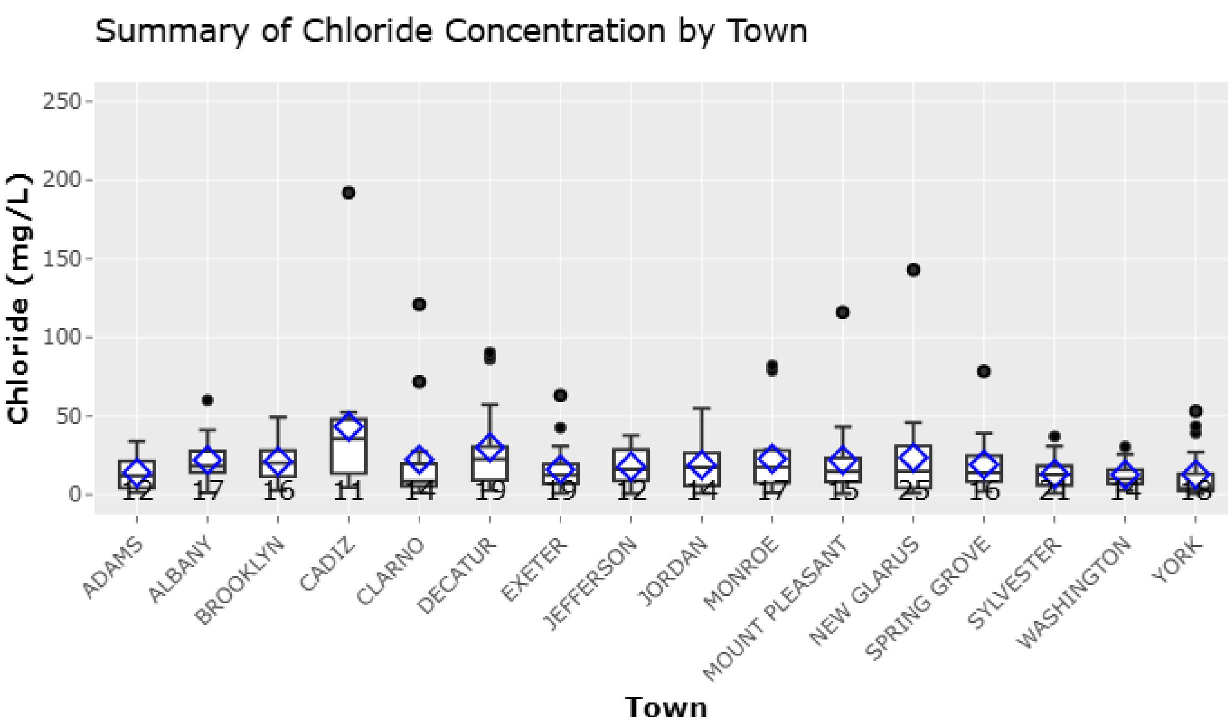


Figure 18. Boxplots of chloride by town for Year 6 (2024).



Nitrate-nitrogen

This test measures the amount of nitrate-nitrogen in a well. Nitrate is a form of nitrogen, commonly found in agricultural and lawn fertilizer, that easily dissolves in water. It is also formed when waste materials such as manure or septic effluent decompose. The natural level of nitrate-nitrogen in Wisconsin's groundwater is less than 1 mg/L. 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 of nitrate-nitrogen. Fifteen percent of wells tested as part of the Green County Well Water Monitoring Project indicated nitrate at levels above what is considered safe for drinking water. The percentage of wells exceeding the standard in Green County has remained relatively consistent (15-19%) throughout the six-year period (Table 2). Statewide, approximately 9% of all private wells contain nitrate-nitrogen above 10 mg/L. Meanwhile, 26-28% of wells tested are testing at what is generally considered to be natural or background levels in Wisconsin's groundwater.

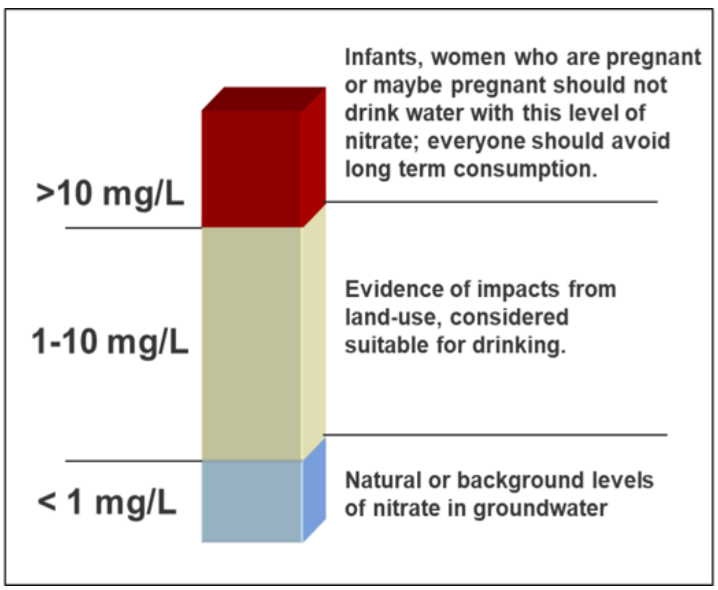
Why Test for Nitrate

Nitrate is an important test for determining the safety of well water for drinking. Like chloride, nitrate testing allows us to understand the influence of human activities on well water quality. Because it can come from a variety of sources and moves easily through soil, it serves as a useful indicator of certain land-use activities. An annual nitrate test can be used to understand whether water quality is getting better, worse, or staying the same with respect to certain land-uses (see Sources).

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 this is not possible, or you need an alternative solution because of time or cost, 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 ensure treatment systems are functioning properly.

Water Treatment Options for Nitrate

Point-of-use devices treat enough water for drinking and cooking needs

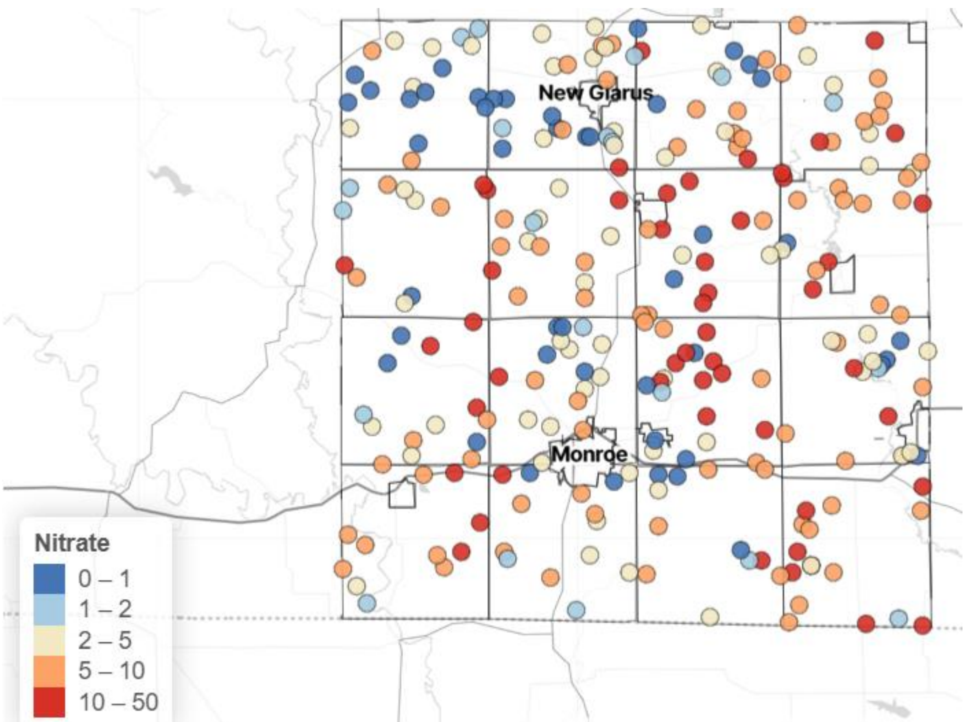
- Reverse Osmosis
- Distillation

Point-of-entry systems treat all water distributed throughout the house

- Anion Exchange

Nitrate-Nitrogen Results

Figure 19. Nitrate-nitrogen results for Year 6 (2024).



