Waupaca Well Water Quality 2017-2018

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This report is a product of the University of Wisconsin – Stevens Point & University of Wisconsin - Extension, Center for Watershed Science and Education. The summary report was completed in partnership with the Waupaca County Land Conservation Department.

We also would like to acknowledge the residents of Waupaca County whose well samples serve as the foundation of this report and the East Central Wisconsin Regional Planning Commission Technical Assistance Program for providing staff support during the well testing.

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EXECUTIVE SUMMARY

Groundwater is the principal water supply for Waupaca 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 what to do if there is a problem. In an effort to effectively target management and public health outreach efforts related to groundwater and private well owners, Waupaca County undertook steps to investigate well water quality across the county.

In the summers of 2017-2018, Waupaca County collaborated with the UW-Stevens Point (UWSP) Center for Watershed Science to analyze samples from private wells for nitrate-nitrogen, chloride, pH, alkalinity, total hardness, conductivity, and coliform bacteria. The Waupaca County Land & Water Conservation Department randomly selected wells from across the county and recruited landowners to participate.

Waupaca County's groundwater can generally be characterized as basic (mean pH = 7.98), moderately hard water (mean total hardness = 286 mg/L as $CaCO_3$), and as having moderate alkalinity (mean = 255 mg/L as $CaCO_3$). Overall, the water on average is well balanced and aesthetically pleasing. The aesthetic characteristics vary only slightly, with water in the northeastern part of the county reporting slightly higher pH, alkalinity, and total hardness values.

Coliform bacteria is not considered harmful to health but is used to evaluate the sanitary integrity of the well water system. Twenty-two percent of samples detected the presence of coliform bacteria and one percent of samples detected E.coli bacteria. The presence of E.coli bacteria suggests human and/or animal waste is contaminating the water supply.

Nitrate is a common health-related contaminant found in Waupaca County's groundwater (mean = 3.6 mg/L nitrate-nitrogen). Eleven percent of wells tested greater than the 10 mg/L drinking water standard. Approximately 51% of wells tested measured greater than 1 mg/L, which provides evidence that land-use activities are impacting water quality in just over half of wells tested.

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. The mean in Waupaca County was 19.2 mg/L. Elevated levels of chloride concentrations are often related to agricultural activities and development density (i.e. roads and septic systems).

This study provides an important assessment of well water quality in Waupaca County. These results highlight the main factors affecting well water quality and build on previous investigations on water quality. These results serve as an important benchmark for tracking how or if groundwater is changing over time in Waupaca County.

Lastly, it is important to acknowledge the many Waupaca County residents that agreed to have their wells sampled. Without their participation, this information would not have been possible.

Introduction to Waupaca County Groundwater

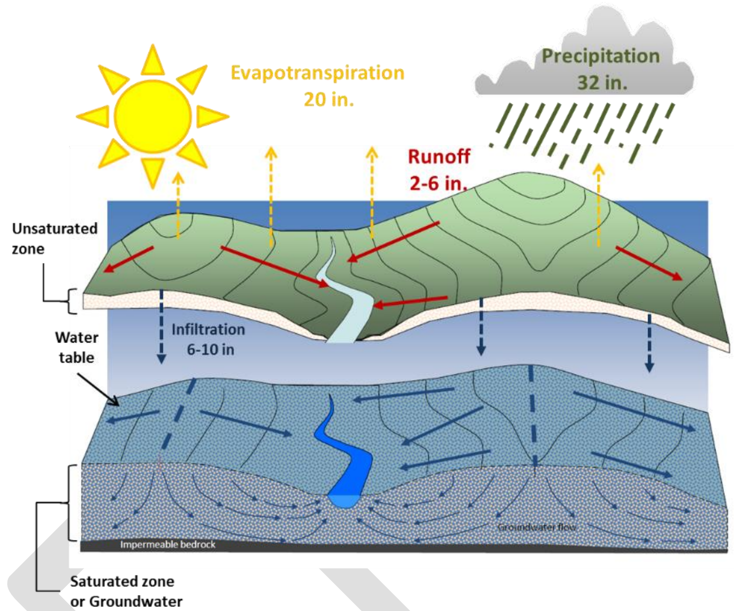


Figure 1. Relative contribution of various components of the water cycle as they relate to Waupaca County. The unsaturated zone is separated from the groundwater to illustrate the water table elevation. Changes in water table elevation are used to infer groundwater flow direction.

Wisconsin receives on average about 32 inches of precipitation annually. Almost two-thirds (roughly 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 inches 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 inches of water actually reaches Waupaca County lakes and rivers as runoff.

The remaining 10 inches of annual precipitation is a good estimate of what actually infiltrates past the root zone of plants and ultimately becomes groundwater. 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 when the empty spaces within aquifer materials 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. Those maps indicate that the water table is not flat; it is oftentimes a more muted version of the actual land surface. From a map of groundwater elevation, groundwater flow direction can be determined.

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

Aquifers and groundwater-surface water interactions

The geologic layers that hold and transmit groundwater, referred to as aquifers, sit like a lopsided layered cake below Waupaca County. The county has three main aquifers: the sand and gravel aquifer, sandstone aquifer, and the crystalline bedrock aquifer. The sand and gravel aquifer is the primary aquifer for Waupaca County residents and industries.

The lowermost geologic unit found in Waupaca County is the crystalline bedrock, which is made up of igneous and metamorphic rocks that are billions of years old. These granite and granite-like rocks slope south. In the northwest corner of Waupaca County, they are near the land surface, but in southeastern Waupaca County, they buried hundreds of feet beneath other layers of geologic materials.

Groundwater scientists have shown that there is very little groundwater in the crystalline bedrock layer; it is generally a poor aquifer. Limited amounts of water can be found where the granite material has been weathered at the top, or where cracks and fractures can be found that connect to the layers above it. Most of Waupaca County's groundwater is contained in the geologic layer(s) that sit on top of the crystalline bedrock.

Sandstone is another aquifer material found in portions of Waupaca County. This geologic layer formed when an ancient ocean covered Wisconsin. Sand deposited on the ocean floor was naturally cemented together over time to form sandstone – a type of sedimentary rock.

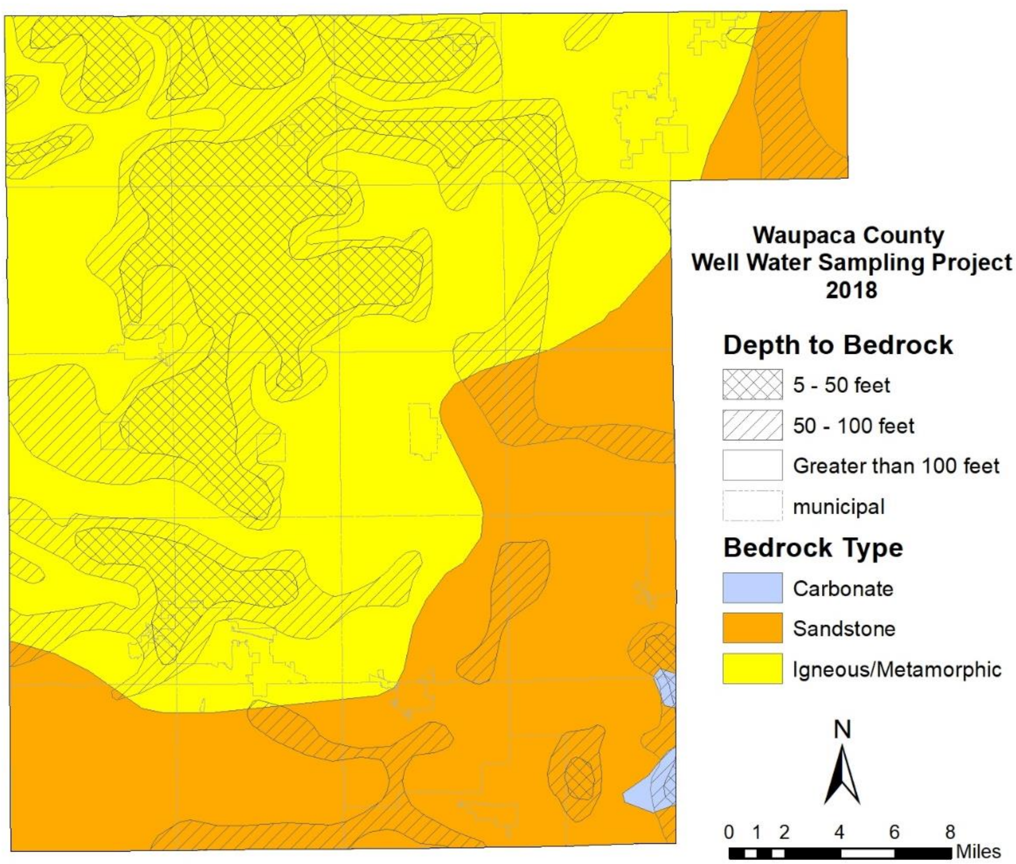


Figure 2. The amount of unconsolidated material that exists above bedrock is denoted by depth to bedrock (shading). The first bedrock unit encountered below the unconsolidated material is indicated by bedrock type (color). Igneous or metamorphic crystalline bedrock also underlies the sandstone aquifer of Waupaca County.

This bedrock layer is very thin where it first appears in the county, and gradually gets thicker as you move south.

Unlike very dense, mostly solid crystalline bedrock, sandstone bedrock has empty spaces between the cemented sand grains that make up sandstone. Because these spaces are interconnected, groundwater can enter and move with relative ease – making sandstone a very productive aquifer.

The uppermost geologic layer consists of sand, silt, clay, gravel, cobbles, and even boulders. Since the particles in this material are not cemented together, geologists refer to these materials as unconsolidated deposits. These deposits cover the two bedrock layers found in Waupaca County and can be greater than 100 feet thick in the eastern and southern portions of the county. The depth to bedrock map (Figure 2) provides insight into how the thickness of the unconsolidated deposits vary in the county.

The unconsolidated materials, and the current land formations in Central Wisconsin, are the result of glaciers that once advanced into Waupaca County. The glaciers, sheets of ice a mile or more thick, advanced into the county from the east. The large boulders, cobbles, and variety of rocks that remain are a reminder of past glacial advances into the region. The farthest advance of these glaciers was just west of Waupaca County in nearby Portage County.

These unconsolidated materials left behind by the glaciers make up the sand and gravel aquifer. The sand and gravel aquifer is the principal source of groundwater for Waupaca County. The spaces between the particles of sand and gravel are well connected and allow for abundant water storage and easy movement of groundwater through the aquifer. Hydrogeologists estimate that water in this aquifer moves horizontally about 1 to 2 feet per day.

Wells

All of Waupaca County's 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 municipalities rely on municipal water systems, which often consist of multiple high capacity wells that provide water for whole cities or villages. High capacity wells are also used to irrigate fields for growing crops or may be used by other industries and activities in Waupaca County.

A water well is basically 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 people located close to a lake, river, or stream. However, for those located on the top of a hill, the groundwater is often located much deeper. A well in this situation will have to be drilled deeper if the well is to be successful at accessing water.

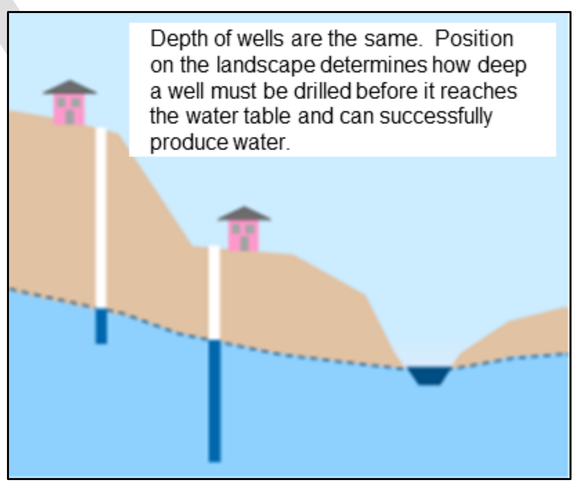


Figure 3. Wells must extend past the water table in order to access water. Wells on ridges or hilltops will often times have to drill much deeper to hit the water table than a well located lower on the landscape like areas next to rivers, lakes or streams.

While the well 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 contained in the spaces in adjacent rock or sand/gravel material replaces the water that was removed from the well. While people might like to think of groundwater as being very old, the truth is most water supplied to wells in Waupaca 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 don't use enough water to create a cone of depression or lowering of the water table. 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 lowering of the water table around the well. We can think of private wells 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 the top of the water table (Figure 7b) and may be greater and more difficult to determine for those wells cased deeper into the aquifer (Figure 7a).

Municipal systems are required to regularly test their water and have an obligation to ensure it meets government standards. In rural areas, meanwhile, 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 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. (Additionally, updates to the state well code now require new wells to be tested for nitrate.) Each owner must decide whether — and how — to verify their well continues to produce quality water.

The objective of the Waupaca County Well Water study was to provide a current assessment of Waupaca County well water quality. Information gained from testing of wells will be used to target outreach efforts, guide future management decisions or testing and provide a baseline of water quality that can be used to understand whether groundwater quality is changing over time.

