Portage County Well Water Quality – 2017

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Contents

Executive Summary 4

Introduction to Portage County Groundwater 5

Aquifers and groundwater-surface water interactions 6

Wells 10

Well Selection, Recruitment, and Water Quality Analysis 12

Well Water Chemistry Results and Interpretation 12

Nitrate-nitrogen 13

Chloride 17

Total Hardness 19

Alkalinity 19

pH 20

Saturation Index 20

Conductivity 21

Conclusions 21

Literature Cited 22

Appendix A – Summary table of water quality by municipality 23

Appendix B – Summary of water quality results by category 24

Appendix C – Maps 25

Appendix D – Statistical Analysis: Output from R 35

EXECUTIVE SUMMARY

Groundwater is the principal water supply for Portage 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, Portage County undertook steps to investigate well water quality across the county.

In the summer of 2017, Portage County collaborated with the UW-Stevens Point (UWSP) Center for Watershed Science to sample private wells for nitrate-nitrogen, chloride, pH, alkalinity, total hardness and conductivity. In the interest of ensuring representation from across the county, the county was divided into grid cells each measuring 2 mi. x 2 mi. One well from each grid cell was randomly selected for sampling. Participation was voluntary. For those households that agreed to participate, UWSP staff traveled to each property to collect the sample. Samples were analyzed at the state-certified Water and Environmental Analysis Lab. In total, 214 samples were collected and analyzed, from 202 of the grid's 229 total cells (88%).

Portage County's groundwater can generally be characterized as slightly basic (mean pH = 7.41), moderate to hard water (mean total hardness = 208 mg/L as $CaCO_3$), and as having moderate alkalinity (mean = 154 mg/L as $CaCO_3$). Overall, the water on average is well balanced and aesthetically pleasing.

The aesthetic characteristics of the water are largely influenced by the geologic materials groundwater is stored and transported in; with two fairly distinct regions of groundwater quality in Portage County. Groundwater in eastern Portage County tends to be harder, and have higher pH and alkalinity. In western Portage County, low pH, total hardness and alkalinity are more prevalent, conditions likely to produce water that is corrosive. Corrosive water can be problematic for households with metal plumbing; potentially resulting in elevated lead levels, pinhole leaks or corrosion of hot water heaters.

Nitrate is a common health-related contaminant found in Portage County's groundwater (mean = 6.5 mg/L nitrate-nitrogen). Twenty-four percent of wells tested greater than the 10 mg/L drinking water standard; nearly 2.5 times the statewide average. Approximately 52% of wells tested measured greater than 2 mg/L, which provides evidence that land-use activities are having an effect on water quality in about half of wells tested. Soil drainage properties combined with areas of concentrated agricultural land cover help to explain both the extent and magnitude of nitrate concentrations in Portage County.

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 Portage County was 22.0 mg/L. There was evidence that increases in chloride concentrations were related to various agricultural land covers and development density (i.e. roads and septic systems).

This study provides an important benchmark of well water quality in Portage County. These results highlight the main factors affecting well water quality and provide a foundation for future investigations to investigate how or if groundwater is changing over time.

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

Introduction to Portage County Groundwater

Portage County 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 Portage County lakes and rivers as runoff.

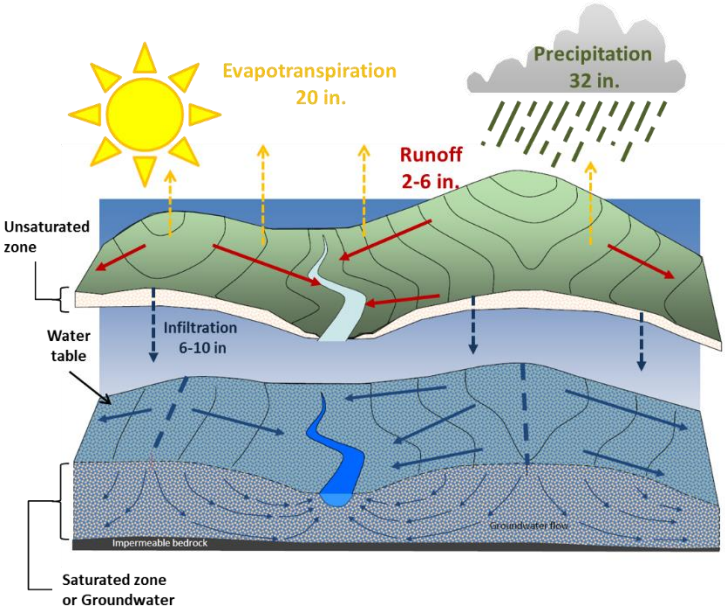


Figure 1. Relative contribution of various components of the water cycle as they relate to Portage County. The unsaturated zone is separated from the groundwater to illustrate the water table elevation. Changes in water table elevation are used to infer groundwater flow direction.

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

Groundwater moves as a result of differences in energy. Water at any point in an aquifer has energy associated with it, and its movement can be predicted by measuring changes in energy between two locations. More simply, groundwater moves from high energy to low energy. One measurement of energy is groundwater elevation.

Groundwater elevation maps show the height of the top of the groundwater above a common measuring point, which is sea level. 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. In Portage County, surface waters are 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 surface waters, such as 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 Portage 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 Portage County residents and industries.

The lowermost geologic unit found in Portage 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 Portage County, they are near the land surface, but in southeastern Portage County, they are up to 500 feet below other 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 Portage 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 Portage 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. This bedrock layer is very thin where it first appears in the county, near Plover, and gradually gets thicker as you move south.

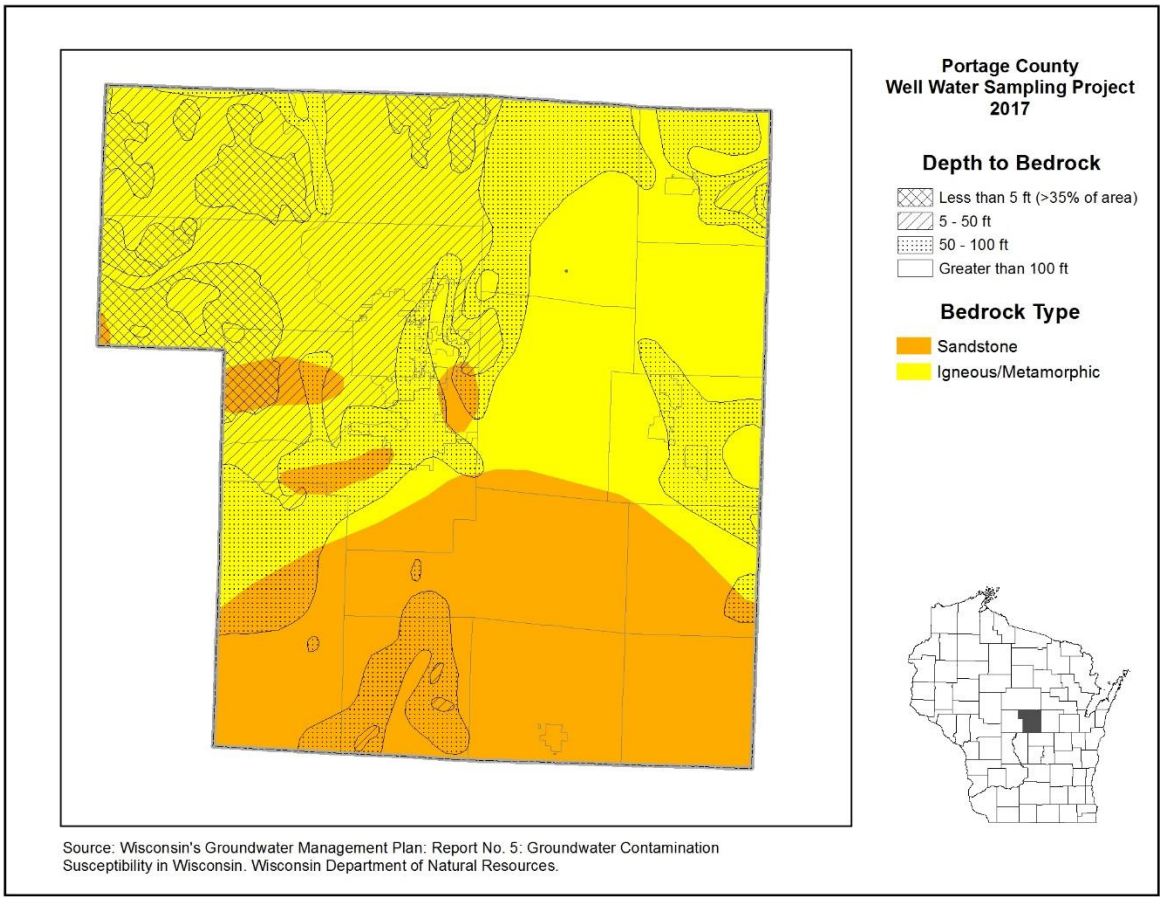


Figure 2. The amount of unconsolidated material that exists above bedrock is denoted by depth to bedrock (shading). The first bedrock unit encountered below the unconsolidated material is indicated by bedrock type (color). Igneous or metamorphic crystalline bedrock also underlies the sandstone aquifer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

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 Portage County and can be greater than 100 feet thick in the eastern and southern portions of the county. The depth to bedrock map provides insight into how the thickness of the unconsolidated deposits vary in the county.