Nitrate-Nitrogen (mg/L)	Number of Samples	Percent
None Detected	27	10%
Less than 2.0	39	15%
2.1 – 5.0	62	24%
5.1 – 10.0	84	32%
10.1 – 20.0	47	18%
Greater than 20.0	1	<1%

Figure 20. Boxplots of countywide nitrate-nitrogen for Year 1 (2019), Year 2 (2020), Year 3 (2021),Year 4 (2022), Year 5 (2023), Year 6 (2024) of the project. Includes only wells that sampled in all 6 years.

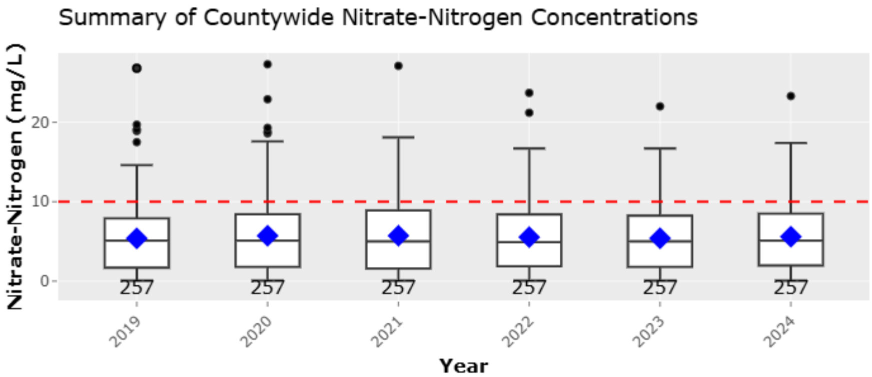


Figure 21. Boxplots of nitrate-nitrogen by town for Year 6 (2024).

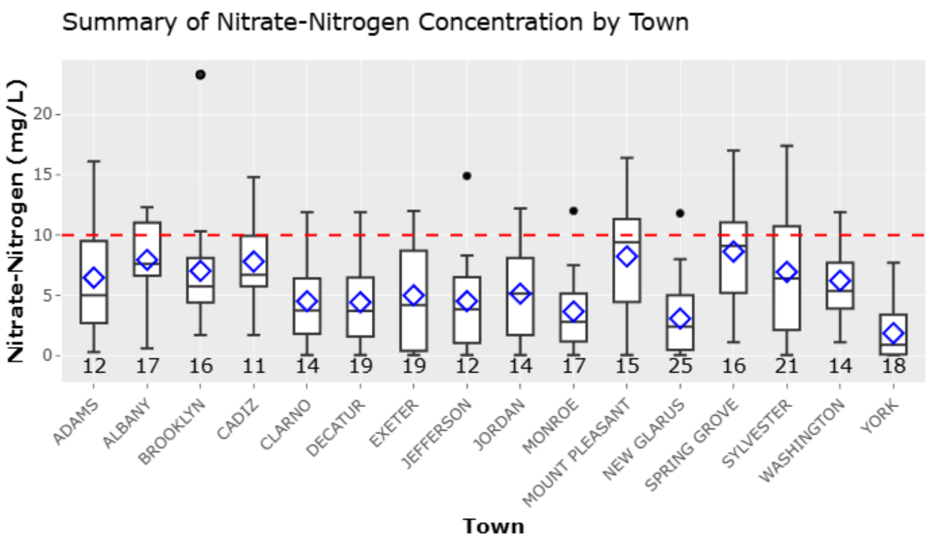


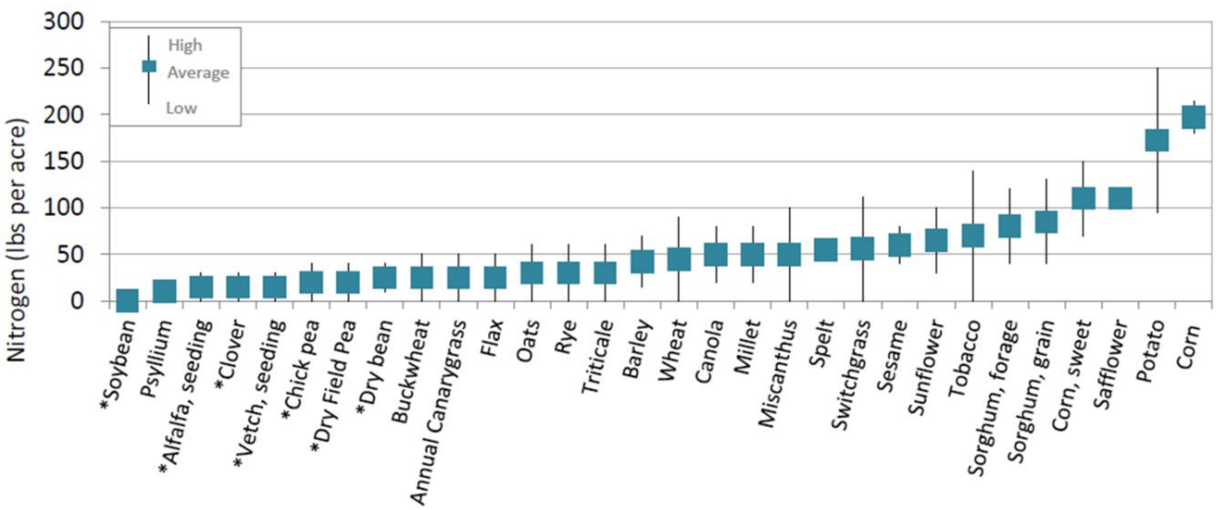
Table 2. Summary stats of all nitrate-nitrogen samples by year.

	2019	2020	2021	2022	2023	2024
	Nitrate-N (mg/L)					
Average	5.4	5.7	5.8	5.5	5.5	5.6
Median	5.0	5.0	5.0	4.9	5.0	5.1
Minimum	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Maximum	26.8	27.3	27.1	23.7	22.0	23.3
Greater than 10	15%	18%	19%	16%	15%	19%
Less than 2	28%	27%	27%	26%	26%	25%
N	348	323	307	294	269	260

Agriculture and nitrate

Within agricultural systems there are various factors that influence the amount of nitrate that gets into groundwater. While significant amounts of nitrogen are taken up by crops, not all 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.

Figure 22. 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).



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).

This budget approach often reveals that even fields with nutrient management plans can leach nitrate-nitrogen 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, and 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.

Figure 23. 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.