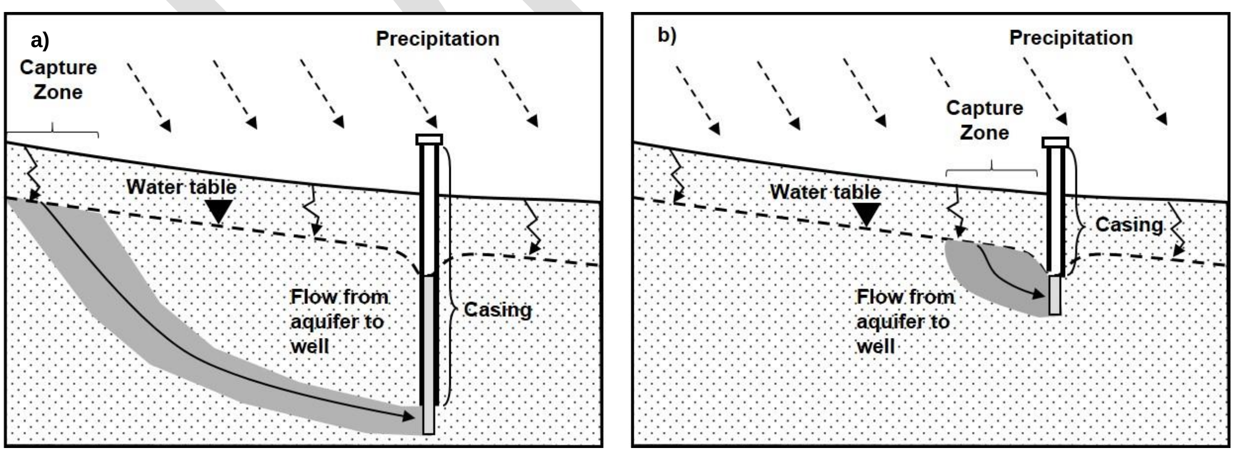


Figure 4. Diagrams illustrating how the well and casing depth influence the capture zone of a well. Wells in which the casing extends below the water table will tend to have capture zones that are located further away from the well (a) than one in which the casing does not extend as far or may not extent past the water table (b).

Well Selection, Recruitment and Water Quality Analysis

A grid sampling approach was used to ensure samples were spatially distributed across the county. A grid consisting of 1 mile x 1 mile grid cell resulted in 756 grid cells for Waupaca County.

One well per grid cell was randomly selected and recruitment mailings were sent to those landowners. Landowners were instructed to indicate their interest (Yes or No) via phone call, email, or text message. If property owners declined or did not respond, an alternative well in that grid cell was selected and offered the opportunity to participate. In total, wells from 526 grid cells out of the 756 were successfully sampled (70% of grid cells). However, a total of 619 well samples were analyzed due to multiple samples taken in several of the grid cells (areas where landowners contacted us after their recruitment deadline)."

Landowners that agreed to participate were contacted with instructions on where and when to pick up sample bottles. Participants were instructed to sample from a faucet that was untreated, run for 10 minutes prior to sample collection. Samples were collected in an unacidified, 125 mL HDPE bottle. Participants returned samples to collection location. Following collection, samples were placed in a cooler with ice and transported back to the laboratory by county or ECWRPC staff. Samples were stored in a refrigerator at 4 degrees Celsius until time of analysis.

All tests were performed at the Water and Environmental Analysis Lab which, is state-certified to perform analyses of interest. A Lachat 8000 flow injection analyzer was used to test for nitrate (Lachat Method 10-107-04-1-A) and chloride (Lachat Method 10-107-07-1-B). Analysis for pH and conductivity was performed using a Thermo Scientific Orion Versa Star Advanced Electrochemistry meter. Alkalinity and total hardness analyses were performed by titration. Coliform bacteria were analyzed for using the Idexx Colilert Presence/Absence Method. Samples that contained coliform bacteria were also checked for the presence of E. coli bacteria.

Well Water Chemistry Results and Interpretation

Bacteria results are reported as number and percentage of wells that detected coliform and E.coli bacteria (Table 1). For all other analytes, mean (average), median, minimum and maximum values are reported for Waupaca County (Table 2) and by municipality (Appendix A) for each of the tests performed. Maps were generated for pH, conductivity, alkalinity, total hardness, nitrate-nitrogen, and chloride showing results by grid cell and mean values by municipality.

Table 1. Summary of Waupaca County bacteria test results

Bacteria Type	Number detects/Total Sampled	Percent Present
Coliform	139/619	22%
E.coli	7/619	1%

Table 2. Summary of Waupaca County well water quality test results.

	pH Standard units	**Conductivity** µmhos/cm	**Alkalinity** mg/L as $CaCO_3$	**Total Hardness**† mg/L as $CaCO_3$	**Nitrate-Nitrogen** mg/L	**Chloride** mg/L
	n = 617	n = 615	n = 617	n = 592	n = 618	n = 618
Mean	7.98	562	255	286	3.6	19.2
Median	7.98	529	251	283	0.9	7.6
Min	7.24	151	54	32	<0.1	0.6
Max	8.79	1868	522	831	35.3	352

† Softened samples excluded from summary stats for total hardness.

Coliform Bacteria

Coliform bacteria are a microorganism found in surface water and soil. While most coliform bacteria are harmless, a sanitary well ideally should <u>not</u> contain any bacteria. The presence/absence of coliform bacteria is used as an indicator of the sanitary condition of your well. It is the most important test to perform on a well.

While coliform bacteria do not usually cause disease, their presence in a water sample indicates a potential pathway for other disease causing organisms to enter your well. If human or animal wastes are contaminating the water, gastrointestinal diseases, hepatitis, or other diseases may result.

If coliform bacteria were detected in a sample that sample was also checked for E.coli, a type of fecal coliform. The presence of E. coli in a water sample is more conclusive evidence of fecal contamination which represents a more significant health risk than the presence of coliform bacteria on its own.

The coliform bacteria test performed for this work was a presence/absence method, meaning that the quantity of bacteria was not determined. So instead of reporting a mean or average concentration, coliform bacteria is reported as the percent of samples that detected bacteria.

Test results showed 22% (139/619) of wells detected the presence of coliform bacteria. If coliform bacteria are present in a water sample resampling is generally recommended. Resampling is important to confirm that it is a persistent bacteria problem and not a temporary occurrence or sample error.

Bacteria problems in water systems can often be related to the well construction. If repeated samples show evidence of coliform bacteria it is important to investigate whether defects with the well may be allowing a pathway for bacteria into the well water system. Some common examples to look for include:

- Well cap is loose or missing (well cap should be a vermin proof cap).
- Casing is cracked or rusted through, or casing does not extend 12 inches above grade.
- Inadequate grout (seal or fill around well casing).

While coliform bacteria is not capable of determining a source of the bacteria, E.coli bacteria does provide likely evidence that human or animal waste is contaminating the well water system. One percent (7/619) of samples showed evidence of E.coli bacteria.

The presence of E.coli represents an immediate health concern. Wells that detect E.coli bacteria should not be used for drinking and/or cooking until the source of the bacteria can be identified and actions taken to ensure the well is capable of producing bacteria free water.

Additional work would need to be done in order to understand whether E.coli bacteria was associated with human or animal waste. In addition future work investigating the magnitude of bacteria in water systems could be useful for understanding the role of well construction, geology, and seasonal/weather variability on bacteria presence in well water systems.

Nitrate-Nitrogen

Nitrate is a chemical commonly found in agricultural and lawn fertilizer. It is also formed when waste materials such as manure, bio-solids or septic effluent decompose. Nitrate is the mobile form of nitrogen that is generally considered the most widespread groundwater contaminant in Wisconsin.

Landscapes in which nitrogen is added artificially (i.e. forests and grasslands) are generally nitrogen limited, meaning plants take up, or assimilate, all available nitrogen found in the soil. As a result, the natural level of nitrate-nitrogen we would expect to find in Wisconsin's groundwater is less than 1 mg/L. In other areas where nitrogen is applied to crops or landscapes as fertilizer, manure or other bio-solid, plants are generally not able to assimilate all the nitrogen that is added.

Even at nitrogen rates recommended by a nutrient management plan, significant amounts of nitrogen can be lost to groundwater as nitrate from unutilized fertilizer or mineralized nitrate from the breakdown of residue or soil organic matter. Areas with well drained soils are particularly prone to nitrate leaching losses to groundwater because of the ease with which water can move past the root zone of plants.

Septic systems also represent a source of nitrate to groundwater. These systems are designed to settle out solids and allow for deactivation of some pathogens in the wastewater. These systems do not effectively remove nitrate, chloride and a host of other dissolved constituents from wastewater.

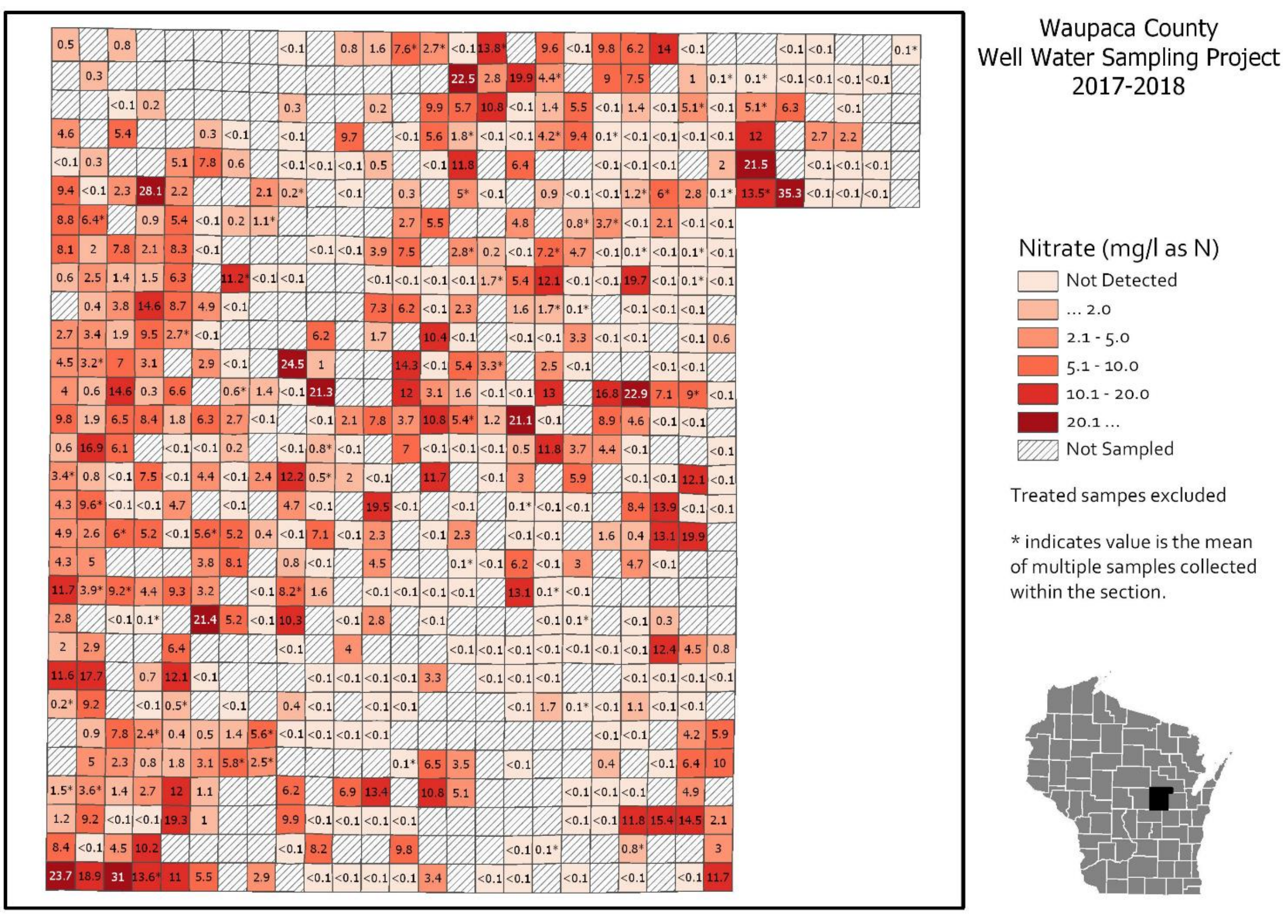


Figure 5. Nitrate-nitrogen concentration by grid cell.