These materials, and the current land formations in Central Wisconsin, are the result of glaciers that once advanced into Portage County. The glaciers, sheets of ice a mile or more thick, advanced into the county from the east. The farthest advance is marked by the boulders found in the eastern portion of the county. These and other materials form a ridge from north to south that is called a terminal moraine.

Just to the west of the terminal moraine sits the former lake bed of Glacial Lake Wisconsin; it is one of the largest and most visible land formations that remain from our glacial past. The lake occupied an area from around Plover all the way down to the Baraboo Hills.

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 Portage 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.

Groundwater is well connected to the surface waters of Portage County. Streams, rivers and lakes represent locations where groundwater emerges from the ground for the first time since entering an aquifer as rain or snowmelt. Groundwater discharge is the term used to represent the contribution of groundwater to surface waters or wetlands.

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

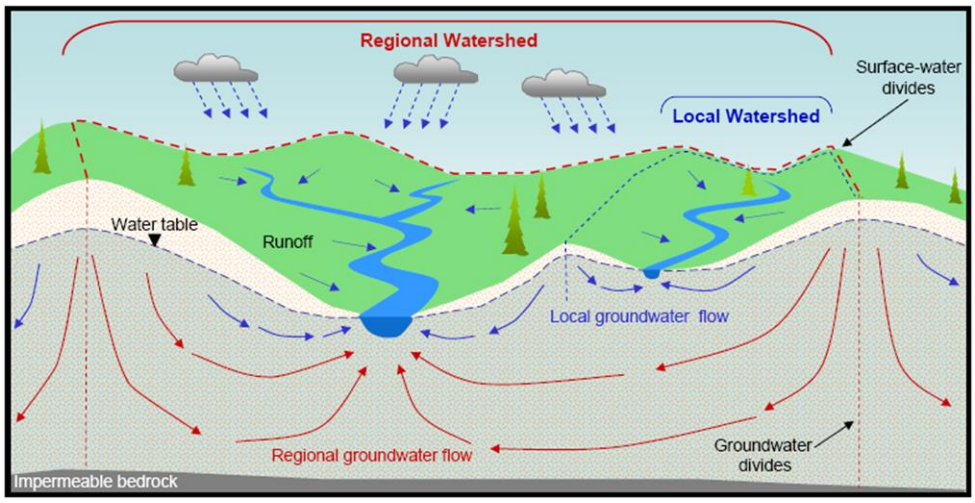


Figure 3. Rain or snow that falls within a watershed boundary moves via runoff or as groundwater flow to a common discharge location, usually a river or stream. Smaller watersheds can be nested within larger regional watersheds.

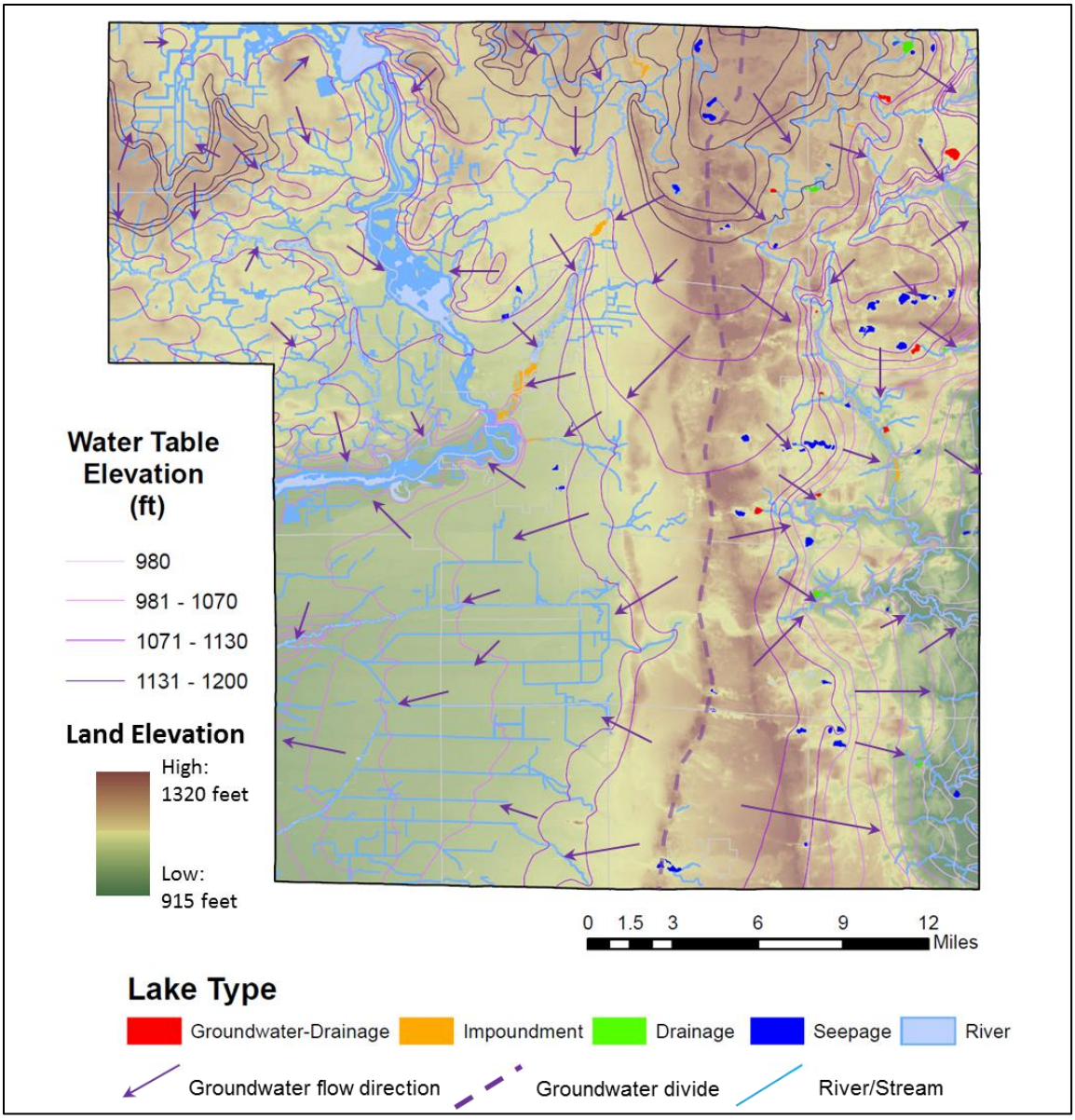


Figure 4. General groundwater flow direction indicated by the purple arrows can be approximated by interpreting changes in water table elevation. Groundwater flows from areas of higher elevation to lower elevation where it discharges to one of Portage County's rivers, streams, lakes, or wetlands. The way in which groundwater interacts with lakes is indicated by lake type. There is a major groundwater divide that runs through the county as indicated by the dashed line.

Topographic maps are used to determine the boundaries of surface watersheds and water table elevation maps are used for ground watershed boundaries. These boundaries are often referred to as divides; water on one side of the divide flows in the opposite direction of water on the other side. Small watersheds of tributary streams are nested within the larger watershed of the river or other large water body that they feed into.

Portage County has a sub-continental divide running from north to south through the county. This divide separates water that drains to the Wisconsin River and ultimately the Mississippi River from that which drains to the Tomorrow River and eventually the Great Lakes.

Each watershed has a water budget. In a water budget, the precipitation that falls in a watershed must equal the water leaving as streamflow or evaporation to the atmosphere. This fundamental law, known as the conservation of mass (water in = water out), is the basis for modern groundwater modeling efforts. The total water flowing in a stream is made up of both runoff from the land surface and groundwater. The proportion of water that comes from one or the other varies by watershed.

For instance, almost 90% of the water in the Little Plover River that enters the stream is from groundwater. However, groundwater only accounts for about 20% of the water entering Mill Creek, with the remainder entering after storm events or snowmelt. Variations in the soils and geology are responsible for the dramatic difference between the proportions of runoff versus groundwater contribution to the stream in each of these watersheds.