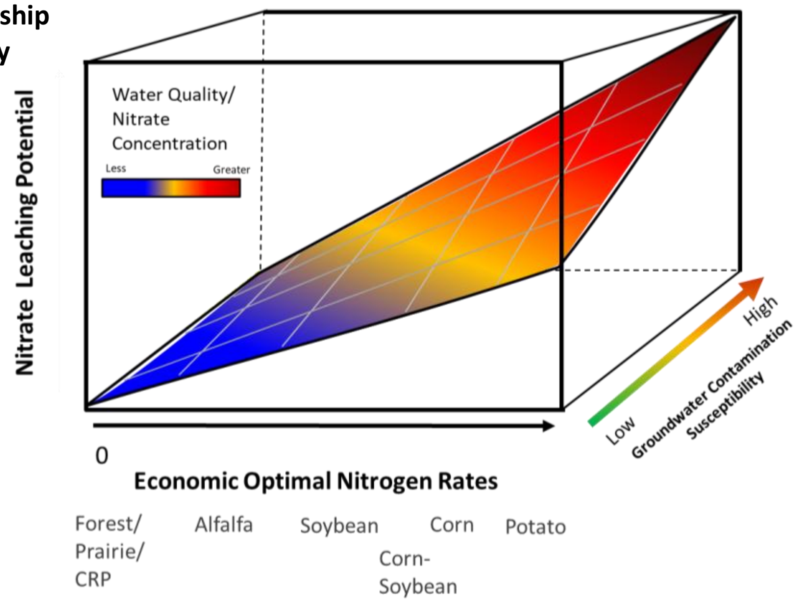
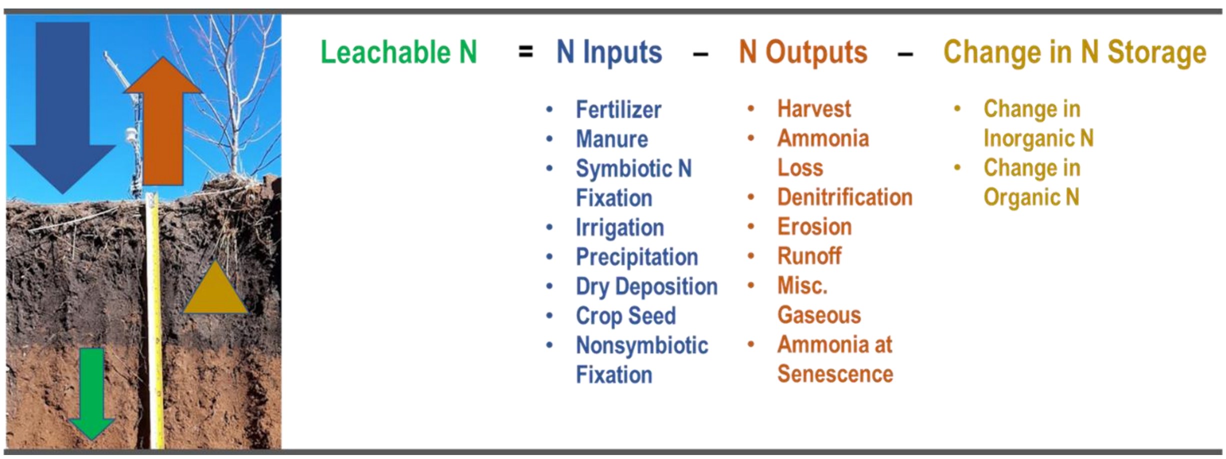


Figure 24. Potential leachable N (nitrate) can be calculated using a nitrogen budget approach. If various inputs are known and a reasonable estimate of yield can be made, estimating leachable nitrogen can be performed.



Minimizing nitrate leaching to groundwater fundamentally requires that we think about how best to maintain nitrogen within 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 often represents the majority of leaching losses during moderate to dry years (Masarik et al., 2014). Therefore, multiple strategies that reduce nitrogen fertilizer inputs that 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 activities that will help to reduce nitrate concentrations in groundwater and nearby wells:

For those that own and operate agricultural fields:

- 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).
- For farms that manage manure, develop cropping systems that allow for the addition of manure to crops during the growing season when plants are better able to utilize the nitrogen in manure.
- 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.

For homeowners and those that manage landscaping:

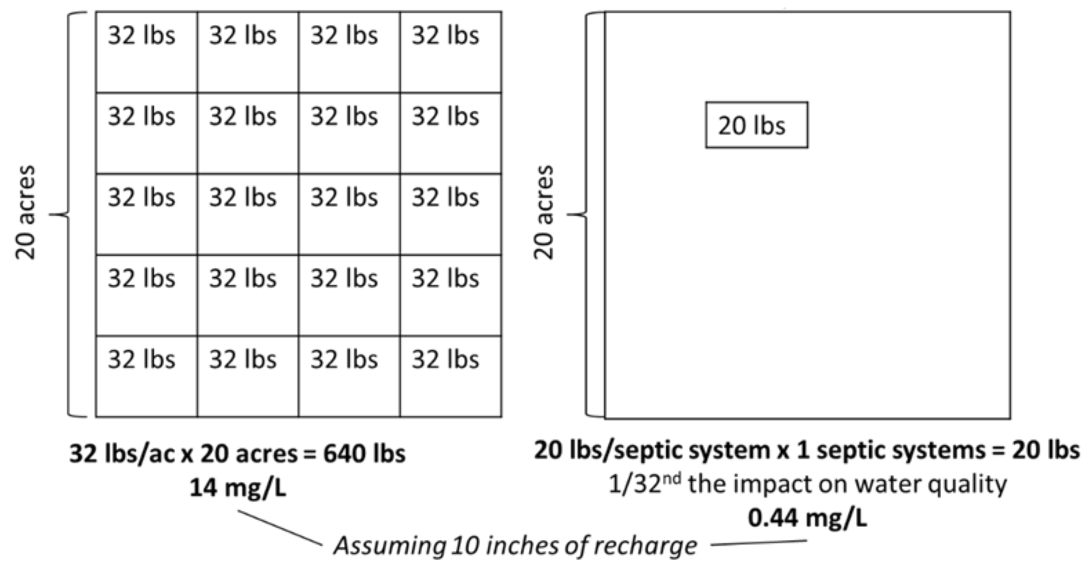
- Limit the amount of nitrogen lawn fertilizer you use or better yet, increase natural areas or incorporate perennial vegetation that doesn't require fertilizer into landscaping.

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. In addition to nitrate and chloride, there is increasing evidence that wells influenced by septic system effluent are more likely to contain pharmaceuticals, personal care products, and per- and polyfluoroalkyl substances (PFAS) (Silver et al., 2023). It is important to point out that even properly functioning septic systems are contributors of nitrate to groundwater. However, in traditional rural development the degree of influence from septic systems on nitrate in well water is significantly less than agricultural systems.

We can use a nitrogen budget approach to 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 25). In some cases, 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.

Figure 25. 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).



When the density of septic systems in a small area increases, there is greater potential for higher nitrate concentrations as a result of increased nitrate loading. The smaller the lot size the greater potential impact that will result from septic systems near one another, not only with respect to nitrate but also other compounds associated with household wastewater (ex. pharmaceuticals, personal care products, PFAS, etc.). For example, using the data from Figure 26, we'd estimate that 32 septic systems in a 20-acre development (i.e. lot sizes of 0.6 acres) would essentially have the same impact as a 20-acre agricultural field leaching 32 lbs of nitrogen per acre.

Figure 26. (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 that septic system effluent travels downgradient of drainfields.

Well Water Quality Trends

One of the goals of this project was to help understand trends or changes in groundwater quality over time. In areas where groundwater quality is changing, it may change very slowly depending on a variety of factors. As a result, it may take longer than six years of data to understand whether changes are occurring; ten years of data from the same wells may result in different interpretation. However, the six years of data collected from 2019-2024 can help us understand how variable well water quality is with respect to nitrate. If there are wells where nitrate concentrations are changing; this data can help us understand what the rate of change is and whether well water quality is generally getting better or worse.