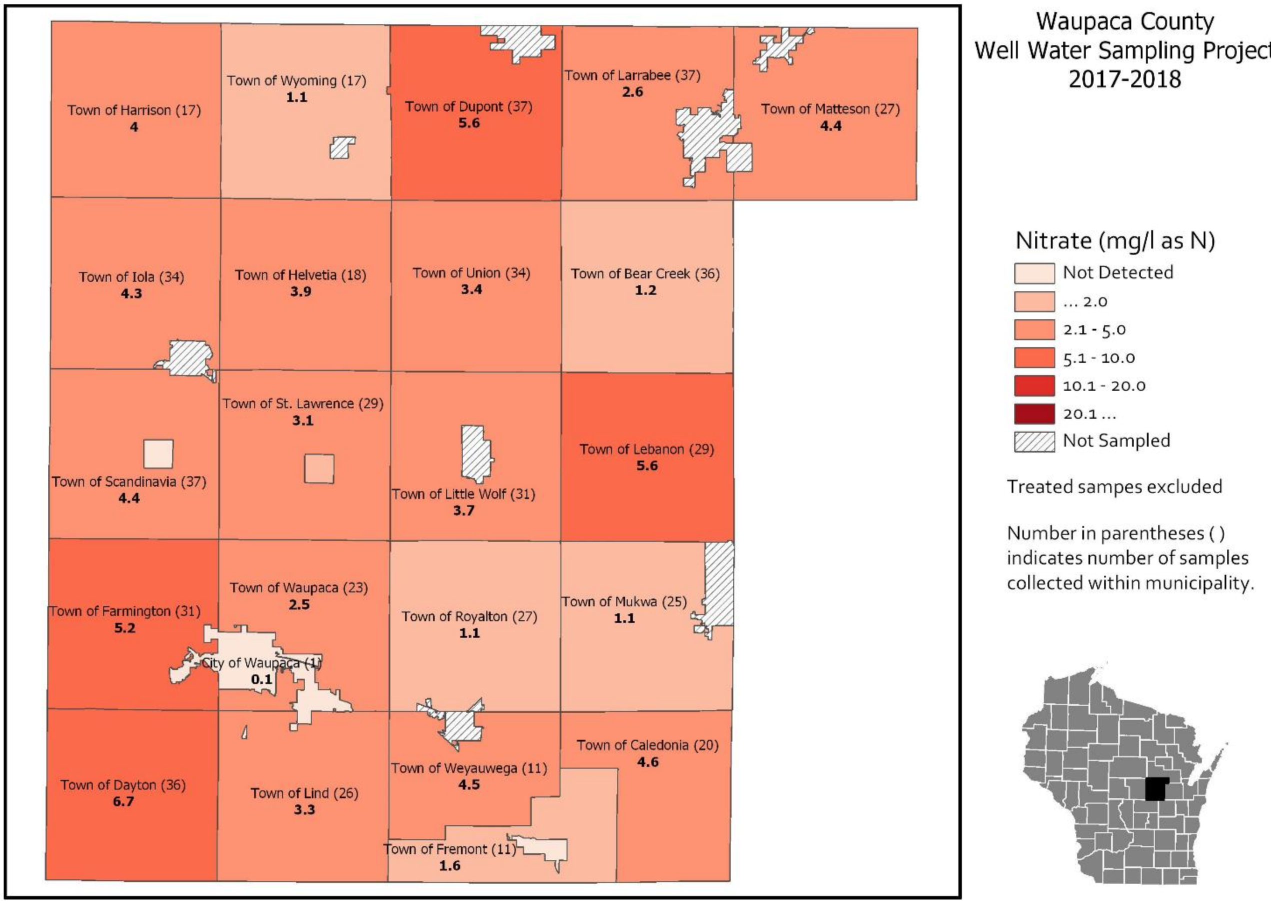
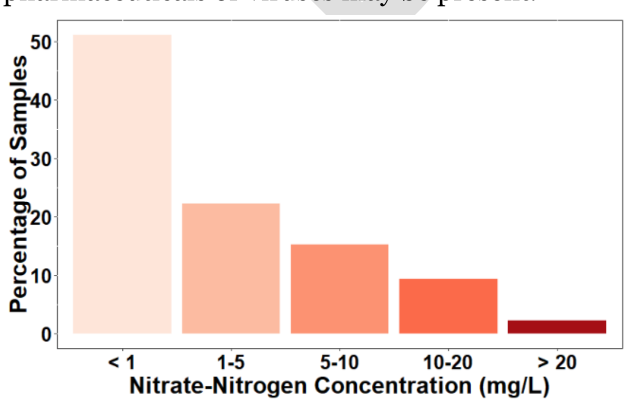


Figure 6. Mean nitrate-nitrogen concentration by municipality.

Concentrations of nitrate above 1 mg/L indicate impacts from nearby land uses; and water may be more likely to contain other contaminants. If the source of nitrate is agricultural activity, then pesticides are more likely. If the source of nitrate is nearby septic system drainfield(s) then wastewater indicators such as personal care products, pharmaceuticals or viruses may be present.



The drinking water standard for nitrate-nitrogen is 10 mg/L. Water with concentrations greater than 10 mg/L of nitrate-nitrogen should not be used by infants, women who are pregnant or trying to become pregnant. The WI Dept. of Health Services recommends that all persons avoid long-term consumption of water with nitrate-nitrogen greater than 10 mg/L as a precaution to prevent potential health effects.

Figure 7. Eleven percent of samples contained greater than the drinking water standard of 10 mg/L for nitrate-nitrogen; meanwhile 51 percent of samples measured background or natural levels.

Reverse osmosis, distillation or anion exchange are effective treatment methods to reduce nitrate levels. Those relying on treatment for health contaminants such as nitrate should periodically submit samples to ensure that the treatment device is reducing levels sufficiently to meet expectations for water quality.

Eleven percent of samples measured nitrate-nitrogen concentrations above the drinking water standard (Figure 8). The rate of nitrate exceedances is slightly more than the statewide estimate of 8.2% (DATCP, 2017). The average concentration in Waupaca County was 3.6 mg/L and the median was 0.8 mg/L. Nitrate concentrations tended to be greater in the western and northeastern portions of the county than in the southeast and northwest (Figure E).

Nitrate data collected for this inventory was compared to data collected in the 1990s in Waupaca County. From 1990 to 1997, Waupaca County conducted voluntary well testing once in each town in Waupaca County. A total of 854 wells were tested through those efforts. The earlier testing resulted in a mean nitrate concentration of 3.1 mg/L (1990-1997) compared to 3.6 mg/L (2017-2018). The differences between sampling periods is not considered significant.

The percent of samples above the 10 mg/L drinking water standard is slightly higher at 11.1% for the 2017-2018 sampling period compared to 8.8% for the period from 1990-1997 however the change is not statistically significant.

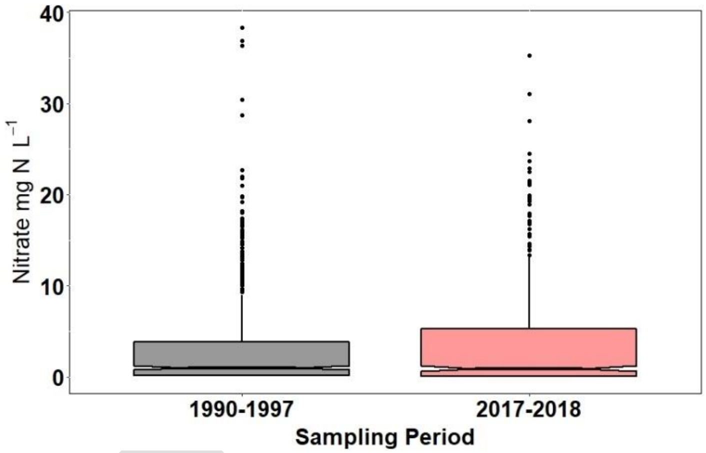


Figure 8. Boxplots of nitrate-nitrogen concentrations for Waupaca sampling efforts during two different time periods. The box represents the interquartile range. The dark horizontal line represents the median concentration. The median is the concentration at which half of the samples are above and the other half of the samples are below that concentration. Because the notches overlap, the data suggests these populations are not significantly different between the two periods.

Chloride

In most areas of Wisconsin, chloride concentrations are naturally low (less than 10 mg/L). Similar to nitrate, chloride is associated with agricultural uses. Chloride is a component of potassium fertilizer and is found in animal waste and other bio-solid amendments.

Potassium fertilizer is commonly applied to agricultural fields; however these amendments often contain significant amounts of chloride as well. Plants and other biological activity have little affinity for chloride, as a result much of it will eventually leach past the root zone into groundwater. Certain crops like potato and alfalfa have higher recommended potassium application rates than do many other crops including corn (Laboski and Peters, 2012). Areas where these crops are grown may be expected to see higher concentrations of chloride in the groundwater.

Septic systems may also represent a source of chloride; chloride is found in human waste and it is added to wastewater when water softeners discharge brine to septic systems. In addition, winter road salting can be a significant contributor to elevated chloride in groundwater. Road salt impacts are expected to be most evident in areas near major roadways or urban areas.

Chloride is not toxic, but some people can detect a salty taste at high levels. Chloride has no health standard, however there is an aesthetic limit. Levels more than 250 mg/L may cause a salty taste or cause corrosion of metal components within the plumbing system. If chloride levels are extremely elevated, there may also be elevated levels of sodium in the water.

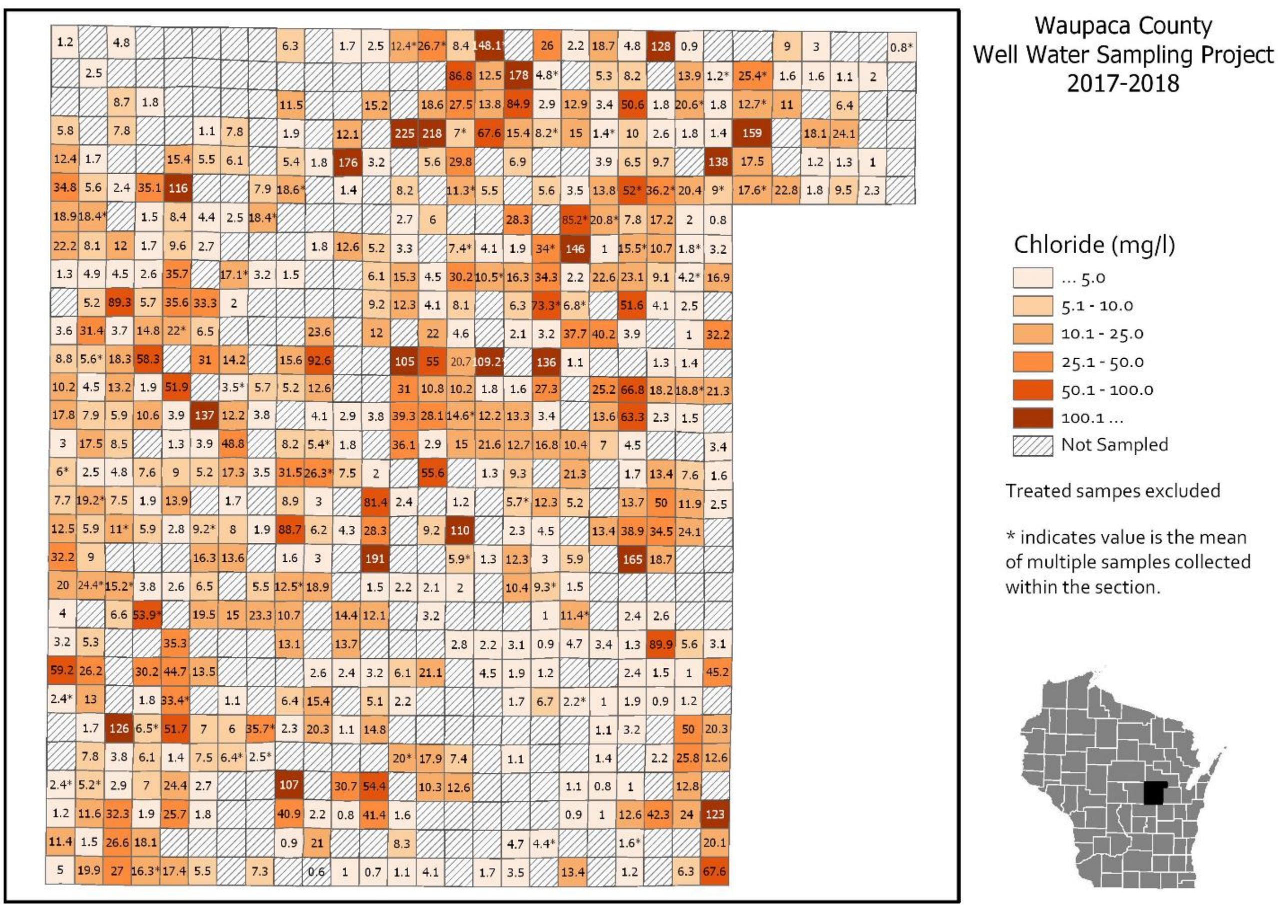
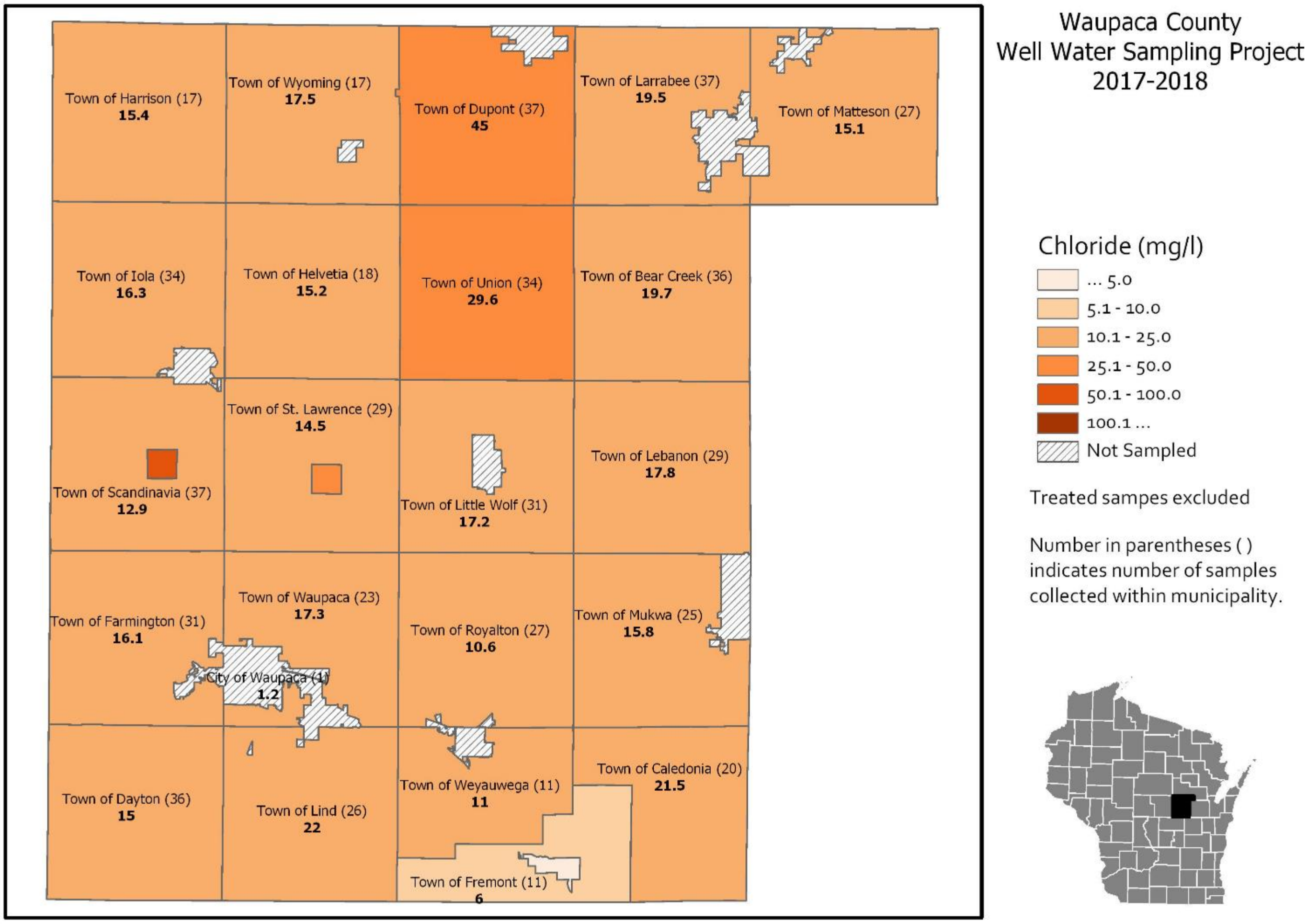