To the west of the Wisconsin River, where Mill Creek is located, heavier soils overlie crystalline bedrock. Here, there is very little empty space within the aquifer that isn't already filled with water. The large expanses of wetlands are proof that the water table is relatively close to the land surface. Therefore, new precipitation often exceeds remaining storage or falls faster than water is able to infiltrate, so it runs off into the creek. As a result, streams in this part of the county are much flashier – meaning they have lots of water in them following a rain event but less flow during other times of the year.

East of the Wisconsin River, are relatively thick deposits of sand and gravel. The sandy soils and sufficient unsaturated conditions between the land surface and the water table allow water to more easily infiltrate into the aquifer.

Because groundwater releases water to rivers and streams slowly, groundwater-dominant streams such as the Little Plover River are not as susceptible to flash flooding and will have higher flows year round relative to watersheds of similar size in the western portion of the county. Rivers and streams with high inputs of groundwater tend to be colder in summer months and have more consistent streamflow – even during drought.

Groundwater is well connected to Portage County lakes as well. In Portage County, all lakes receive some amount of water via groundwater, runoff, and directly through precipitation. Some might also have surface water inlets (streams) that supply water. Lake scientists categorize lakes into four types based on how water enters and exits the lake.

Drainage lakes have streams at both the inlet and outlet ends. In Portage County, these include Collins, Fountain, Spring, and Tree Lakes. Impoundments are basically drainage lakes created artificially by the damming of a stream; these include Amherst Millpond, Bently Pond, Jordan Pond, McDill Pond, Rosholt Millpond, and Springville Pond.

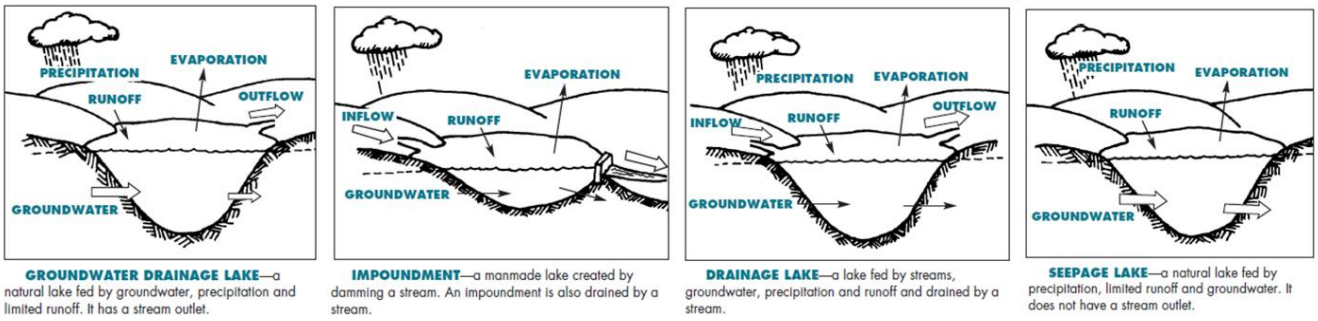


Figure 5. Illustrations of groundwater interactions with different lake types. Lake levels of seepage lakes are more sensitive to fluctuations in the water table than are other lake types (Source: Shaw et al., 2004)

Groundwater-drainage lakes have an outlet stream but no inlet stream feeding them. In Portage County, Adams, Ebert, Helen, Lions, and Rinehart Lakes are included in this category.

Seepage lakes have neither a surface water inlet or outlet. Groundwater enters one side of the lake and exits on the opposite side. These are the most common lake type in Portage County. Seepage lakes include Becker, Bear, Emily, Jacqueline, Joanis, Lime, Onland, Pickerel, Severson, Skunk, South Twin, Sunset, Thomas, and Wolf Lakes.

Lakes vary in how much their water levels fluctuate. The water level in drainage lakes and groundwater-drainage lakes is controlled by the bottom elevation of the lake outlet stream, which remains constant. The total amount of water flowing out of these lakes can differ from one year to the next; however, the lake level remains relatively constant.

This is true of impoundments as well. Unless the lake level is artificially adjusted while managing a dam, the level of water in an impoundment remains relatively constant.

The largest fluctuations in lake levels occur in seepage lakes. Water levels in these lakes depend on the level of the water table. If the water table fluctuates, seepage lakes with steeper shorelines may notice drops or increases in lake level, but little difference in the overall surface area of the lake. However, if the slope of a seepage lake's shoreline is gradual and water is shallow, even small fluctuations in the water table may dramatically affect the surface area of the lake. For instance large areas of shoreline might be exposed when the water table drops. Conversely, low lying areas could be submerged if groundwater levels rise.

Wells

All of Portage 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 Portage 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 must often be drilled much deeper if the well is to be successful at accessing water.

A well's casing and screen help to prevent the well borehole from filling in with sediment and other geologic material. The depth of casing or location of a well screen also determine where in the aquifer the well is receiving water from. Casing depth or screen

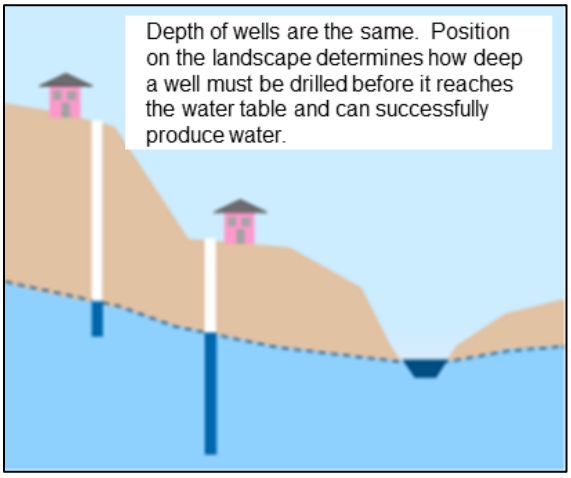


Figure 6. Wells must extend past the water table in order to access water. Wells on ridges or hilltops will often times have to drill much deeper to hit the water table than a well located lower on the landscape like areas next to rivers, lakes or streams.

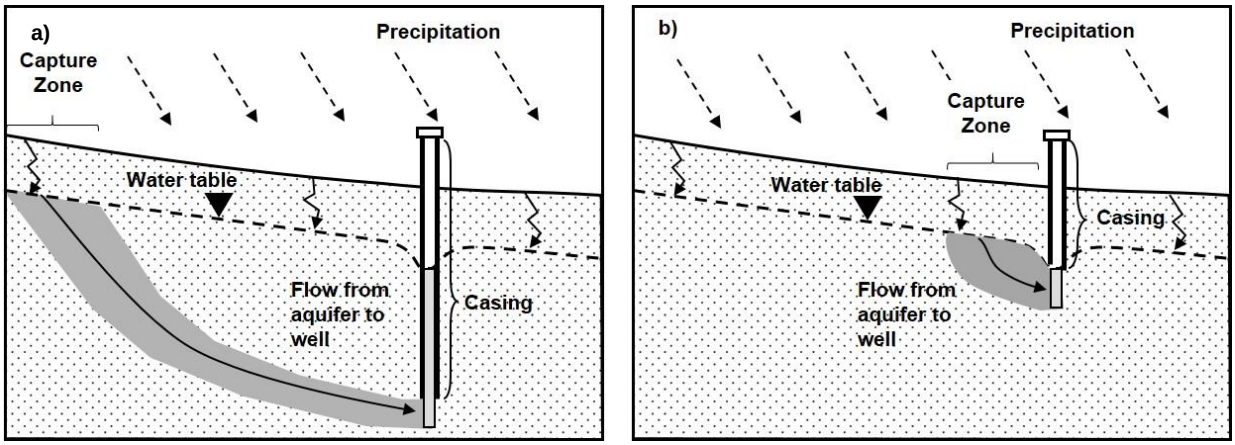


Figure 7. Diagrams illustrating how well and casing depth influence the capture zone of a well. Wells in which the casing extends below the water table will tend to have capture zones that are located further away from the well (a) than one in which the casing does not extend as far or may not extent past the water table (b).

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 Portage 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 they do not benefit from the day-to-day oversight of municipal water systems.

Wells in Portage County range from shallow drive point wells that may only be 20 feet deep to drilled wells that may be a 100 feet or more deep.

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

Well Selection, Recruitment and Water Quality Analysis

We utilized a grid sampling approach to ensure samples were spatially distributed across the county. A grid consisting of 2 mile x 2 mile grid cells resulted in 229 grid cells for Portage 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 postcard, phone call or email. 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 202 grid cells out of the 229 were successfully sampled (88% of grid cells).