While additional years will provide more confidence in this analysis, the initial six-years of data provides 1) an initial starting point for understanding nitrate variability from year-to-year, 2) provides an estimate of trending wells over the past six years, 3) serves as a reference for future years of data and/or baseline dataset for comparison at some point in the future, and 4) shows the importance of the current recommendation for private wells to be tested annually for nitrate.

Water quality trends within individual wells were analyzed using the Mann-Kendall (MK) rank correlation (Mann, 1945; Helsel and Frans, 2006; Jurgens *et al.*, 2020). Tests were computed using the R Programming Language (R Core Team, 2022) for private wells that had sample data spanning six continuous years. Seasonality was not considered because samples kits were sent to participants and returned around the same time of year.

When using the non-parametric Mann-Kendall rank correlation and Sen's slope estimator to assess trends in water-quality data, trends in individual wells were accepted as statistically significant when MK rank correlation p-values were below a significance level (α) of 0.1. The Sen's slope is a measure of the linear rate of change and was computed with the sens.slope function (trend package). Positive Sen's slopes indicate increasing concentrations while negative slopes indicate decreasing concentrations. The Sen's slope provides the ability to compare rates of concentration increases or decreases between wells. Nitrate-nitrogen trends were determined to be significant if the sen.slope estimate resulted in a concentration change of greater than 0.1 mg/L; whereas as value of 1.0 mg/L was used for chloride.

Data on water quality trends can be found in the figures below, including maps showing individual wells that detected significant trends for nitrate-nitrogen (Figure 27) and chloride (Figure 28). Blue symbols represent wells with decreasing nitrate trends, red symbols represent wells with evidence of increasing trends, and beige symbols indicate wells with no discernable trend. The size of the symbol indicates the rate of change observed over the six-year period.

Boxplots were also generated for nitrate-nitrogen (Figure 29) and chloride (Figure 30). The boxplots show the concentration distribution of each participating well for the six year period. The wider the boxplot the more variable the concentration for the parameter of interest.

Figure 27. Year 6 (2024) nitrate-nitrogen trends for wells with five continuous years of data. Data shows 12% (32 wells) detected increasing trends, 9% (24 wells) detected decreasing trends, and 78% (201 wells) that did not detect a trend in nitrate-nitrogen concentrations.

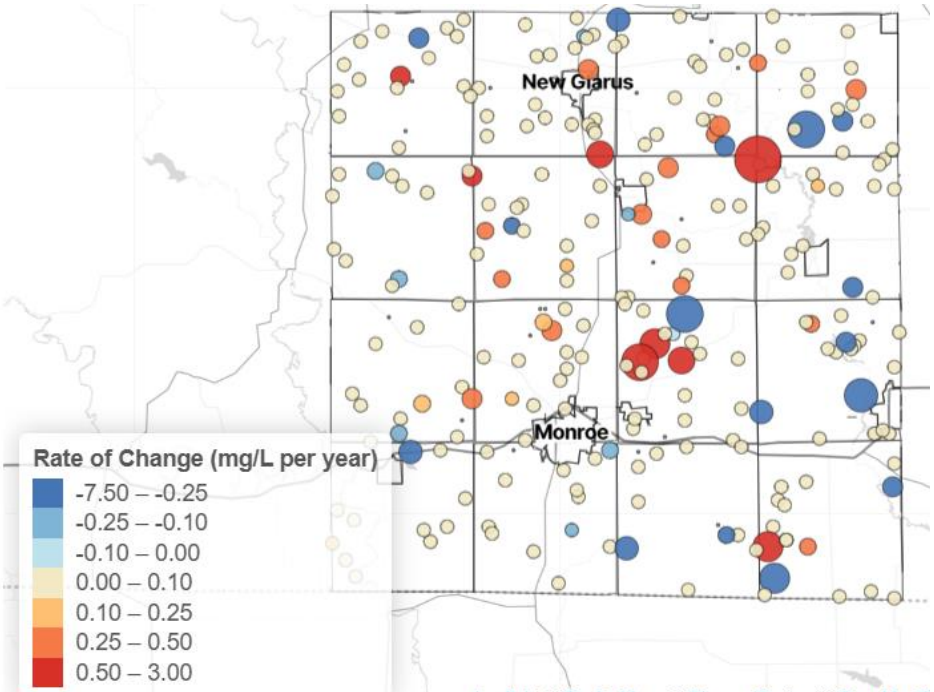


Figure 28. Year 6 (2024) chloride trends for wells with five continuous years of data. Data shows 7% (17 wells) detected increasing trends, 6% (16 wells) detected decreasing trends, and 87% (224 wells) that did not detect a trend in chloride concentrations.

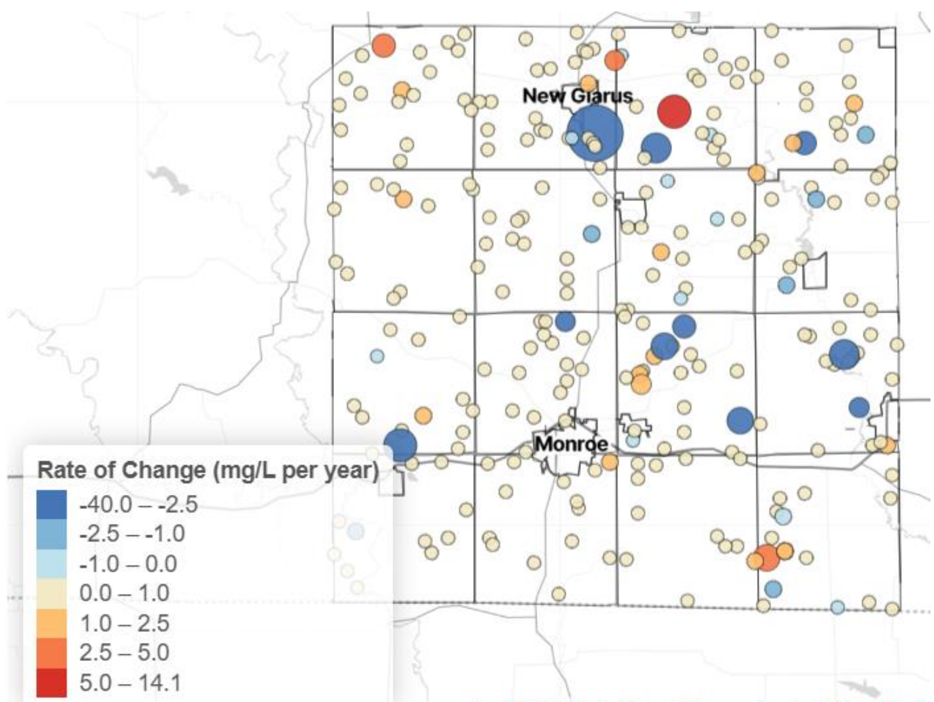


Figure 29. Boxplots arranged by increasing mean nitrate-nitrogen concentration for wells with 6 years of data. Red dashed line indicates the 10 mg/L Nitrate-Nitrogen drinking water standard.