Figure 9. Chloride concentration by grid cell.

Figure 10. Mean chloride concentration by municipality.



The mean chloride concentration for Waupaca County was 19.2 mg/L; higher than what we would typically expect for natural concentrations of chloride in groundwater.

Chloride data collected for this inventory can also be compared to the data from the 1990s. From 1990 to 1997, Waupaca County conducted voluntary well testing once in each town in Waupaca County. A total of 854 wells were tested through those efforts. The earlier testing resulted in a mean chloride concentration of 14.7 mg/L (1990-1997) compared to 19.2 mg/L (2017-2018) for this most recent testing. While the differences are not large, boxplots comparing the datasets do suggest that chloride concentrations have increased slightly over that time period (Figure 11).

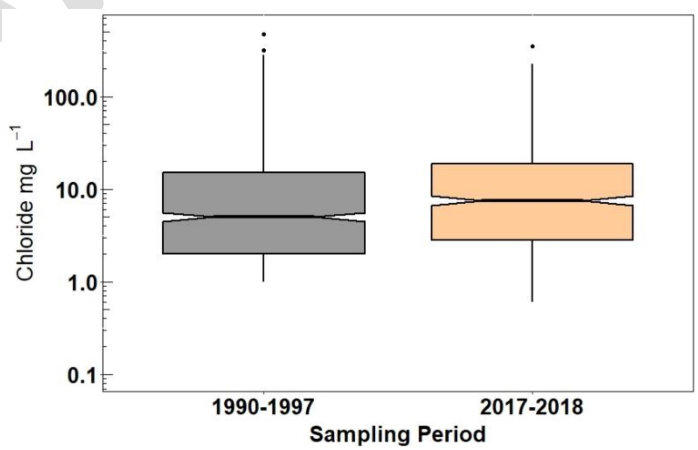


Figure 11. Boxplots of chloride (log scale) for Waupaca sampling efforts during two different time periods. The box represents the interquartile range. The dark horizontal line represents the median. Because the notches do not overlap, the data suggests these populations are significantly different with slightly greater concentrations in the most recent sampling.

Total Hardness

Hardness measures the amount of calcium and magnesium in water. It results primarily from dissolving limestone or dolomite minerals in the aquifer.

Total hardness is mainly an aesthetic concern. Hard water causes scale deposits on fixtures, in pipes or water heaters. Water naturally low in hardness is often referred to as soft and can be corrosive. There are no health concerns related to drinking hard water.

Water between 150 mg/L and 200 mg/L are generally ideal from an aesthetic point of view. Water less than 150 mg/L is considered soft while values greater than 200 mg/L are considered hard.

Water softeners are commonly used to treat against the negative effects of hard water. The greater the total hardness value in well water, the more softener salt needed to soften water.

The average total hardness concentration for Waupaca County was 286 mg/L as $CaCO_3$. Wells in the northeastern part of Waupaca County generally contained harder water than areas to the west and south (Figure 12).

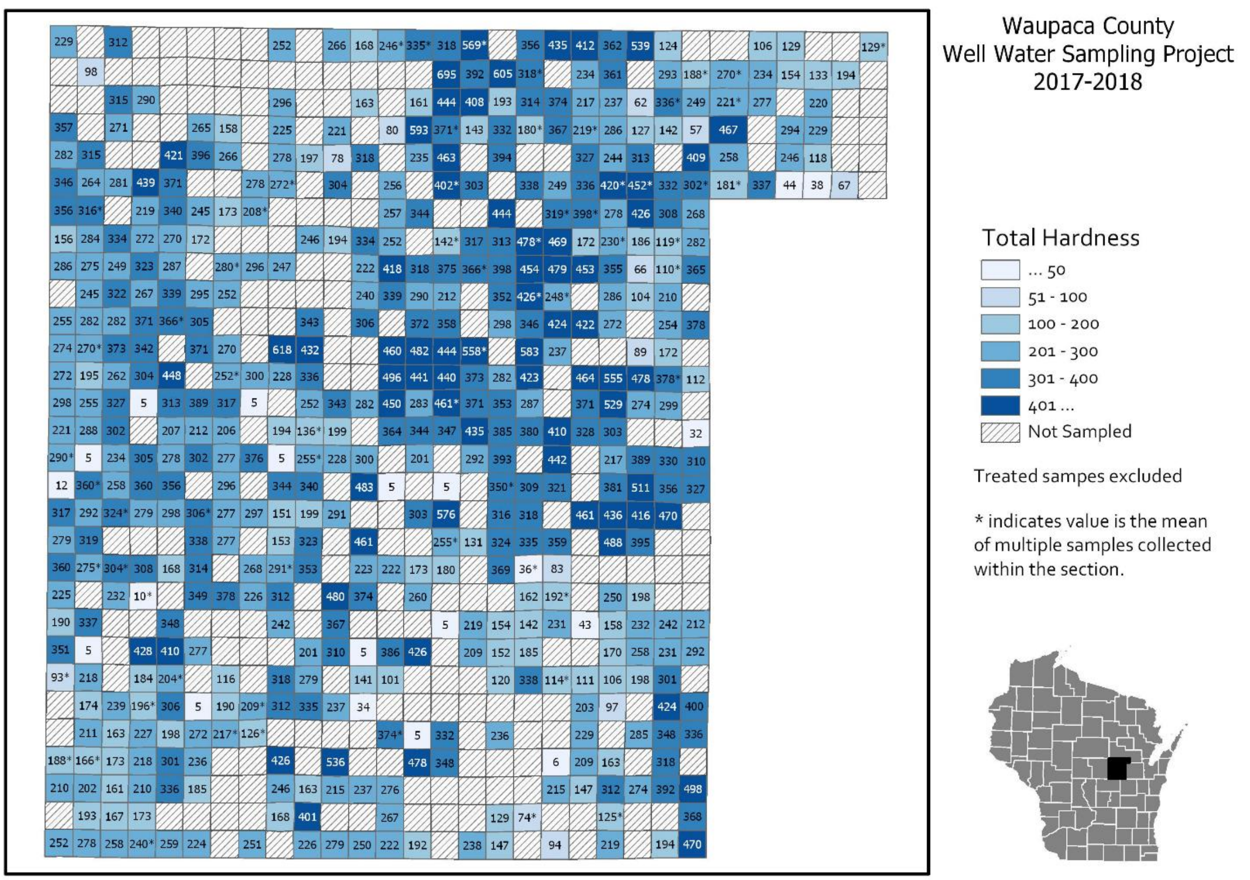


Figure 12. Total hardness concentration by grid cell.

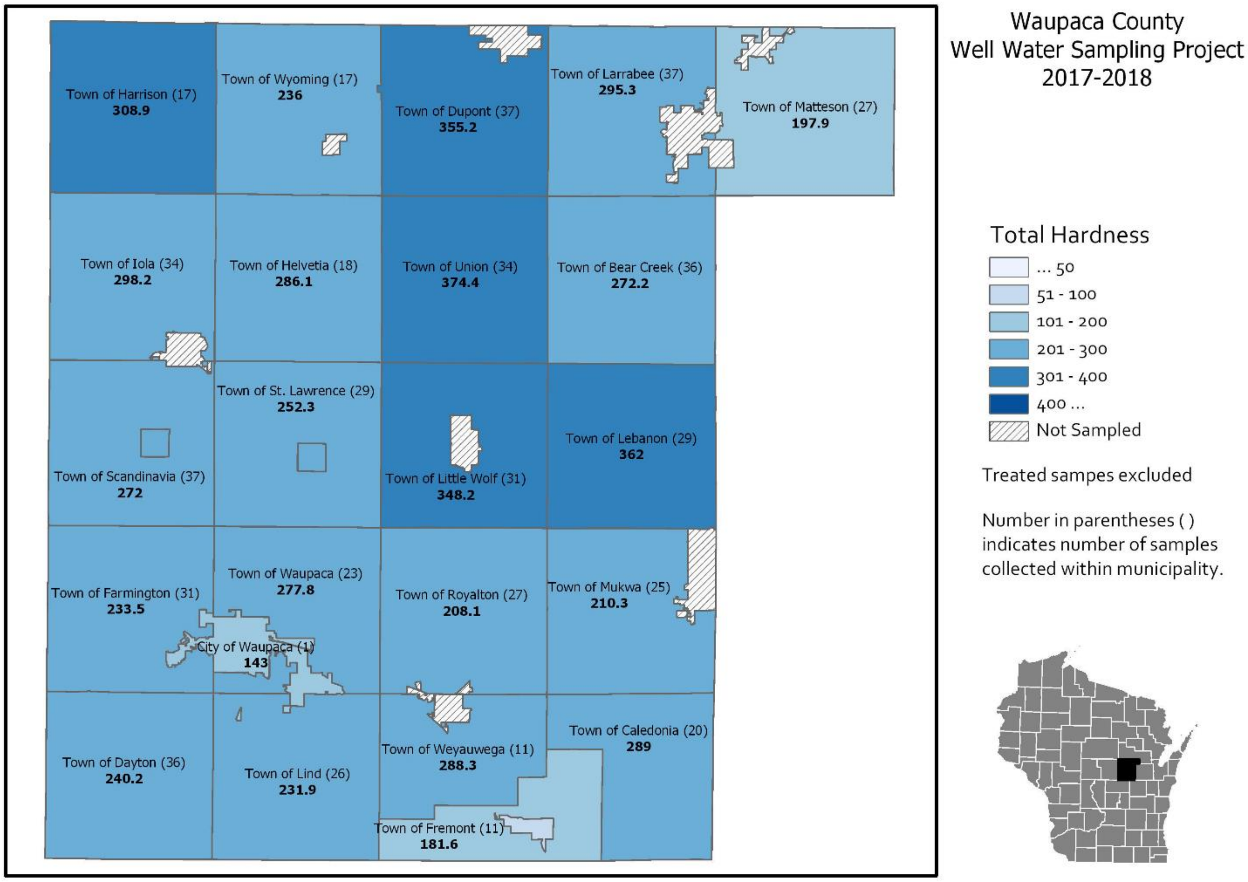


Figure 13. Mean total hardness concentration by municipality.