Landowners that agreed to participate were contacted to arrange a time for UWSP staff to travel to the property and sample the well. Staff were instructed to sample from a faucet that was untreated, water was run for 10 minutes prior to sample collection, and samples were collected in an unacidified, 125 mL HDPE bottle. If homeowners authorized staff to collect a sample while the homeowner was not home, an outside faucet was used for sample collection. Following collection, samples were placed in a cooler with ice and transported back to the laboratory where they 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.

Well Water Chemistry Results and Interpretation

Mean (average), median, minimum and maximum values are reported for Portage County (Table 1) and by municipality (Appendix A) for each of the tests performed. Maps were generated for each analyte that showing results by grid cell and mean values by municipality (Maps are labeled Figure A-R and can be found in Appendix C).

We investigated various factors known to influence well water quality. Geologic influences (i.e. soil drainage classification) and human activities (i.e. agricultural land use or septic systems) were characterized for the area within ½ mile of the centroid of each well location parcel.

The Wiscland 2.0 coverage was used to determine the area of various agricultural (Figure A), forest (Figure D), and other land covers (Figure C) within ½ mile radius of each well (WDNR, 2016).

The SSURGO database was used to characterize soil drainage class (Figure B) for the area around the well. Rankings were assigned to each drainage classification with 1 representing very poorly drained soils and 7 representing excessively drained soils. A

Table 1. Summary of Portage 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 = 214	n = 214	n = 214	n = 198	n = 214	n = 214
Mean	7.41	439	154	208	6.5	22.0
Median	7.60	448	156	220	2.4	11.9
Min	5.43	28	<4	9	<0.1	0.6
Max	8.83	1404	346	436	44.1	351

† Softened samples excluded from summary stats for total hardness.

weighted average of soil drainage class was then determined for ½ mile buffer around each of the wells (Soil Survey Staff, 2014).

A septic system count was determined by intersecting the ½ mile buffer with the parcel layer for Portage County. Any parcel with a septic system that was intersected by or contained within the ½-mile buffer. Septic counts ranged from 0 to 267 septic systems within a ½ mile buffer. The highest septic count equates to an average density of 0.5 septic systems/acre or 1 septic system for each 1.9 acres. Of the 214 wells investigated here, only 4 samples were collected in areas where the septic density was greater than 0.2 septic systems/acre or 1 septic system for each 5.02 acres. Septic system counts were normalized (0-1.0) by dividing each value by the maximum value of 267.

Admittedly, using the radius around the well is an imperfect variable for understanding the effects of land-use on well water quality. Ideally groundwater flow direction would also be used to narrow down the capture zone or area of influence with greater confidence. Identifying capture zones for the large number of wells sampled in this study was beyond the scope of the project. However, future efforts looking to better understand and explain variability of well water quality could consider a more refined area of influence when investigating land-use relationships.

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 highly soluble and mobile form of nitrogen that contributes to it being the most widespread groundwater contaminant in Wisconsin.

Landscapes in which nitrogen is not 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 inorganic nitrogen fertilizer, manure or other bio-solid, plants are generally not able to assimilate all the nitrogen that is added. Even at economic optimal rates as 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 sandy soils are particularly prone to nitrate leaching losses to groundwater because of the ease with which water is able to 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.

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.

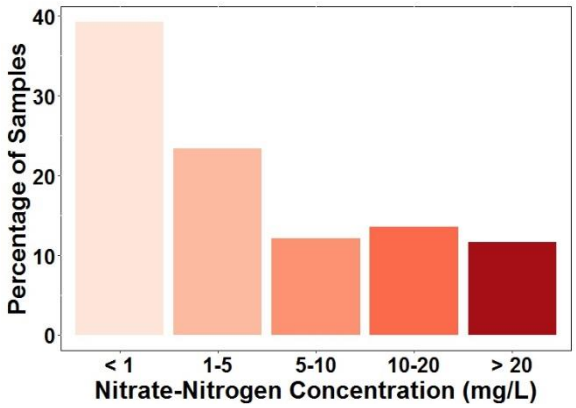


Figure 8. Twenty-four percent of samples contained greater than the drinking water standard of 10 mg/L for nitrate-nitrogen; thirty-nine percent of samples measured background or natural levels.

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.

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.

Twenty-four percent of samples measured nitrate-nitrogen concentrations above the drinking water standard (Figure 8). The rate of nitrate exceedances is more than 2.5 times the statewide estimate of 9% (DATCP, 2017). The average concentration in Portage County was 6.5 mg/L and the median was 2.4 mg/L. Nitrate concentrations tended to be greater in the southern and eastern portions of the county (Figure E). Wells in the Towns of Grant, Linwood and Dewey were generally low (Figure F).

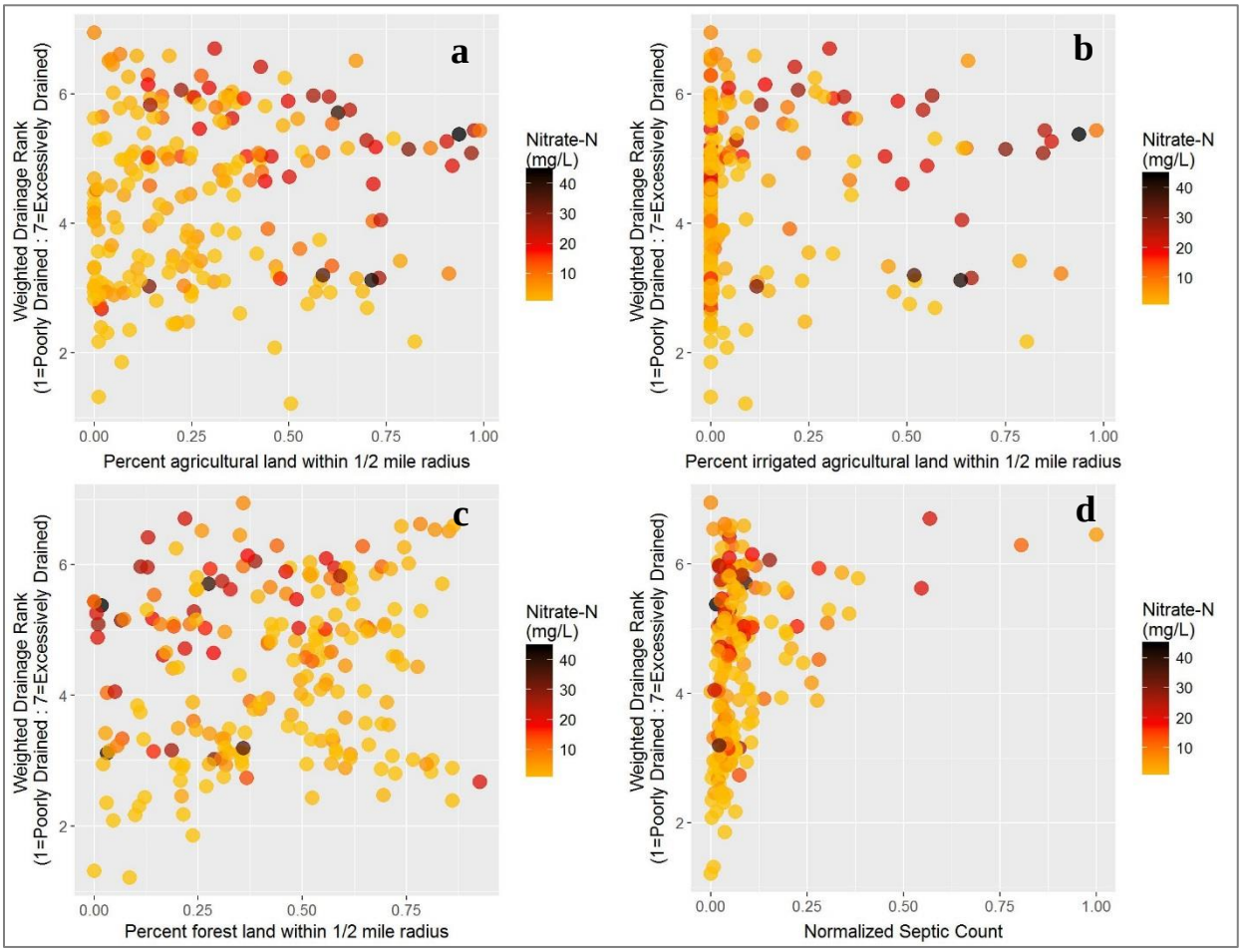
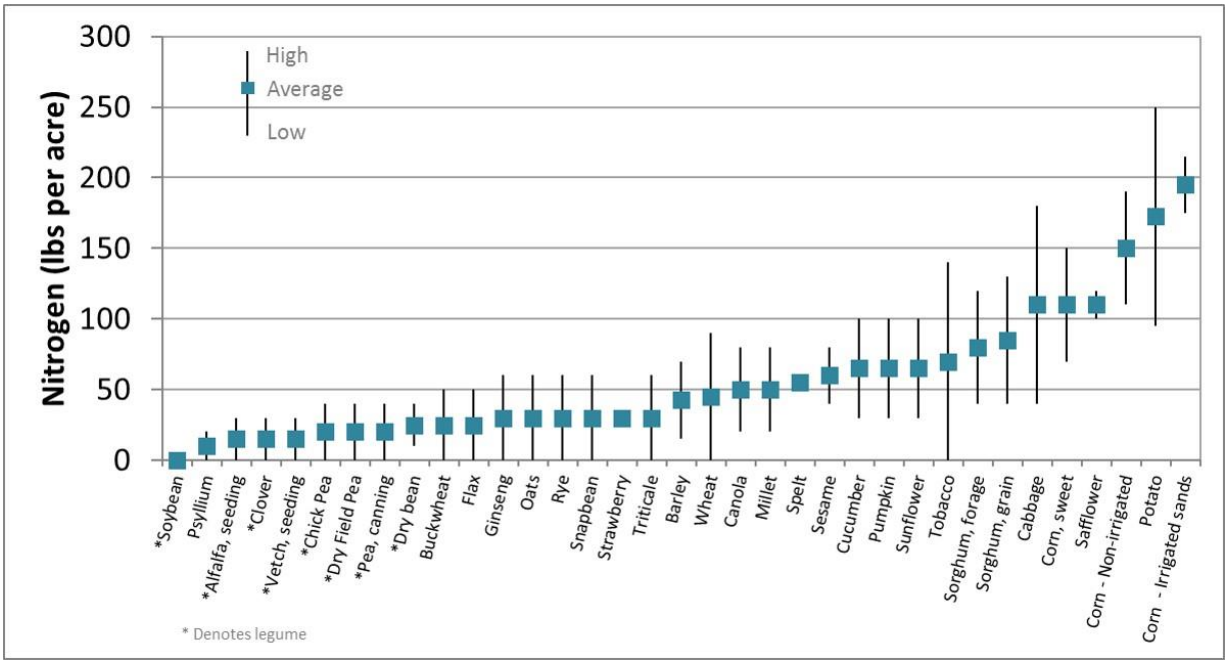