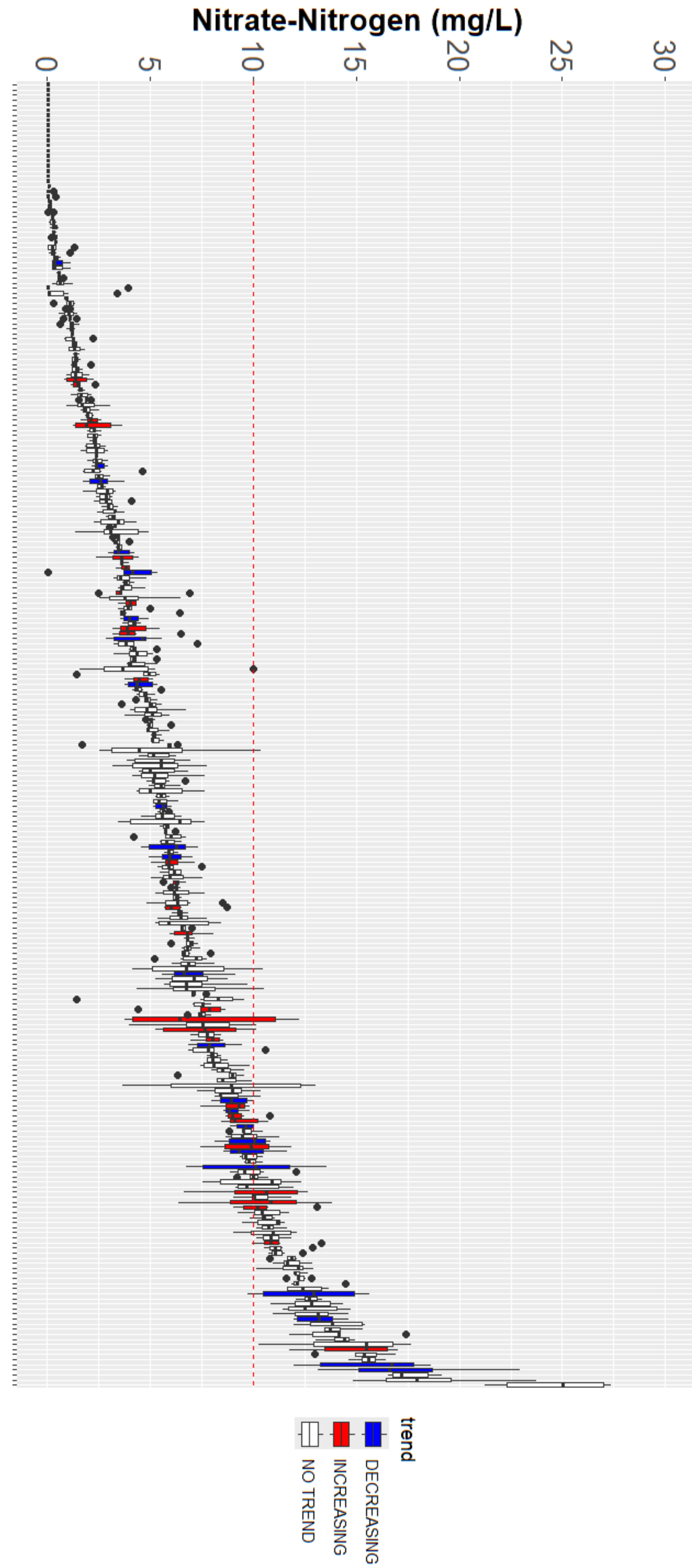
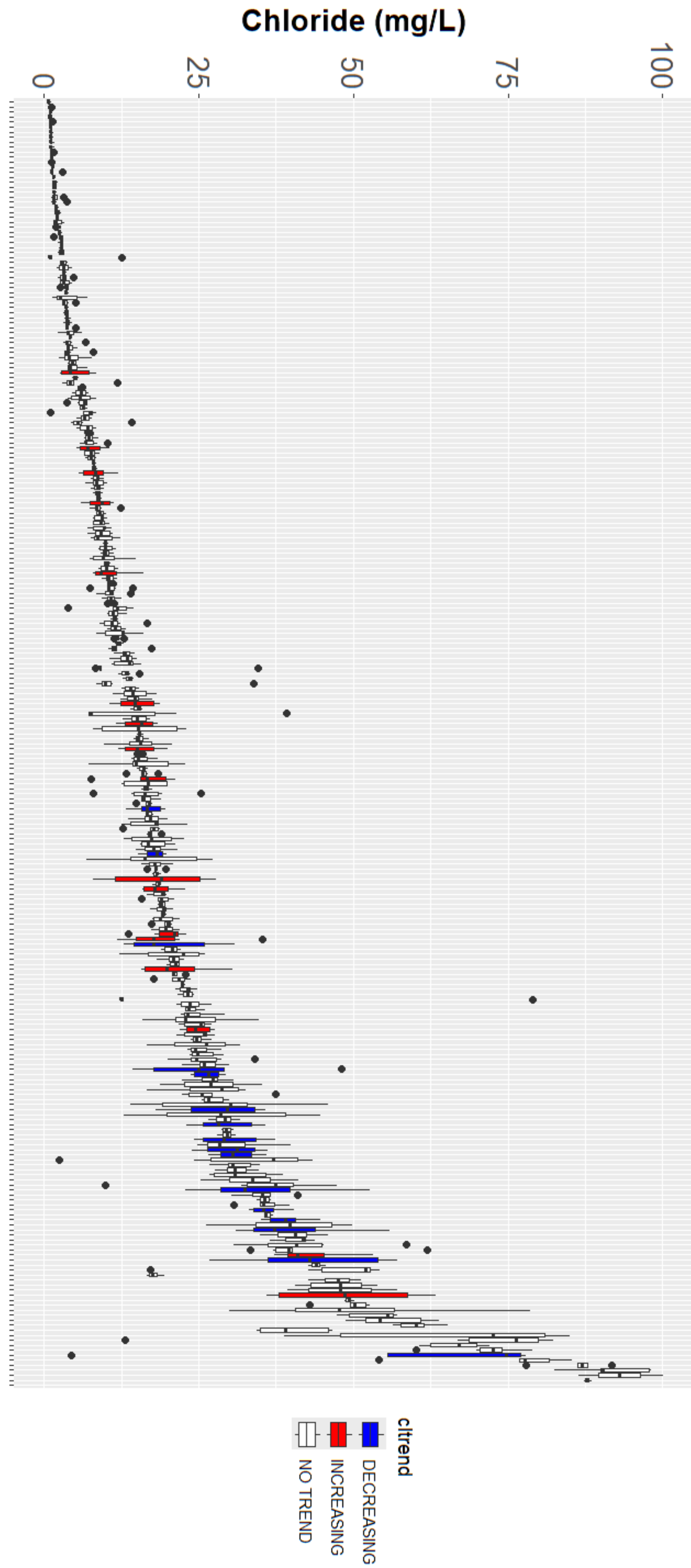


Figure 30. Boxplots arranged by increasing mean chloride concentration for wells with 6 years of data.



Important observations on nitrate-nitrogen trends:

- The majority of wells (73%) had a standard deviation of less than 1.0 mg/L of nitrate-nitrogen over the six year period.
- Large variability in nitrate-nitrogen concentrations was observed in wells without evidence of a trend, meaning concentrations can go up or down from year to year.
- Wells that measured less than 5 mg/L showed a low likelihood of exceeding 10 mg/L at any point during the five-year period.
- Because a well has an increasing trend it does not mean that it will increase indefinitely.
- Nitrate-nitrogen concentrations may stabilize as land-use reaches equilibrium with current land use practices.

Important observations on chloride trends:

- The majority of wells (78%) had a standard deviation of less than 5.0 mg/L of chloride over the six year period.
- Large variability in chloride concentrations was not always observed in wells with trends.
- Chloride increases were more frequently observed when average chloride concentrations were less than 25 mg/L; whereas chloride decreases were observed more frequently in wells with greater than 25 mg/L of chloride.
- Because chloride is often associated with road salt, additional analysis on weather conditions over the years preceding the six-year period should be investigated further.