Alkalinity

Alkalinity measures the water's ability to neutralize acids. It results primarily from dissolving limestone or dolomite minerals in the aquifer. Water with alkalinity less than 150 mg/L is more likely to be corrosive.

Alkalinity results correlate well to total hardness measurements (r = 0.89). Similar to total hardness, northeastern Waupaca County measured higher amounts of alkalinity, with lower values found as you move towards the southwest (Figure 14).

Alkalinity and total hardness should be roughly equal in groundwater because they form from the same minerals. Samples collected in Waupaca County reveal that total hardness was often greater than alkalinity, particularly in samples containing elevated levels of nitrate and chloride (Figure 16). Wells having elevated levels of nitrate and/or chloride show greater total hardness values than may be expected under natural conditions.

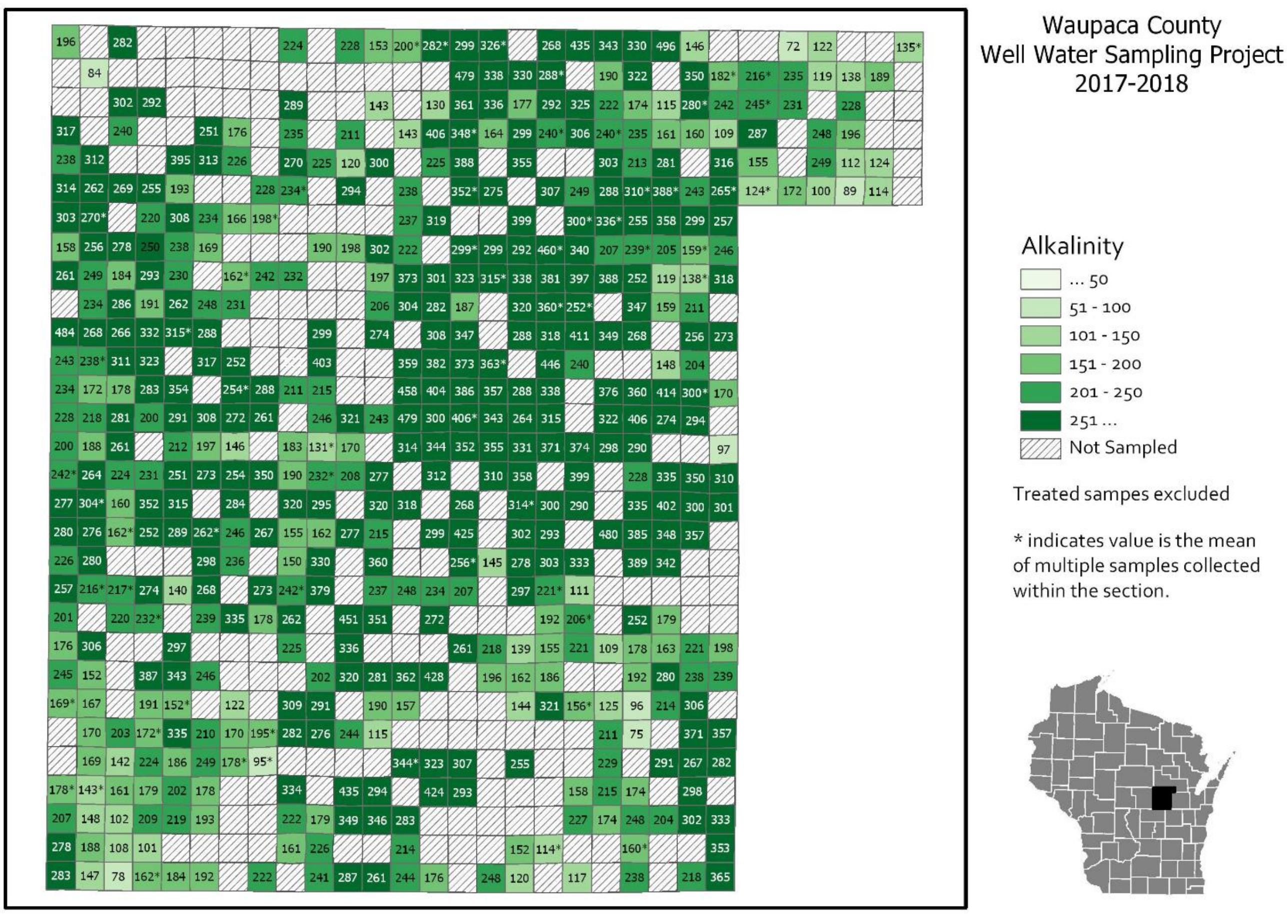


Figure 14. Alkalinity concentration by grid cell.

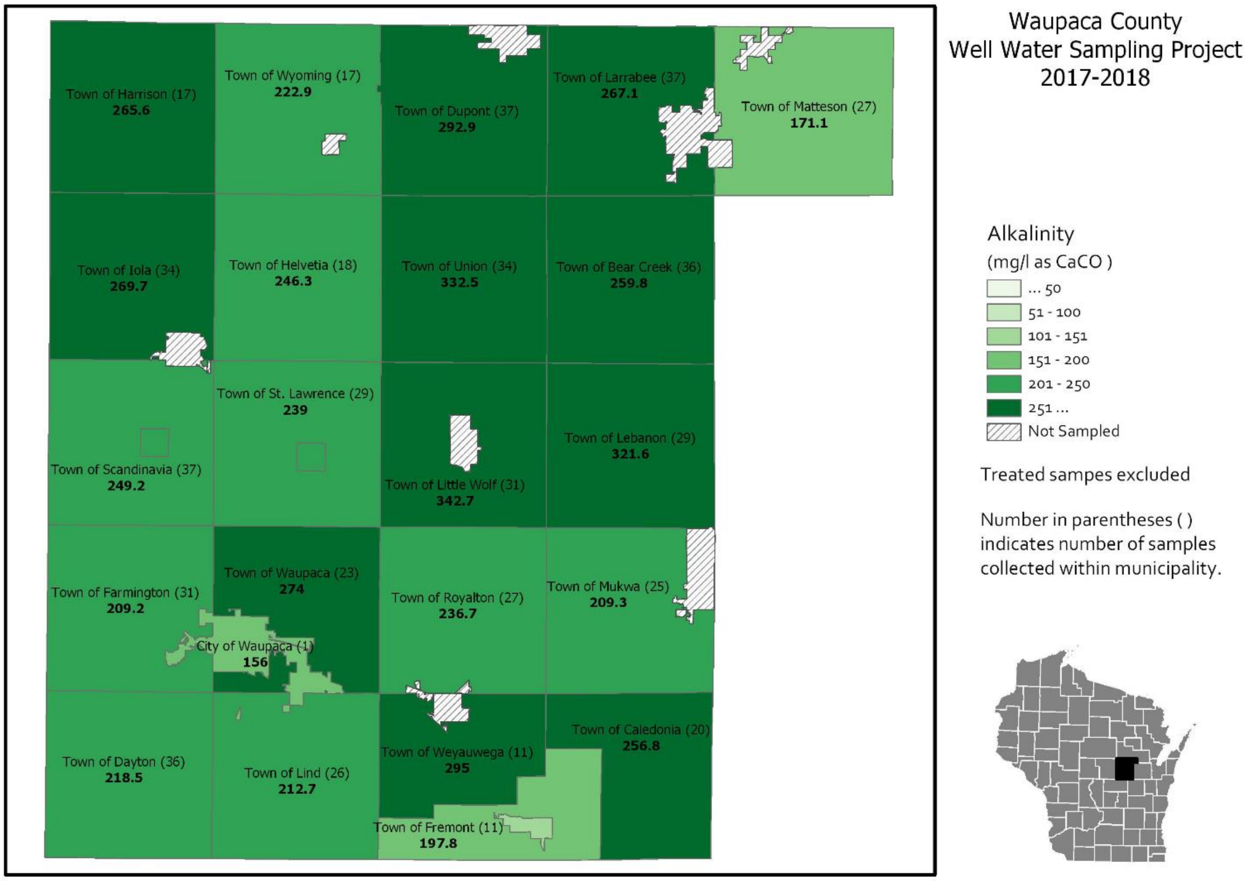


Figure 15. Mean alkalinity concentration by municipality.

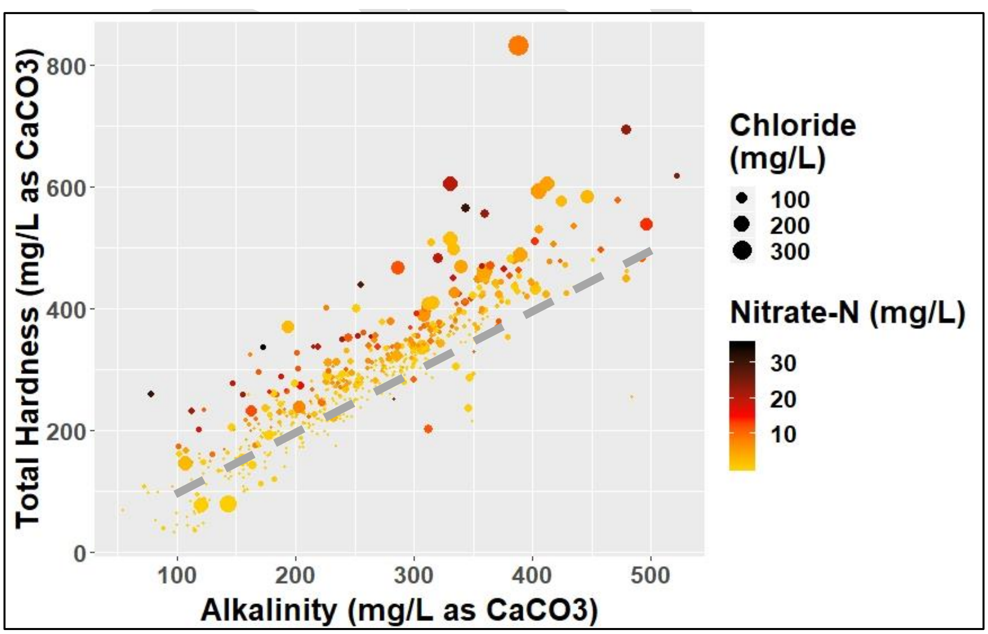


Figure 16. Alkalinity and hardness often occur at roughly equal concentrations (grey dashed line represents 1:1 ratio of alkalinity to hardness). Wells with elevated nitrate and/or chloride generally show greater total hardness values than may be expected under natural conditions.

pH

The pH test is a measure of acidity. The lower the pH, the more corrosive the water. There is no health standard for pH, however corrosion of metal plumbing or fixtures is more likely to occur when pH levels are less than 7.0. Water greater than 7.0 is more likely to result in scaling. Low pH is more likely to result in elevated levels of copper and/or lead if those elements are included in your plumbing system. Acid-neutralizers are a type of treatment installed to counteract the negative effects (i.e. corrosion of plumbing components or blueish-green staining indicative of copper corrosion) that can result from low pH.

Measurements of pH generally occur in a pretty narrow range throughout Waupaca County. The mean pH for Waupaca County well water was 7.98.

In eastern Waupaca County groundwater pH levels were slightly greater than 8.0 whereas pH levels in western portions of the county were slightly less than 8.0 (Figure 17).