Figure 9. Nitrate-nitrogen concentration as influenced by soil drainage classification and various land covers within a ½-mile radius of the well. a) Percent agricultural land (includes Wiscland 2.0 land covers for cash grain, continuous corn, dairy rotation, potato/vegetable, and cranberries). b) Irrigated agricultural land (Wiscland 2.0 land cover for potato/vegetable). c) Percent forest land (Wiscland 2.0 land covers for all forest cover). d) Normalized septic count.

Figure 10. Nitrogen recommendations for various Midwestern crops (Laboski and Peters, 2012). Nitrogen recommendations vary depending on percent soil organic matter and nitrogen:corn price ratio.



Multiple linear regression was used to investigate the relationship of nitrate to weighted drainage rank, normalized septic count, and the percentages of land cover classified as: potato/vegetable, continuous corn, and dairy rotation. The model is able to explain almost one-third of variability in nitrate concentrations and shows very strong evidence of positive, linear relationships to potato/vegetable (irrigated land) ($p<0.001$) and weighted drainage rank ($p<0.001$), strong evidence to continuous corn ($p=0.006$), and weak evidence to dairy ($p=0.060$) (Appendix D). There was no evidence of a linear relationship to normalized septic count ($p=0.530$).

The lack of significance in the model related to normalized septic count should not be interpreted as there being no relationship between septic density and nitrate. The grid sampling was limited in its ability to sample wells in more densely populated areas of Portage County. Future investigations in Portage County would benefit from better stratification of samples according to development density.

Plots of nitrate as a function of land cover and weighted drainage rank were created for general agricultural land, irrigated land, forest land and normalized septic count (Figure 9).

Nitrate increased with percent agricultural land and increasing weighted drainage rank (Figure 9a). In areas with poorly drained soils, nitrate concentrations were low. Anaerobic conditions are more likely to occur in poorly drained soils. Anaerobic conditions promote denitrification – the conversion of nitrate into other gaseous forms of nitrogen which results in lower groundwater nitrate concentrations.

The amount of nitrate that leaches to groundwater is partially a function of soil type but also dependent on the types of crops that are grown. Potato and corn have significantly higher rates of nitrogen application than other crops such as alfalfa or soybean (Figure 10). The nitrate leaching losses are exacerbated by the sandy soils common to Portage County that do not hold onto water (and nutrients) as well as other soils (Figure 11).

Additional plots were created for other land covers; potato/vegetable land cover is used as a proxy for irrigated land (Figure 9b). The main observation is that many of the wells with the highest nitrate concentrations from Figure 9a are located in the same upper right quadrant of Figure 9b. This supports the results of the multiple linear regression analysis, which suggest that potato/vegetable land cover is a strong predictor of elevated

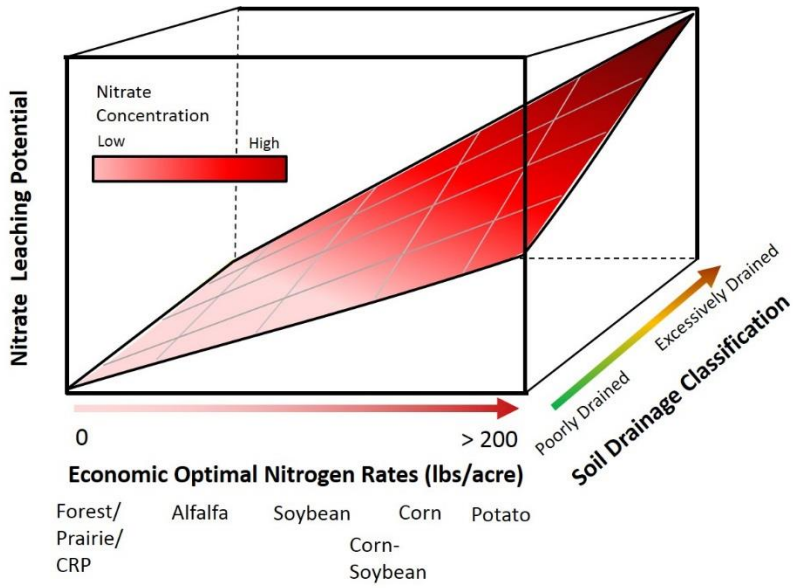


Figure 11. Diagram illustrating the relationship between various land covers as related to anticipated nitrogen contributions, soil drainage classification and potential for nitrate to be lost to groundwater.

nitrate in groundwater. The distribution of wells on Figure 9b is not as equal as that on Figure 9a. It is worth pointing out that while potato vegetable (irrigated fields) are a significant source of nitrate to groundwater, it is currently only a portion of agricultural activity in Portage County. The types of crops grown on irrigated fields and subsequent nitrogen application rates tend to be greater than non-irrigated fields. Conversion of dryland agriculture into irrigated acreage would likely result in increases to groundwater nitrate near those areas.

The low number of samples collected in areas with higher counts of septic systems make it difficult to compare the influence of small lot size and septic systems on well water quality (Figure 9d). While the grid sampling method ensured that samples were spatially distributed it only obtained 4 wells with a septic count greater than 100 septic systems within a ½-mile radius of the well.

However, previous work performed in Portage County provides insight into the role of septic system drainfields and lawn fertilizers on groundwater and nearby well water quality. A study on nitrate impacts from subdivisions showed that a minimum lot size of ~2 acres is needed in sandy areas to keep nitrate-nitrogen concentrations in nearby wells below the drinking water standard of 10 mg/L (Shaw et al., 1993).

A more recent study used both private wells and monitoring wells to investigate nitrate sources below a subdivision. Those wells that contained evidence of wastewater tracers from septic systems (i.e. artificial sweeteners and pharmaceuticals) ranged from 2-15 mg/L of nitrate-nitrogen. These results suggest that the shallow groundwater below subdivisions can be impacted by septic systems and other activities within and upgradient of the subdivision (McGinley et al., 2016).

Figure 9c highlights the value to groundwater of maintaining forest cover on the landscape. Even in areas classified as excessively drained, nitrate concentrations tended to be low in those areas with greater than 50% forestland.