This data provides some timely feedback on the question of where and to what degree groundwater quality is changing in Green County. Future work will try to investigate whether there are common factors which explain increases or decreases; and the role of weather variability for helping explain changes over time. These trend statistics are likely to change with more years of data, however initial results suggest that while well water quality can be variable, most wells have not changed significantly over the six-year period. Areas with more wells increasing should receive special attention, particularly for wells that are approaching the nitrate-nitrogen standard of 10 mg/L.

Modeling Nitrate in Green County

Multiple linear regression (MLR) was used to investigate the relationship between nitrate-nitrogen and chloride concentrations of well water data with continuous explanatory variables related to land cover (Appendix A) and soil drainage (Appendix B) within a 500 m buffer of each participating well. It is appropriate to use MLR when scientific knowledge on causal relationships are understood or widely known; and can be useful for understanding the degree to which explanatory variables influence the dependent variable (Helsel *et al.*, 2020):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \varepsilon \qquad \text{[Eq. 1]}$$

where y is the response variable, β_0 is the intercept, x_i is the i^{th} explanatory variable, β_1 is the coefficient for the first explanatory variable, β_2 is the coefficient for the second explanatory variable, β_k is the coefficient for the k^{th} explanatory variable, and ε is the error term.

A square root transformation was applied to the dataset and the lm function was used to analyze data with multiple linear regression. Backward elimination was used to evaluate various models for the ability to explain variability in the dependent variable. A model with all explanatory variables initiates the elimination process; variables with a p-value greater than 0.05 are removed and the model is analyzed again. The process is repeated until only explanatory variables with significant p-values remain (Faraway, 2002; Haque *et al.*, 2018).

Table 3. Multiple linear regression analysis applied to modeling of square root transformed nitrate-nitrate concentrations and explanatory variables related to land cover, soils, and well construction. Model 3 was used to create a map of nitrate-nitrogen concentrations for Green County.

	Model 1	**Model 2**	**Model 3**	**Model 4**
Variable		Coefficients		
Cash Grain	1.695***	1.387***	1.393***	1.241***
Continuous Corn	1.636***	1.561***	1.573***	1.345**
Dairy Rotation	1.730***	1.812***	1.816***	1.796***
Potato/Vegetable	4.290**	4.357**	4.363**	4.971***
Hay	1.604***	1.694***	1.675***	1.574***
Pasture	-0.180	-0.051	-	-
Drainage Rank	0.261***	0.214**	0.216**	-
Depth Below WT	-0.001	-	-	-
Intercept	-0.096	0.141	0.126	1.193***
Degrees of freedom	662	746	747	748
R-squared	0.189	0.176	0.176	0.164
p-value	<2.2e-16	<2.2e-16	<2.2e-16	<2.2e-16

***Significant at the $p < 0.001$ level
** Significant at the $p < 0.01$ level
* Significant at the $p < 0.1$ level
(-) Explanatory variable not included in the model

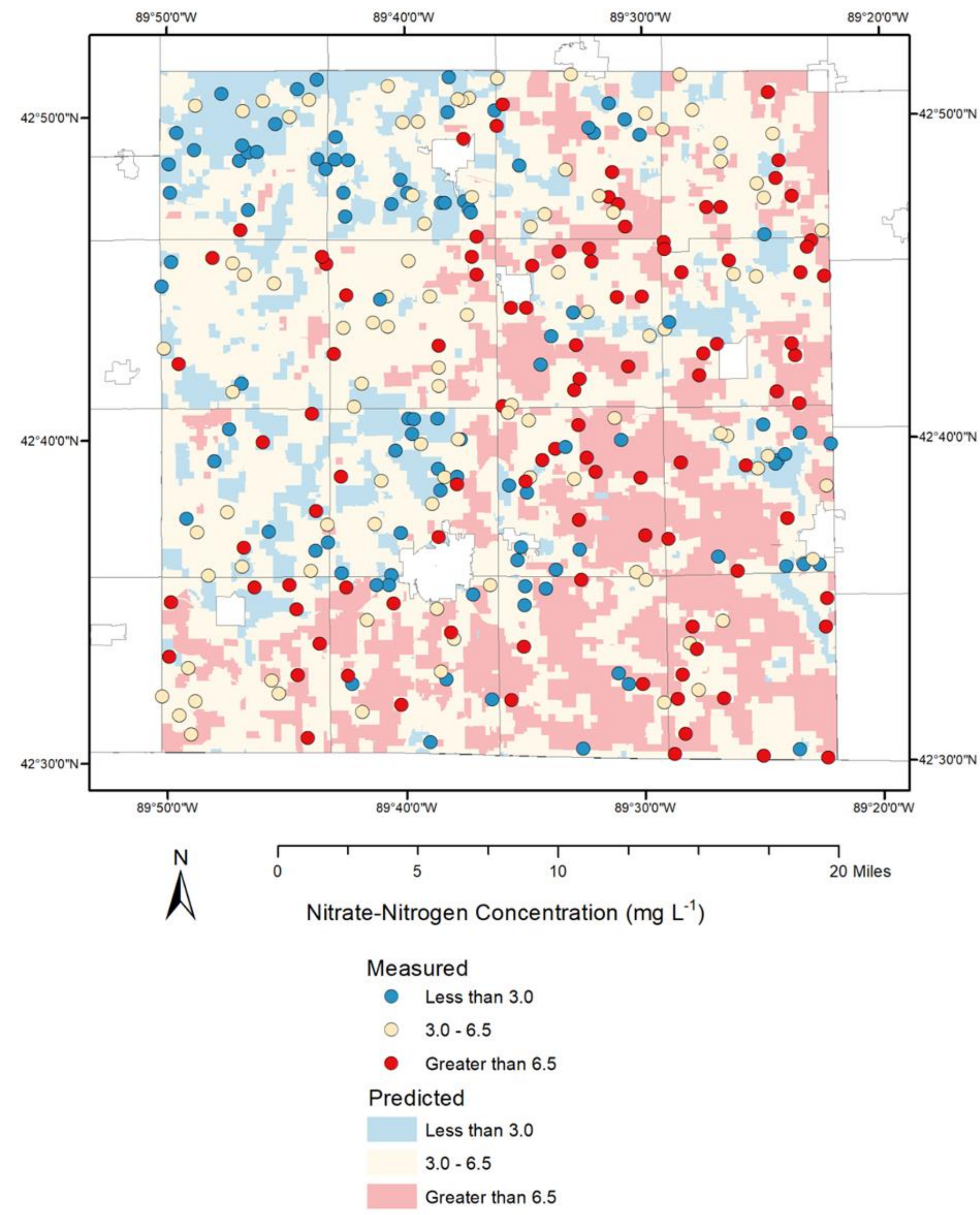
Well water nitrate-nitrogen concentrations increased as the percentage of agricultural land cover near the well increased. Agricultural activity is a major source of nitrate to water resources (Dinnes *et al.*, 2002; Shrestha *et al.*, 2023) and results presented in this study confirm that private well water quality is influenced by this relationship. The MLR analysis quantified the influence of individual agricultural land cover types on nitrate-nitrogen concentrations. Potato/vegetable had more than twice the influence on well water nitrate than the next most influential explanatory variable. Dairy rotation was second followed by hay, continuous corn, and finally cash grain. These findings are similar to other research highlighting the role that cropping systems have on nitrate leaching losses (Randall *et al.*, 1997; Heineman and Kucharik, 2022; Shrestha *et al.*, 2023).

In addition to crop type, soil properties influence water drainage and conveyance of contaminants like nitrate to groundwater. Better drained soils are more prone to nitrate losses than areas of finer textured materials and higher organic matter content (Meisinger and Randall, 1991; Tesoriero *et al.*, 2017; Shrestha *et al.*, 2023). The positive coefficient of weighted drainage rank observed in the best fitting MLR model suggests increasing nitrate-nitrogen concentrations as the soil drainage category around a well becomes more well drained.