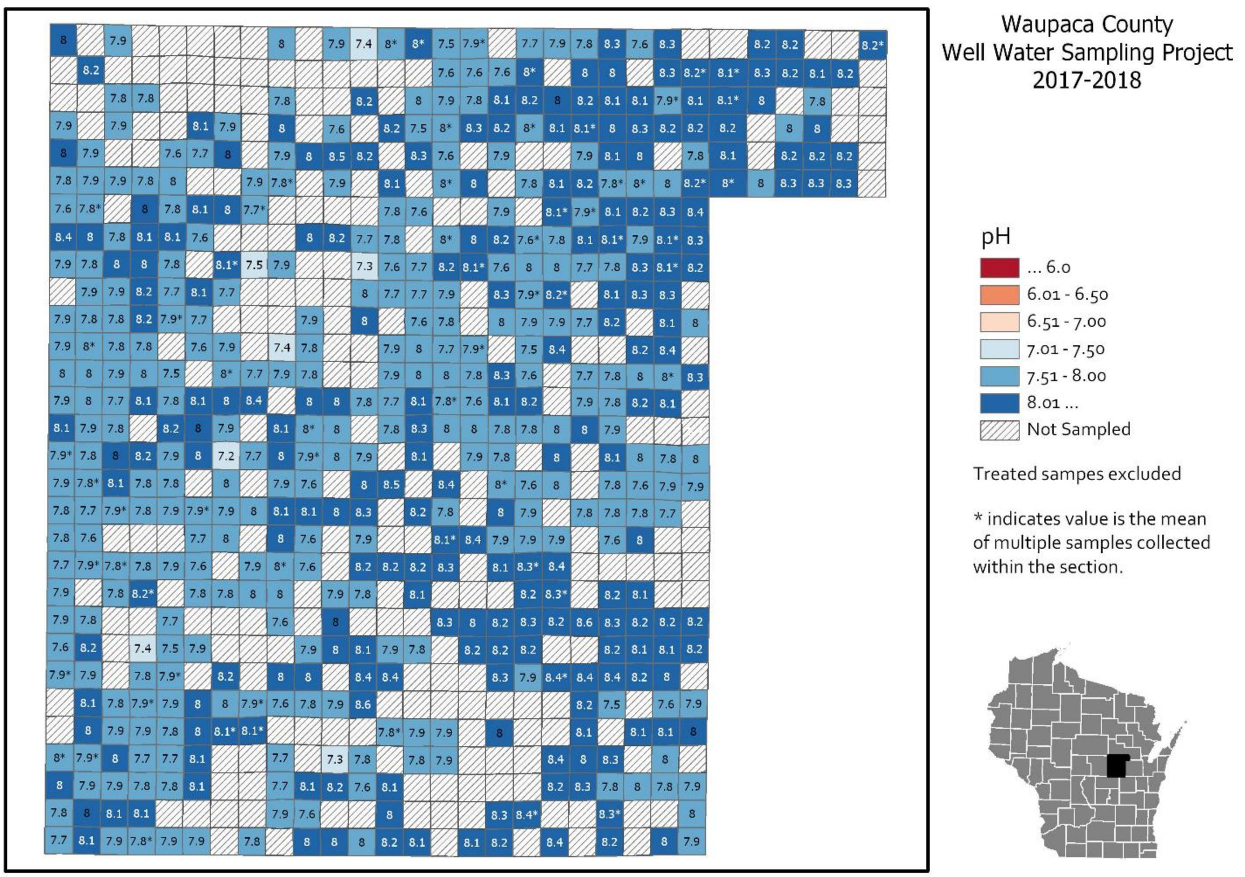


Figure 17. pH concentration by grid cell.

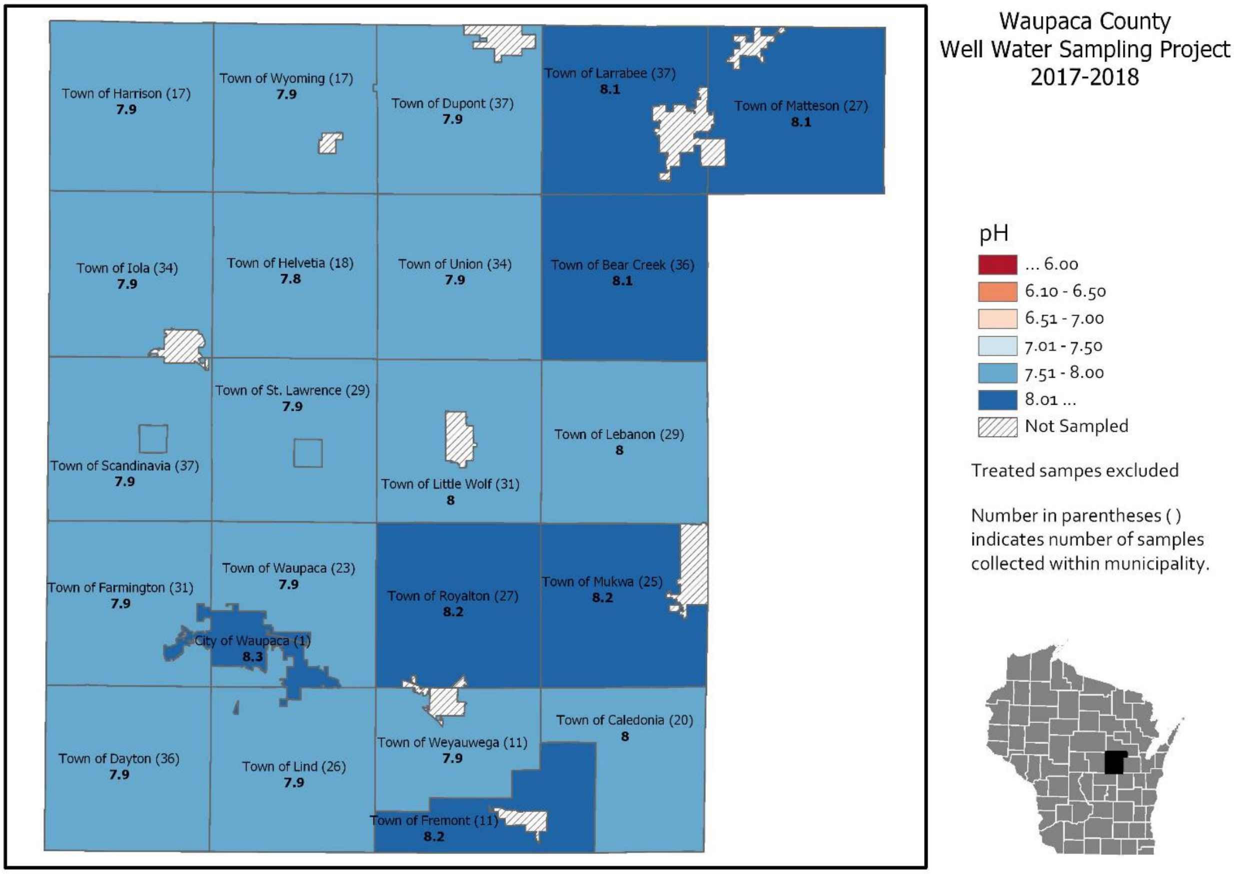


Figure 18. Mean pH concentration by municipality.

Saturation Index

The saturation index is a measure of water's ability to corrode or form scale. It is calculated using values from the pH, alkalinity, total hardness and conductivity tests.

A negative value indicates that water is likely to be corrosive, while a positive value indicates a tendency for scale (calcium carbonate) formation. If plumbing systems contain copper or lead, corrosive water is more likely to increase levels of these metals in drinking water – potentially to unsafe levels. Symptoms of corrosive water may also include pinhole leaks in pipes or bluish-green staining on sinks.

Low pH, alkalinity and total hardness in water will cause water to be more corrosive; this is reflected in a more negative saturation index value (Figure 21). As pH, alkalinity and hardness values increase, the water becomes less corrosive and will have a greater ability to form calcium carbonate scale on plumbing and fixtures.

Water between 0 and 1.0 is generally considered ideal from an aesthetic point of view; most of the wells tested through the Waupaca County well testing efforts indicate that groundwater is balanced with respect to the saturation index. These results suggest that most households served by private wells in the Waupaca County are unlikely to expect problems with corrosion as indicated by the saturation index.

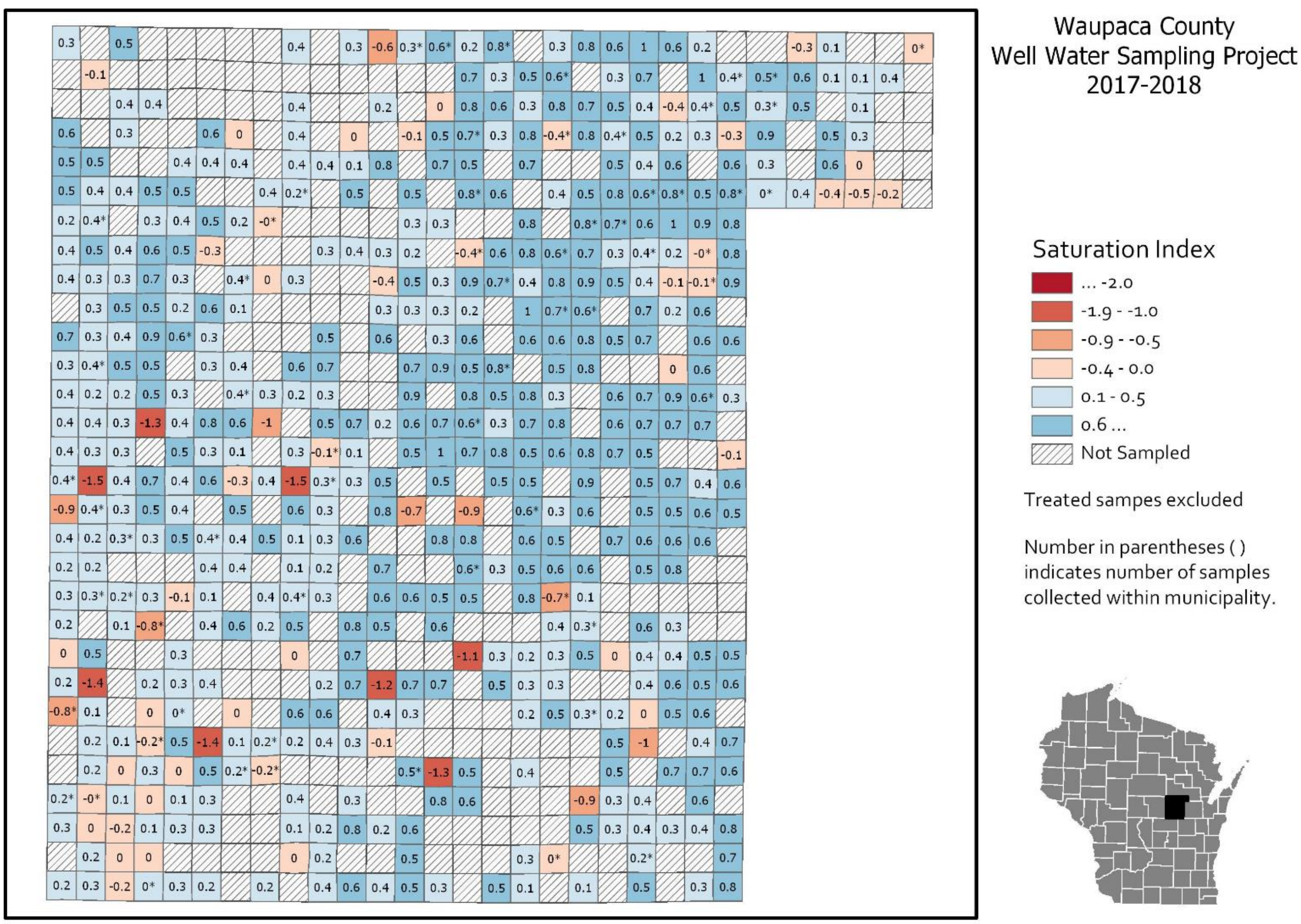


Figure 19. Saturation index by grid cell.