Data collected for this inventory are similar to other datasets available for Portage County. The WI Well Water Viewer indicates a slightly lower mean concentration of 6.2 mg/L of nitrate-nitrogen and lower nitrate exceedance rates; 20% > 10 mg/L (CWSE, 2018). That patterns observed in the results of the voluntary testing behind the Well Water Viewer largely match those observed in this scientific study corroborates these voluntarily-submitted private well water samples, collected in Portage County since the 1970s (Figure 12). Inclusion of historical Portage County well testing data provides much greater resolution than was obtained in this study, however questions often are raised regarding the age of samples and how representative they may be of current well water quality.

A 1981 study showed a mean concentration of 5.2 mg/L and maximum of 32 mg/L of nitrate-nitrogen for Portage County

Figure 12. Nitrate-nitrogen concentrations by section for historical well water sampling data in Portage County. Samples represent data from the WI Well Water Quality Viewer (CWSE, 2018). Spatial patterns of nitrate concentrations are similar to those observed in the current study of nitrate (Figure D). Blank cells represent areas with insufficient data.

groundwater. This suggests that Portage County groundwater may contain slightly greater nitrate concentrations on average than what existed nearly 40 years ago (Kammerer, 1981). This would suggest that when summarizing historical well water quality data for Portage County, inclusion of samples before a certain date could be underestimating both the mean nitrate concentration and the percentage of samples that currently exceed the drinking water standard for nitrate. Additional analysis would be needed to understand how historical data compares to current water quality results.

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. It is also found in animal waste and other bio-solid amendments. Septic systems are also 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. 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 greater

than 250 mg/L, there may also be elevated levels of sodium in the water.

The average chloride concentration for Portage County was 22.0 mg/L; higher than what we would typically expect for natural concentrations of chloride in groundwater. The Town of Hull had the greatest mean concentration of chloride (Figure H).

A previous study that summarized chloride values for Portage County showed a mean concentration of 8.9 mg/L (Kammerer, 1981); providing evidence that chloride concentrations have likely been increasing over time.

Multiple linear regression was used to investigate the relationship of chloride to weighted drainage rank, normalized septic count, and the percentages of land cover classified as: potato/vegetable, continuous corn, and dairy rotation. While the model is only able to explain about 9% of the chloride variability, significant relationships were detected. The following variables provided evidence of positive relationships to chloride concentrations: percent potato/vegetable land cover (irrigated land) – very strong

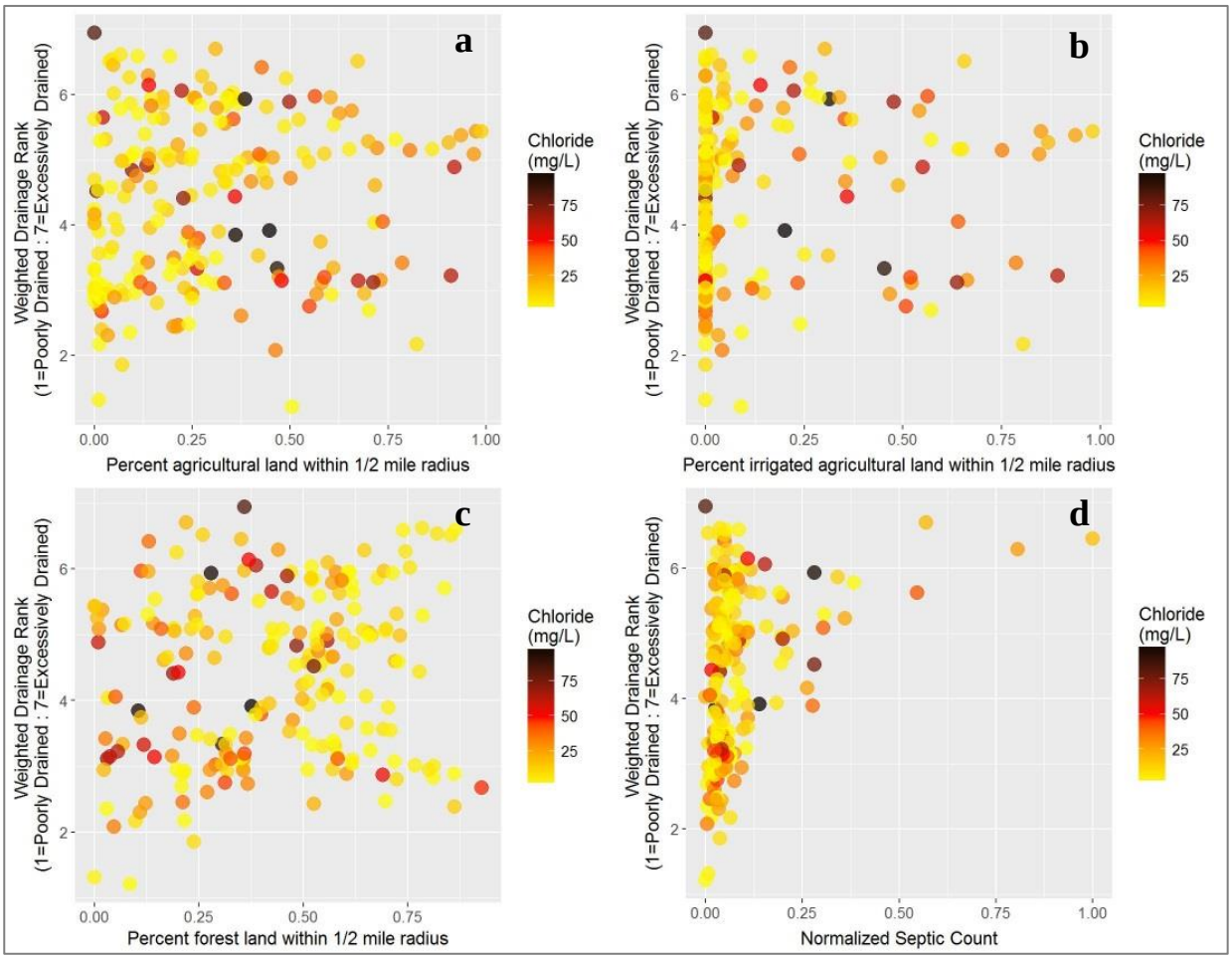


Figure 13. Chloride concentration as influenced by soil drainage classification and various land covers within a ½- mile radius of the well. a) Percent agricultural land (includes Wiscland 2.0 land covers for cash grain, continuous corn, dairy rotation, potato/vegetable, and cranberries). b) Irrigated agricultural land (Wiscland 2.0 land cover for potato/vegetable). c) Percent forest land (Wiscland 2.0 land covers for forest cover). d) Normalized septic count.

evidence ($p<0.001$), normalized septic count – moderate evidence ($p=0.033$), and percent dairy rotation land cover – weak evidence ($p=0.052$) (Appendix D).

Potassium is an essential nutrient to plants; and potassium amendments often contain significant amounts of chloride. 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. Potato and alfalfa have higher recommended potassium application rates than do many other crops including corn (Laboski and Peters, 2012). Alfalfa may occupy four out of six years in a field considered part of common dairy rotation (Wiscland 2.0). The relationship of chloride to potassium fertilizer recommendations potentially explains the significance of potato/vegetable and dairy rotation land covers in the model.

While normalized septic counts were not significant in the nitrate model, they are moderately important to the chloride model. This difference may be attributed to road salt and the strong influence winter deicing activities have on chloride variability in groundwater. In the model, normalized septic count may be acting as a proxy for areas of greater road density as well as accounting for chloride from septic system influences.

Weighted drainage rank was not significant in the chloride model. Because chloride is not as susceptible to biological uptake or other biological transformations, it often serves as a more conservative tracer or indicator of land-use impacts to groundwater. If soil drainage classification is a proxy for denitrification of nitrate, which chloride is not susceptible to – then this difference between the two ions could account for drainage classification not having a significant effect on chloride concentrations.

Similar to nitrate, plots were created illustrating the effects of weighted drainage class and various land covers on chloride concentrations (Figure 13). Given the relationships between variables of interest and chloride concentrations explained less of the variability, it is not surprising that the plots do not show clear associations. Figure 13c provides evidence of the benefit of forestland to groundwater quality. When greater than 50% of the land within a ½ mile radius around a well is forest land, there is a noticeable lack of chloride in those wells.

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.