Land cover variables (Appendix A) and soil drainage (Appendix B) were obtained for each parcel using a 500 meter buffer around the parcel centroid. These data allowed the best fitting MLR model to be applied countywide and to predict nitrate-nitrogen concentrations for each parcel in Green County.

Nitrate-nitrogen categories of low (< 3 mg L^{-1}), moderate (3 – 6.5 mg L^{-1}), or high (> 6.5 mg L^{-1}) were used to represent data mapped by parcel (Figure 24).

Figure 31. Nitrate-nitrogen concentrations for wells sampled as part of the Green County well water testing efforts. The shaded portions of the map represent the predicted nitrate-nitrogen concentration for each parcel in Green County.



Good agreement was generally observed between the lowest observed/predicted category and the highest observed/predicted categories (Figure 31). Portions of the county where the model predicted moderate impacts were more likely to contain well water quality results that did not match the actual data. Discrepancies between actual and predicted nitrate-nitrogen concentrations are attributed to lack of site-specific information on actual agricultural management; the current model relies on the Wiscland 2.0 datalayer which treats all similar land cover types the same even though management on similar categories can be highly variable. Actual fertilizer rates and crop yields of individual fields are known to influence nitrate leaching to groundwater. While including that information in the model would likely improve performance, this information is not readily available at a county wide scale. Well and casing depth are also important factors. However, wells are often constructed with similar dimensions/depths depending on the local geology and topography; as a result being able to obtain observations of water quality differences as a function of depth is difficult when relying solely on rural residential wells.

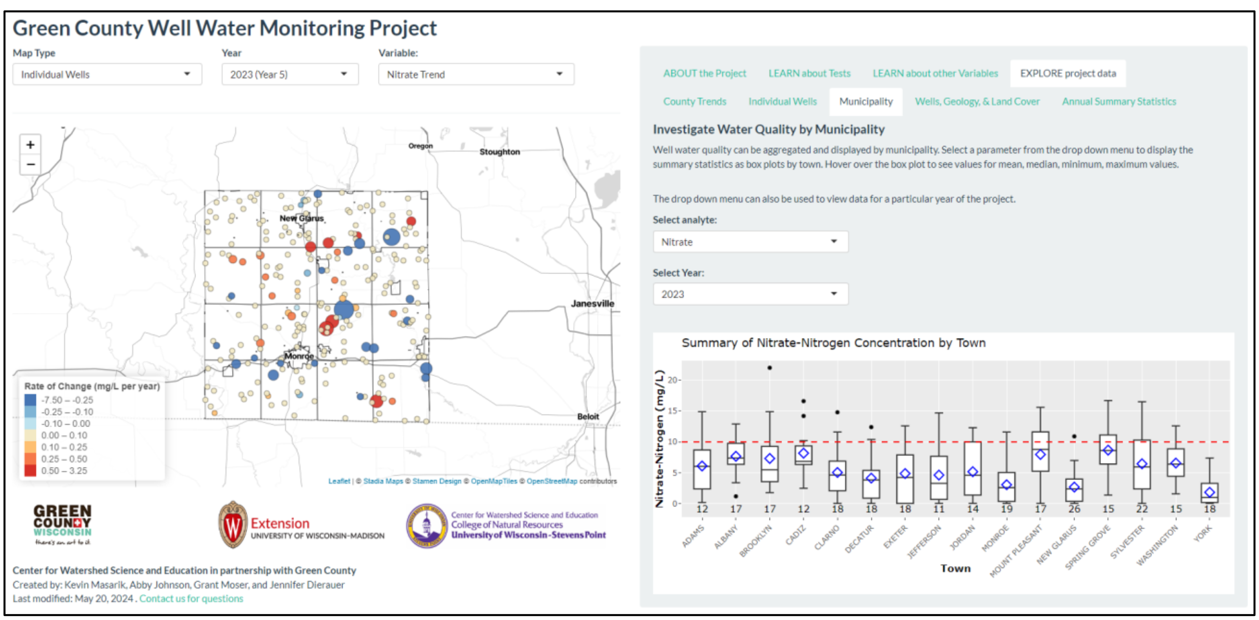
Project Dashboard

An interactive dashboard has been developed to communicate project results. The dashboard provides interactive data visualization of project results and will contain the most up to date information. As additional years of data are collected the dashboard will evolve over time and provide an annual assessment of changes in groundwater quality.

Features or examples of the information able to be viewed:

- Maps of each analyte for individual wells for each year
- Maps of analytes with respect to important well variables; such as geology, land cover within 500 meter buffer of well, soil drainage classification, well casing depth, etc.
- Maps of each analyte by Town for each year
- Observe changes in analyte concentrations for individual wells
- View summary statistics by municipality
- County-wide summary of all analytes for each year
- Maps showing wells detecting trends for nitrate and chloride

Figure 32. Screen capture of the Green County Well Water Monitoring Project dashboard.



The dashboard (Figure 32) is an evolving resource, meaning that additional wells can be added over time. With the framework in place, we are exploring ways for Green County residents to voluntarily participate in building this resource and database.

The database and dashboard can be explored by visiting the following website:

- http://68.183.123.75/wisconsinwater/County-Apps/Green/

Conclusions

This study provides an important benchmark of well water quality in Green County and serves as a model for other communities interested in learning about groundwater/well water quality variability and trends over time. Data shows that Green County well water quality is generally good, however there are areas for potential improvement.

Nitrate and chloride show evidence of human activity influencing groundwater quality throughout much of the county. Trends were revealed for both nitrate and chloride in roughly one in five wells; with about equal percentages suggesting increasing and decreasing concentrations of each parameter. Most wells did not contain evidence of trends, which could mean that groundwater is in equilibrium with current landscape practices or changes are occurring more slowly than can be observed over a five-year period. Trends observed in individual wells could not be explained with generalized data sets. Additional years of data will help confirm whether these changes in water quality are short-term or long-term trends. Meanwhile detailed data (i.e., nitrogen fertilizer rates, yield measurements, manure applications, etc.) could be beneficial in interpreting trends, but this type of detailed data is not readily available, particularly at regional scales.

The nitrate predictive model and dashboard provide important tools for outreach and management of groundwater quality in Green County. Understanding nitrate risk 1) is valuable for educating rural landowners about the importance of annual testing and 2) important for prioritizing conservation practices and placement of management strategies for agricultural landowners and rural subdivisions.

Private well owners are willing and capable partners for characterization and monitoring of regional well water quality. Well owners have a responsibility when it comes to maintaining the integrity of their well water system, which includes routine testing to determine its safety. Valuable information can be learned about well water quality regionally if a subset of wells is monitored and the data is collected in a systematic way. The dashboard provides an ongoing assessment of well water quality that is capable of evolving over time to include additional participants. Opening up the resource to voluntary participation would allow for an even more detailed look at well water quality changes over time.

This work reinforces other studies showing that groundwater is influenced by what happens locally and that groundwater nitrate-nitrogen concentrations are heavily influenced by local land-use activities and physical attributes of the landscape and geology such as soil drainage. Local governments or state agencies do not need to be responsible for testing every single private well, but this work shows the value of routine monitoring and serves as a model for other communities looking to understand temporal changes in well water quality.