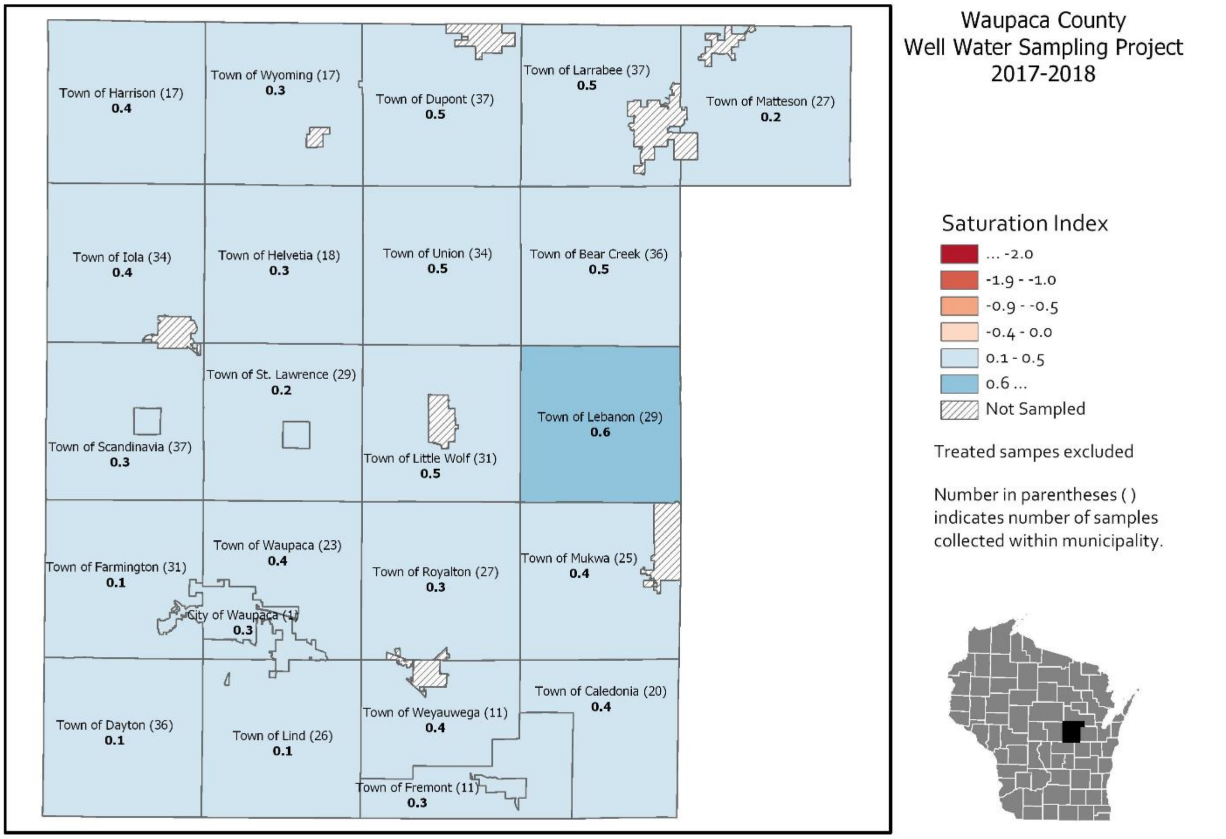


Figure 20. Mean saturation index by municipality

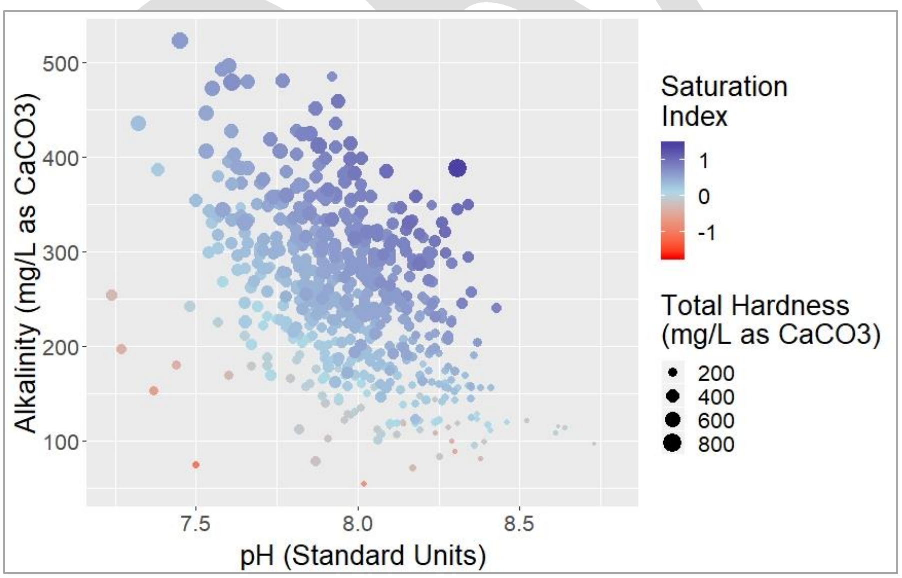


Figure 21. Corrosive water, as indicated by a negative saturation index, results from low pH combined with low alkalinity and lack of dissolved minerals (low total hardness). Most water falls in the ideal range between 0 and 1 for the saturation index. These data illustrate fairly balanced water throughout most of Waupaca County.

Conductivity

Conductivity is a measure of the amount of total dissolved ions in water but does not give an indication of which minerals are present. Conductivity provides one more indicator of water quality, and changes in conductivity over time may indicate changes in overall water quality.

The dissolution of carbonate minerals often generates the bulk of ions associated with conductivity. As a result, conductivity is about twice the total hardness value in most uncontaminated waters.

The mean conductivity value for Waupaca County was 562 umhos/cm. Elevated levels (greater than 750 umhos/cm) tended to be associated with samples containing high concentrations of chloride in the water.

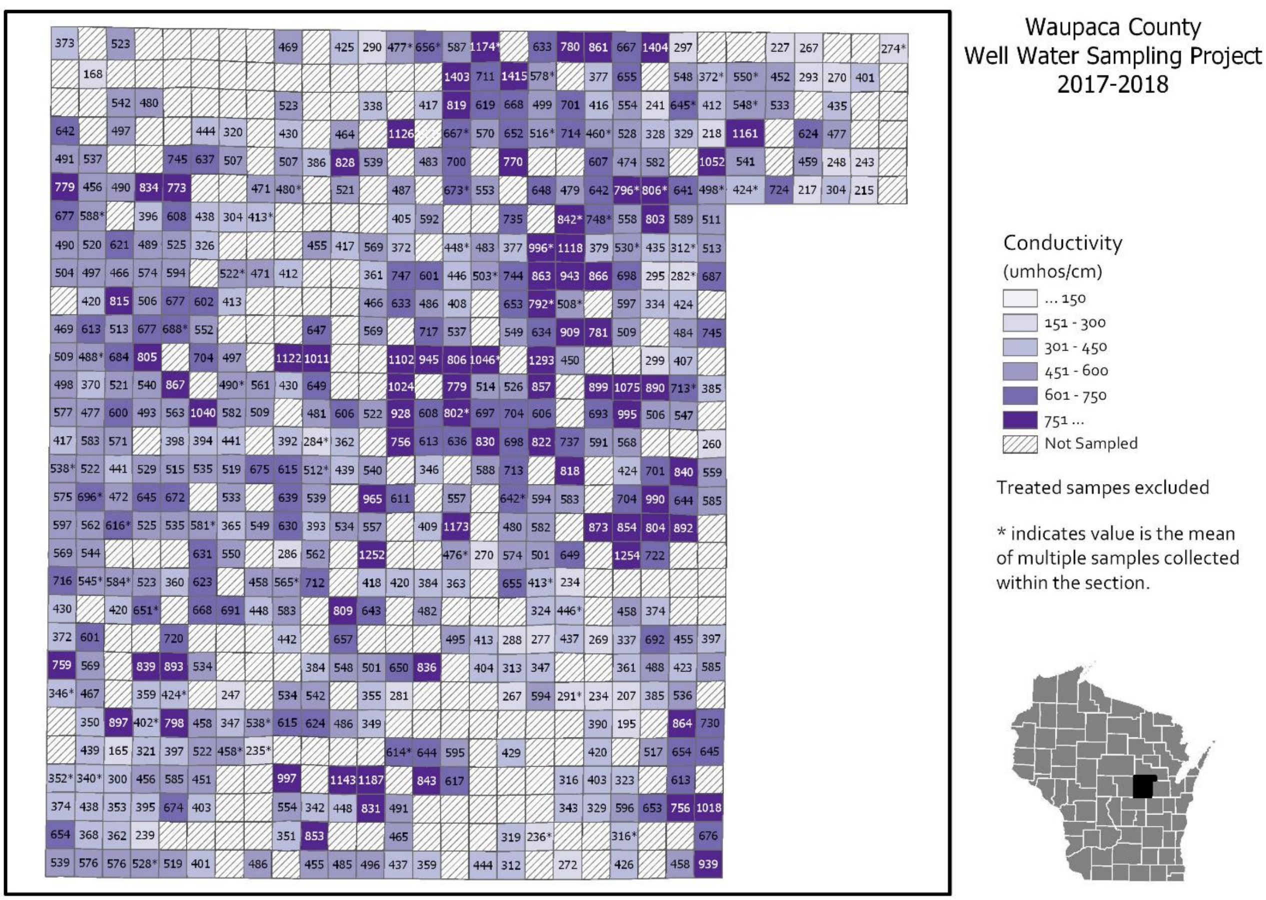


Figure 22. Conductivity concentration by grid cell.

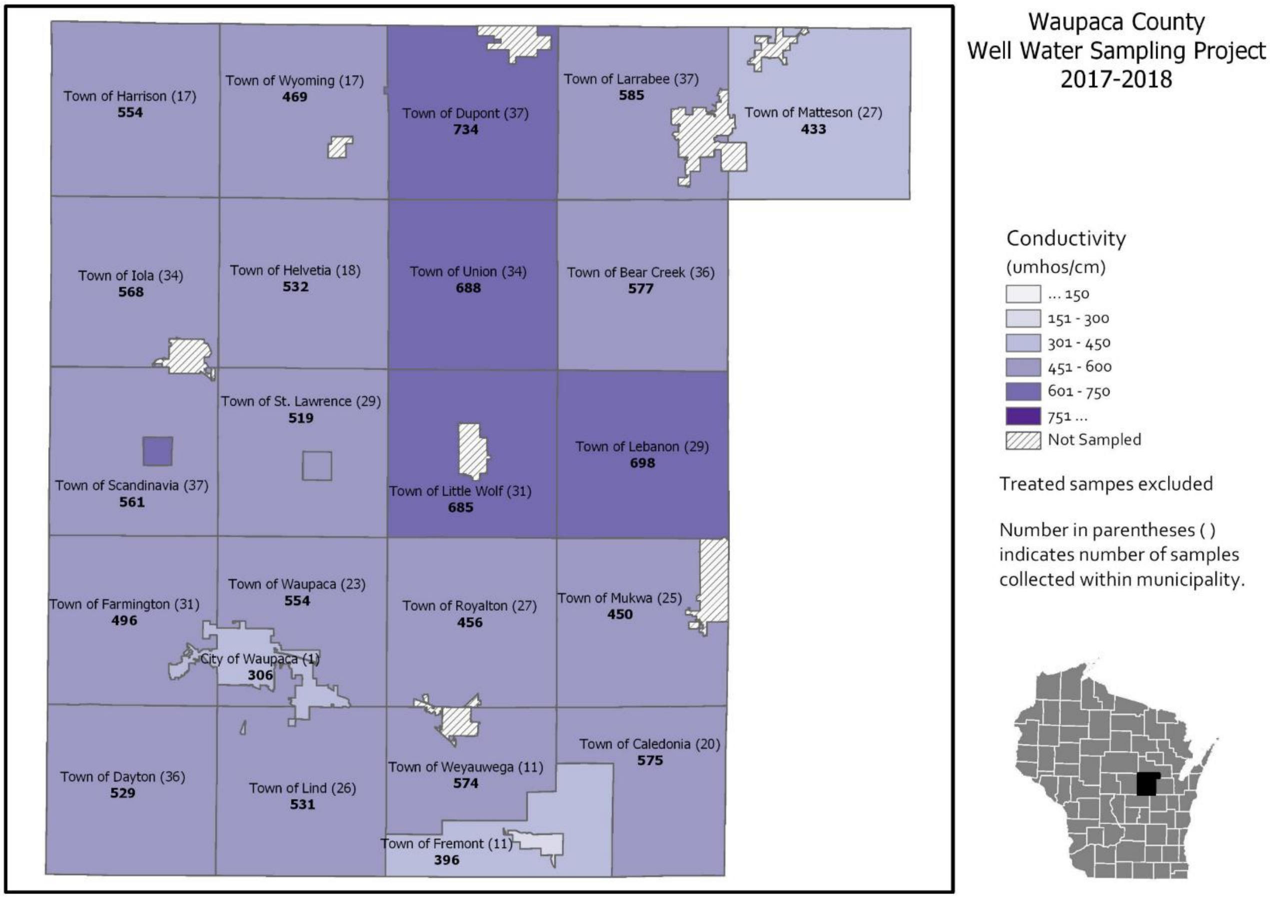


Figure 23. Conductivity concentration by municipality.

Conclusions

Well water in Waupaca County is generally of good aesthetic quality and similar to statewide averages with respect to analytes related to land-use such as nitrate and chloride.

Approximately one in five wells detected coliform bacteria. Coliform bacteria are generally not considered harmful to health but may indicate a defect with the well water system that should be investigated with follow up testing and possible well inspection. One percent of samples were found to contain E.coli. While coliform bacteria are not associated with any particular source, E.coli bacteria are a specific type of fecal bacteria associated with human and/or animal waste.

Slight differences in quality were observed with slightly higher total hardness, alkalinity and pH in northeastern Waupaca County, with lower amounts in the south and east.

Fifty-one percent of wells measured background or natural levels of nitrate (<1 mg/L), while 11% contained concentrations greater than the drinking water standard of 10 mg/L of nitrate-nitrogen. The mean concentration of nitrate and percentage of wells greater than the drinking water standard of 10 mg/L nitrate-nitrogen is virtually unchanged from sampling performed from 1990-1997.

Fifty-eight percent of wells measured background or natural levels of chloride (<10 mg/L). The mean chloride concentration was 19.2 mg/L, this represents a slight increase over the 14.7 mg/L mean chloride concentration measured in samples collected from 1990-1997.

This study establishes another important benchmark of well water quality in Waupaca County. It provides a solid foundation for future studies that investigate how or if groundwater is changing over time. While not the goal of this report, additional data analysis could be performed to investigate relationships between well water quality, land-use, geology, well construction, and other factors.