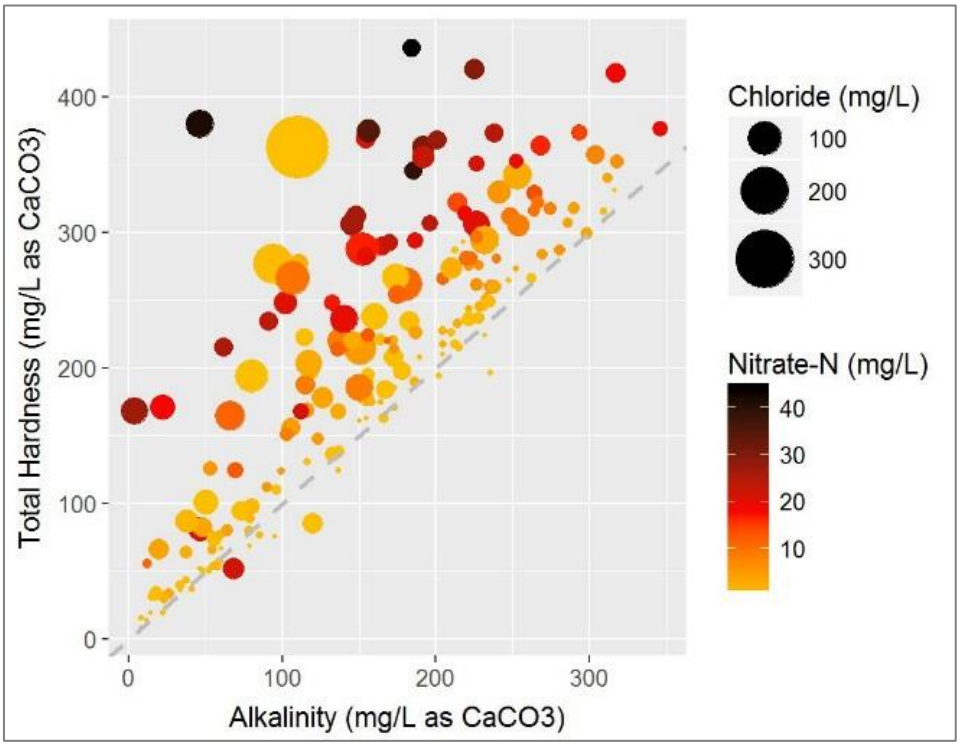
The average total hardness concentration for Portage County was 208 mg/L. Wells in the eastern part of Portage County generally contained harder water than the western portions of the county (Figure I). Wells in the Towns of Grant, Linwood, Carson, Eau Pleine and Dewey generally produced soft water (Figure J). Differences in the composition of aquifer materials is responsible for differences in hardness.

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 ($r = 0.82$). Similar to total hardness, eastern Portage County measured higher amounts of alkalinity, with significantly lower values found in the western

Figure 14. 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 show greater total hardness values than may be expected under natural conditions.



and northwestern portions of the county (Figure K). Differences in the chemical makeup of the geologic materials of Portage County are mostly responsible for these differences.

Alkalinity and total hardness should be roughly equal in groundwater because they form from the same minerals. Samples collected in Portage County reveal that total hardness was often greater than alkalinity, particularly in samples containing elevated levels of nitrate and chloride (Figure 14). Wells having elevated levels of nitrate and/or chloride 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.

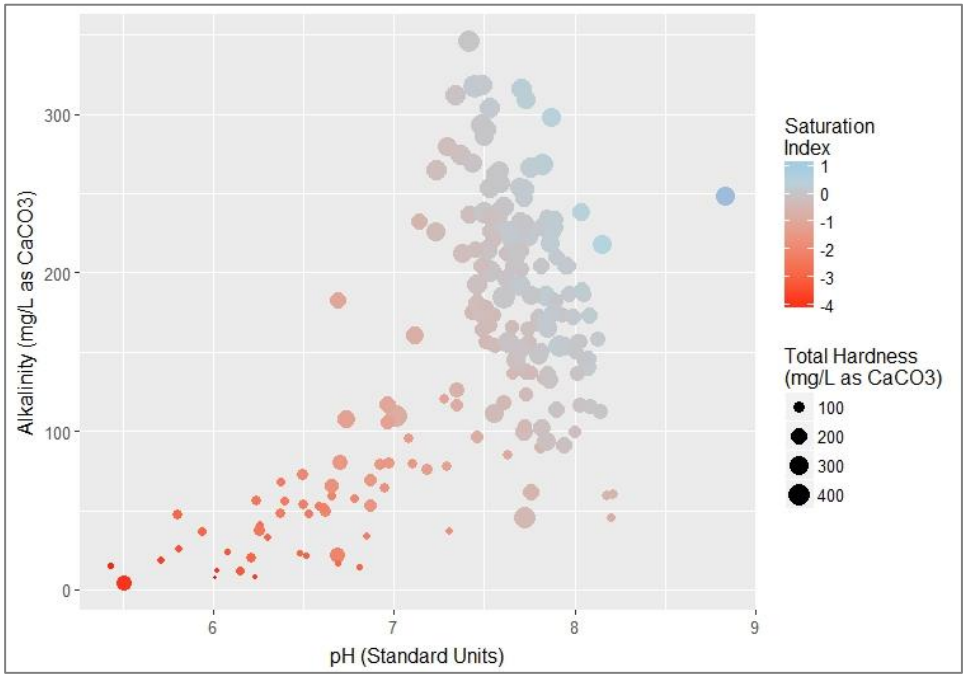
Eastern Portage County groundwater generally shows pH levels greater than 7.5 (Figure M). Levels of pH less than 7.0 were more likely to occur in wells tested in the western parts of the county in the Towns of Grant, Linwood, Carson, Eau Pleine and Dewey (Figure O).

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

Figure 15. 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). The data illustrate two distinct zones of groundwater quality; western Portage County, which has low hardness and corrosive water, and eastern Portage County, which has greater hardness levels, and water which is less corrosive.



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 15). 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; eastern Portage County's groundwater is fairly balanced with respect to the saturation index. Households served by private wells in the western part of the county may expect more problems with corrosion as indicated by the saturation index (Figure O & P).

Households in western Portage County that contain copper or lead in their plumbing system should consider testing for those elements, particularly if there are young children in the home.

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. However, chloride and nitrate also contribute to conductivity measurements.

Conclusions

Differences in the chemical makeup of aquifer materials creates two fairly distinct groundwater chemistry zones in Portage County. Wells in eastern Portage County generally produce water with higher total hardness, alkalinity and pH, while western Portage County wells produce water that is

generally corrosive (low total hardness, low alkalinity, low pH).

Thirty-nine percent of wells measured background or natural levels of nitrate (<1 mg/L), while 24% contained concentrations greater than the drinking water standard of 10 mg/L of nitrate-nitrogen. Soil drainage has a significant effect on the concentration of nitrate that ends up in well water. Concentrations of nitrate were elevated in areas near agricultural land cover, particularly fields where potato and corn are grown.

Forty-six percent of wells measured background or natural levels of chloride (<10 mg/L). Concentrations of chloride tended to be higher near urban areas and agricultural land cover, particularly fields where potatoes or alfalfa are grown.

This study provides an important benchmark of well water quality in Portage County. These results highlight the main factors responsible for well water quality, and provide a solid foundation for future studies that investigate how or if groundwater is changing over time.