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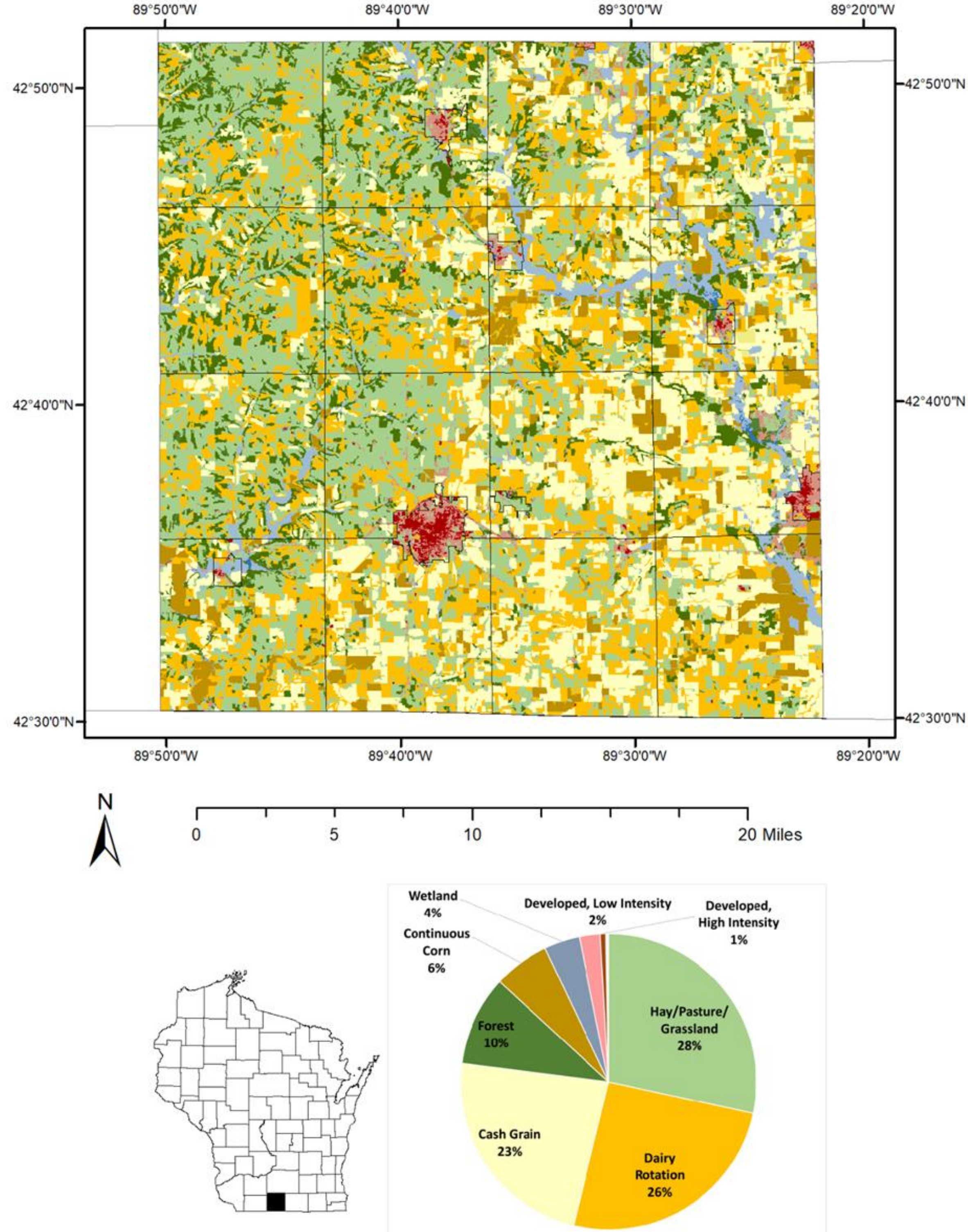
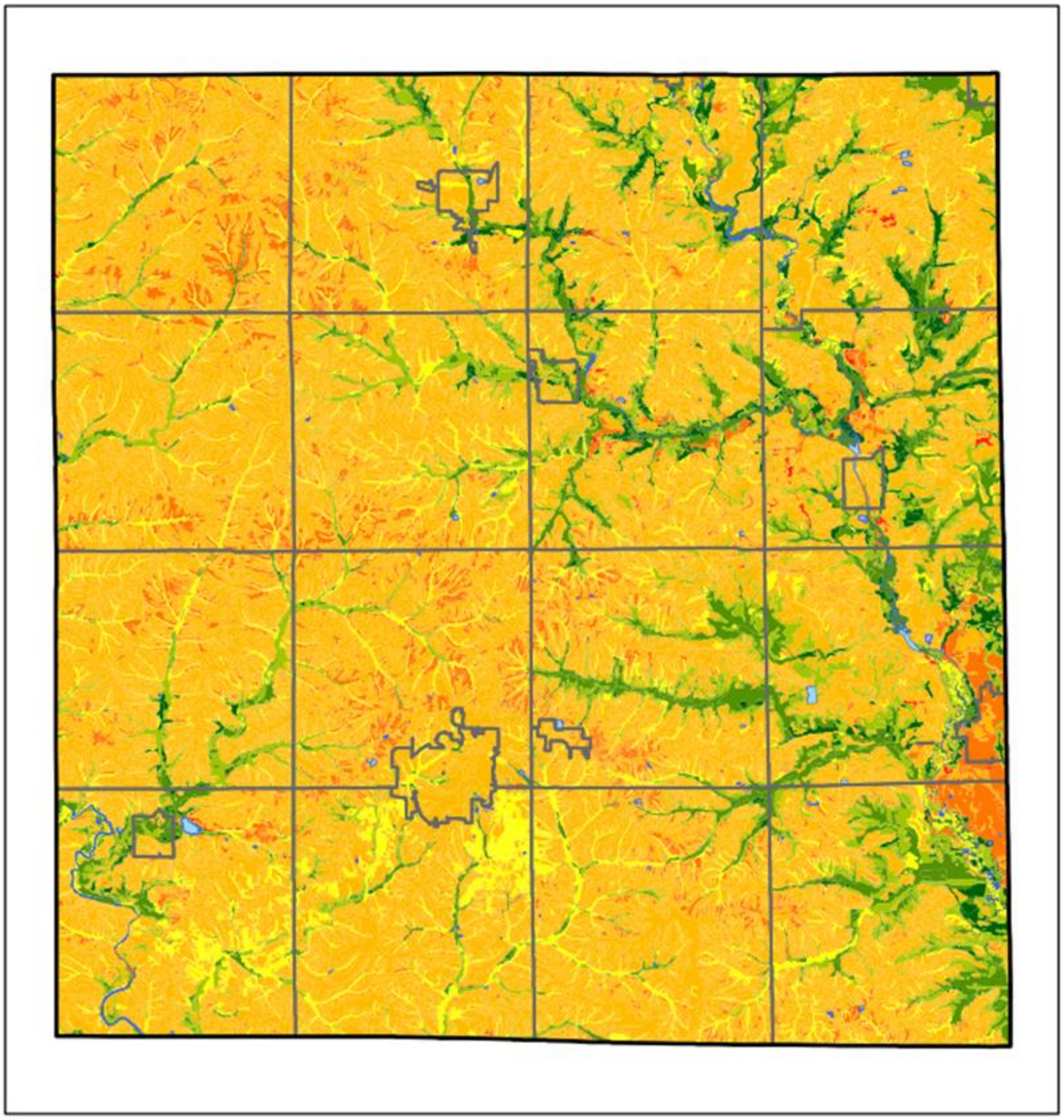
Appendix A. Map of land cover and percentages of each category for Green County.



Appendix B. Soil drainage classification map for Green County



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

Drainage Classification

- Excessively drained
- Somewhat excessively drained
- Well drained
- Moderately well drained
- Somewhat poorly drained
- Poorly drained
- Very poorly drained
- Water