Literature Cited

Center for Watershed Science and Education (CWSE). WI Well Water Viewer. Accessed online 2/1/2018. https://www.uwsp.edu/cnr-ap/watershed/Pages/WellWaterViewer.aspx

Dept. of Agriculture, Trade and Consumer Protection (DATCP). 2017. Agricultural Chemicals in Wisconsin's Groundwater. Final Report. https://datcp.wi.gov/Documents/GroundwaterReport2017.pdf

Gotkowitz, M.B., 2006. Well Water for Rural Residential Subdivisions: Using groundwater flow models to evaluate options for water supply. University of Wisconsin – Extension & Wisconsin Geological and Natural History Survey. http://clean-water.uwex.edu/pubs/pdf/well-water.pdf

Franke, O.L., Reilly, T.E., Pollock, D.W. and LaBaugh, J.W., 1998. Estimating areas contributing recharge to wells, United States Geological Survey Circular 1174. https://water.usgs.gov/ogw/pubs/Circ1174/circ1174.pdf

Laboski, C.AM. and J.B. Peters. 2012. Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin. University of Wisconsin Extension. A2809. http://learningstore.uwex.edu/Assets/pdfs/A2809.pdf

McGinley, P.M., W.M. Devita, and A.L. Nitka. 2016. Evaluating Chemical Tracers in Suburban Groundwater as Indicators of Nitrate-Nitrogen Sources. Final Report to WI Dept. of Natural Resources. University of Wisconsin – Stevens Point. https://www.uwsp.edu/cnr-ap/watershed/Documents/Eval_chemtracers_suburbanGW.pdf

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.

Shaw, B., P. Arntsen, and W. VanRyswyk. 1993. Subdivision impacts on groundwater quality. University of Wisconsin – Stevens Point. https://www.uwsp.edu/cnr-ap/watershed/Documents/subdivision_final.pdf

WDNR. 2016. Wiscland 2.0. Wisconsin Department of Natural Resources, Bureau of Technology Services. http://dnr.wi.gov/maps/gis/datalandcover.html

APPENDIX A. Summary table of water quality by municipality

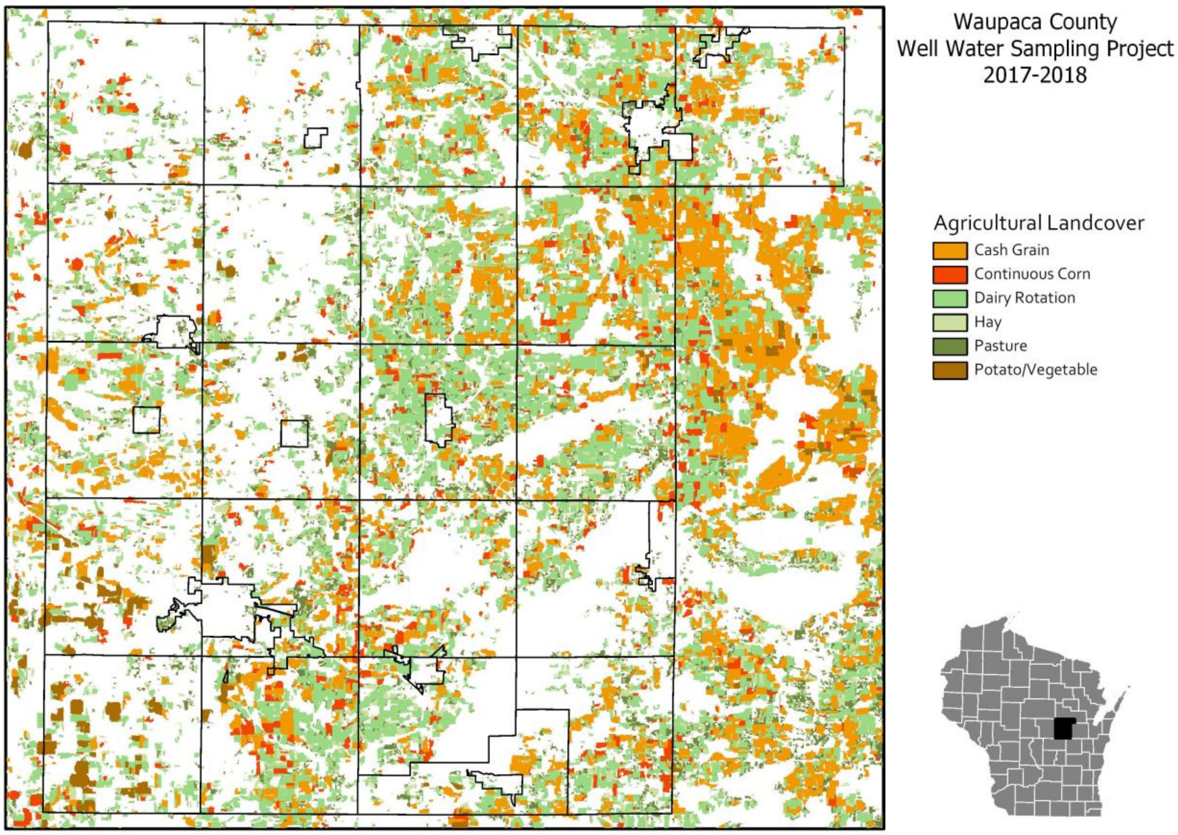
Municipality	N	pH Standard units			Conductivity μhos/cm			Alkalinity mg/L as $CaCO_3$			Total Hardness† mg/L as $CaCO_3$			Nitrate-Nitrogen mg/L			Chloride mg/L		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
T. of Bear Creek	35	7.7	8.4	**8.1**	238	1141	**576**	118	418	**257**	42	506	**272**	<0.1	19.7	**1.2**	0.8	168	**18.8**
T. of Caledonia	21	7.5	8.6	**8.0**	195	1018	**583**	75	371	**259**	38	498	**294**	<0.1	15.7	**5.1**	1	123	**21.5**
T. of Dayton	33	7.7	8.1	**7.9**	165	897	**455**	78	335	**179**	149	336	**220**	<0.1	31.0	**6.6**	0.7	126	**15.2**
T. of Dupont	36	7.5	8.3	**7.9**	426	1868	**743**	143	479	**297**	80	831	**371**	<0.1	31.0	**5.4**	2.9	352	**45.8**
T. of Farmington	37	7.4	8.3	**7.8**	306	893	**541**	122	387	**224**	143	428	**274**	<0.1	21.4	**5.1**	1.2	59.2	**19**
T. of Fremont	14	8.0	8.4	**8.2**	232	725	**367**	99	269	**183**	64	336	**175**	<0.1	13.4	**1.3**	0.8	36.0	**5.6**
T. of Harrison	18	7.6	8.3	**7.9**	168	834	**554**	84	395	**266**	98	439	**309**	<0.1	28.1	**4.0**	1.1	116	**15.4**
T. of Helvetia	17	7.3	8.2	**7.8**	304	1122	**539**	123	522	**247**	173	618	**288**	<0.1	24.5	**4.1**	1.5	92.6	**15.9**
T. of Iola	36	7.6	8.4	**7.9**	326	815	**568**	158	484	**267**	156	420	**296**	<0.1	14.6	**4.2**	1.5	89.3	**16.4**
T. of Larrabee	37	7.6	8.3	**8.1**	218	1404	**585**	109	496	**267**	57	539	**295**	<0.1	14.0	**2.6**	0.7	138	**19.5**
T. of Lebanon	31	7.6	8.7	**8**	260	1075	**692**	97	480	**321**	32	555	**359**	<0.1	22.9	**5.3**	1.3	66.8	**17**
T. of Lind	26	7.3	8.6	**7.9**	151	1187	**548**	54	435	**227**	34	536	**240**	<0.1	13.4	**3.4**	0.6	107	**17.7**
T. of Little Wolf	29	7.6	8.5	**7.9**	346	1173	**692**	264	479	**344**	201	577	**376**	<0.1	21.1	**4.0**	1.2	110	**18.2**
T. of Matteson	27	7.8	8.4	**8.1**	174	1161	**433**	72	370	**171**	38	467	**198**	<0.1	35.3	**4.4**	0.6	159	**15.1**
T. of Mukwa	27	7.6	8.6	**8.2**	207	1254	**439**	96	389	**206**	43	488	**205**	<0.1	12.4	**1.1**	0.9	165	**14.7**
T. of Royalton	25	7.8	8.8	**8.2**	267	987	**467**	139	428	**235**	99	426	**233**	<0.1	13.1	**1.1**	0.9	155	**13.8**
T. of Scandinavia	41	7.5	8.2	**7.9**	370	1040	**565**	160	354	**250**	195	448	**296**	<0.1	16.9	**4.3**	1.3	137	**14.3**
T. of St. Lawrence	28	7.2	8.4	**7.9**	266	965	**523**	127	350	**238**	132	483	**271**	<0.1	21.3	**3.1**	1.4	88.7	**14.2**
T. of Union	34	7.5	8.3	**7.9**	372	1342	**688**	187	492	**333**	212	606	**386**	<0.1	14.3	**3.4**	1.9	176	**29.6**
T. of Waupaca	29	7.6	8.4	**7.9**	247	1252	**544**	122	451	**271**	116	480	**284**	<0.1	10.8	**2.6**	1.1	191	**17**
T. of Weyauwega	10	7.7	8.2	**7.9**	429	843	**585**	169	424	**303**	177	478	**322**	<0.1	10.8	**3.1**	1.1	20.2	**11.3**
T. of Wyoming	17	7.4	8.5	**7.9**	290	828	**469**	120	300	**223**	78	318	**236**	<0.1	9.7	**1.0**	1.4	176	**17.5**

† Softened samples excluded from summary of total hardness.

APPENDIX B

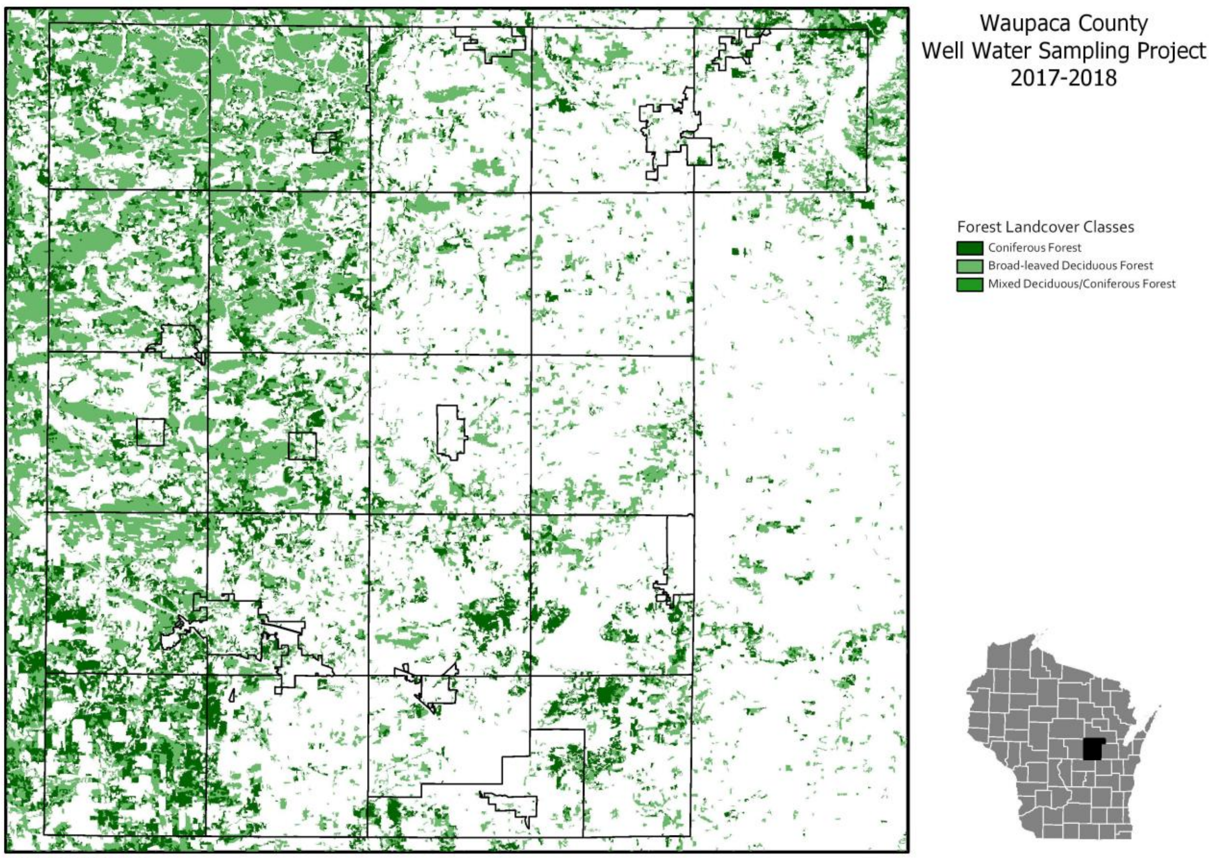
Maps

Figure A. Agricultural land cover classification (Wiscland 2.0)



Source: Wiscland 2.0

Figure B. Forest landcover (Wiscland 2.0)



Source: Wiscland 2.0

Figure C. Urban landcover and major roadways of Waupaca County