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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
Portage County	214	5.43	8.83	**7.41**	28	1404	**439**	<4	346	**154**	9	436	**208**	<0.1	44.1	**6.5**	<0.6	351	**22.0**
T. of Alban	12	7.23	8.07	**7.78**	287	789	**470**	142	252	**195**	175	314	**247**	<0.1	20.4	**5.5**	2.1	59.7	**17.8**
T. of Almond	11	7.42	8.07	**7.77**	382	886	**593**	140	236	**206**	208	436	**297**	<0.1	44.1	**13.8**	1.9	65.8	**18.8**
T. of Amherst	11	7.45	7.91	**7.71**	412	805	**610**	132	317	**245**	218	418	**316**	<0.1	38.9	**11.4**	3.1	43.0	**18.0**
T. of Belmont	11	7.65	8.13	**7.86**	309	597	**433**	145	228	**185**	161	290	**225**	0.5	20.2	**5.8**	1.3	29.1	**8.3**
T. of Buena Vista	14	7.18	8.83	**7.78**	129	753	**488**	60	316	**190**	67	363	**248**	<0.1	29.9	**9.3**	1.2	40.9	**12.8**
T. of Carson	15	6.24	7.73	**7.04**	94	615	**333**	41	173	**111**	37	266	**144**	<0.1	16.6	**2.9**	1.0	102	**26.8**
T. of Dewey	14	6.39	7.63	**6.76**	52	488	**194**	24	95	**62**	50	165	**84**	<0.1	11.7	**1.6**	0.8	75.3	**14.6**
T. of Eau Pleine	12	5.81	8.07	**7.18**	94	431	**288**	26	148	**93**	34	178	**116**	<0.1	12.7	**3.4**	3.7	42.1	**19.5**
T. of Grant	22	5.71	8.20	**6.90**	28	547	**266**	8	232	**81**	9	277	**106**	<0.1	20.8	**1.7**	0.6	48.1	**14.7**
T. of Hull	11	5.43	8.03	**6.95**	57	1404	**415**	15	180	**85**	20	363	**163**	<0.1	16.8	**5.0**	1.8	351	**57.6**
T. of Lanark	9	7.51	7.93	**7.73**	350	626	**478**	136	290	**222**	185	322	**246**	<0.1	12.0	**4.0**	1.7	17.0	**8.3**
T. of Linwood	7	6.30	7.84	**7.06**	80	961	**410**	33	183	**89**	36	277	**127**	<0.1	0.4	**0.1**	1.3	138	**28.1**
T. of New Hope	10	7.29	7.91	**7.58**	404	714	**544**	154	312	**249**	197	369	**288**	<0.1	20.4	**5.6**	1.8	31.0	**10.2**
T. of Pine Grove	10	7.38	8.18	**7.84**	169	923	**547**	46	218	**120**	77	380	**245**	<0.1	42.0	**15.8**	1.2	91.7	**31.6**
T. of Plover	11	5.51	8.14	**7.21**	244	644	**500**	<4	186	**99**	52	306	**191**	<0.1	26.7	**15.4**	3.2	62.6	**37.2**
T. of Sharon	16	6.15	7.99	**7.50**	154	827	**535**	12	346	**211**	56	376	**261**	<0.1	22.4	**5.9**	1.9	70.7	**26.5**
T. of Stockton	12	7.43	8.09	**7.74**	390	730	**535**	115	318	**223**	188	373	**278**	0.4	24.1	**9.1**	1.3	29.3	**15.4**
V. of Amherst Junction	1	-	-	**7.69**	-	-	**675**	-	-	**254**	-	-	**305**	-	-	**8.7**	-	-	**40.2**
V. of Junction City	1	-	-	**6.70**	-	-	**468**	-	-	**80**	-	-	**194**	-	-	**0.1**	-	-	**96.8**
V. of Plover	2	7.73	7.79	**7.76**	566	638	**602**	138	160	**149**	-	-	**220**	7.7	8.6	**8.2**	57.8	82.9	**70.4**
V. of Rosholt	1	-	-	**7.87**	-	-	**618**	-	-	**298**	-	-	**299**	-	-	**3.5**	-	-	**9.7**
C. of Stevens Point	1	-	-	**8.02**	-	-	**361**	-	-	**136**	-	-	**168**	-	-	**3.0**	-	-	**20.5**

† Softened samples excluded from summary of total hardness.

APPENDIX B

Summary of water quality results by category

Summary — UWEX Private Well Project

Portage County Well Water Inventory — 2017

2/4/2018 9:34 PM

Total Number Samples: 214 Sample Dates: 6/5/2017 to 9/26/2017

pH		
... 5.00	0	0 %
5.01 - 6.00	6	3 %
6.01 - 7.00	43	20 %
7.01 - 8.00	143	67 %
8.01 - 9.00	22	10 %
9.01 ...	0	0 %
Avg: 7.41 for 214 Samples		

Conductivity (umhos/cm)		
... 100	14	7 %
101 - 250	32	15 %
251 - 500	89	42 %
501 - 750	67	31 %
751 - 1000	11	5 %
1001 ...	1	<1 %
Avg: 439 for 214 Samples		

Alkalinity (mg/L CaCO3)		
... 50	30	14 %
51 - 100	34	16 %
101 - 200	76	36 %
201 - 300	67	31 %
301 - 400	7	3 %
401 ...	0	0 %
Avg: 154 for 214 Samples		

Total Hardness (mg/L CaCO3)		
... 50	32	15 %
51 - 100	27	13 %
101 - 200	43	20 %
201 - 300	73	34 %
301 - 400	36	17 %
401 ...	3	1 %
Avg: 193 for 214 Samples		

Nitrate (mg/L as N)		
None Detected	59	28 %
... 2.0	42	20 %
2.1 - 5.0	34	16 %
5.1 - 10.0	27	13 %
10.1 - 20.0	28	13 %
20.1 ...	24	11 %
Avg: 6.5 for 214 Samples		

Chloride (mg/L)		
None Detected	0	0 %
... 10	100	47 %
11 - 50	90	42 %
51 - 100	21	10 %
101 - 200	2	<1 %
201 ...	1	<1 %
Avg: 22 for 214 Samples		

Saturation Index		
... -3.0	21	10 %
-2.9 - -2.0	21	10 %
-1.9 - -1.0	24	11 %
-0.9 - 0.0	77	36 %
0.1 - 1.0	70	33 %
1.1 ...	1	<1 %
Avg: -0.8 for 214 Samples		

APPENDIX C

Maps

Figure A. Agricultural land cover classification (Wiscland 2.0) 26

Figure B. Soil drainage classification (SSURGO) 26

Figure C. Urban landcover and major roadways of Portage County 27

Figure D. Forest landcover (Wiscland 2.0) 27

Figure E. Nitrate-nitrogen concentrations by grid cell 28

Figure F. Nitrate-nitrogen concentration summarized by municipality 28

Figure G. Chloride concentration by grid cell 29

Figure H. Chloride concentration summarized by municipality 29

Figure I. Total hardness concentration by grid cell 30

Figure J. Total hardness concentration summarized by municipality 30

Figure K. Alkalinity concentration by grid cell 31

Figure L. Alkalinity concentration summarized by municipality 31

Figure M. pH by grid cell 32

Figure N. pH summarized by municipality 32

Figure O. Saturation index by grid cell 33

Figure P. Saturation index summarized by municipality 33

Figure Q. Conductivity by grid cell 34

Figure R. Conductivity summarized by municipality 34

Figure A.

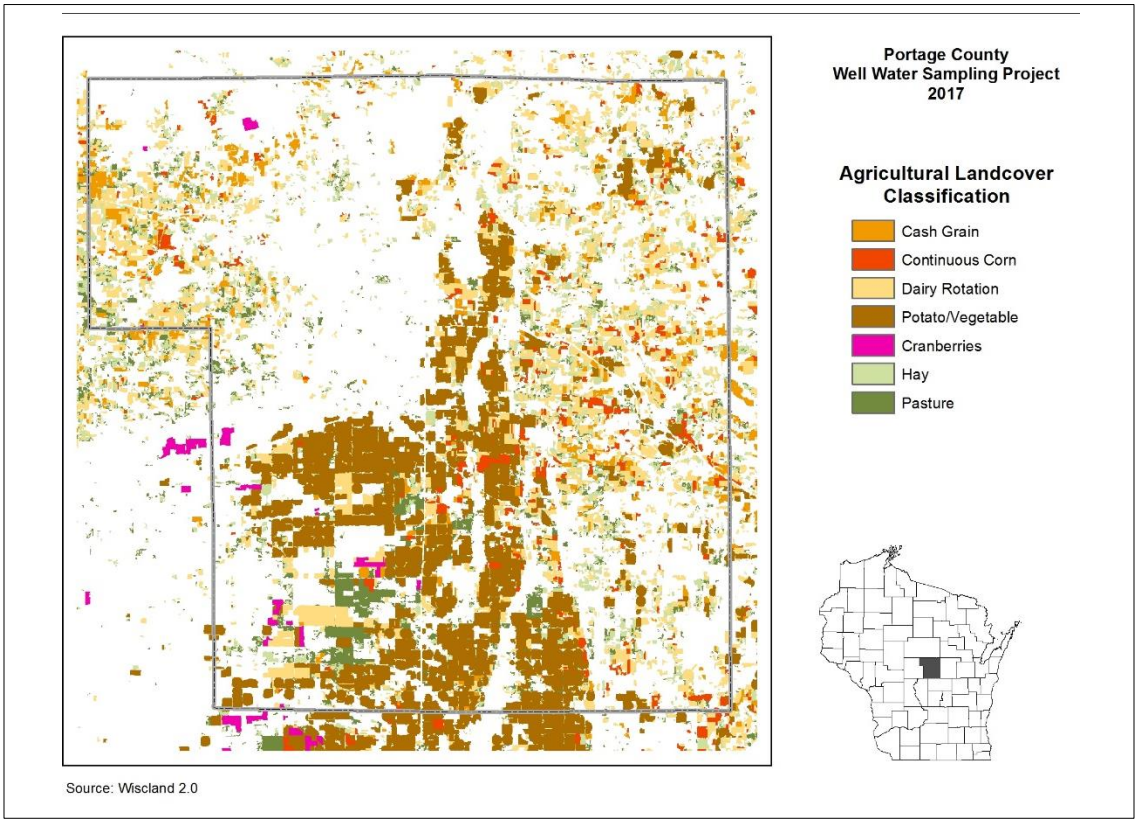


Figure B.

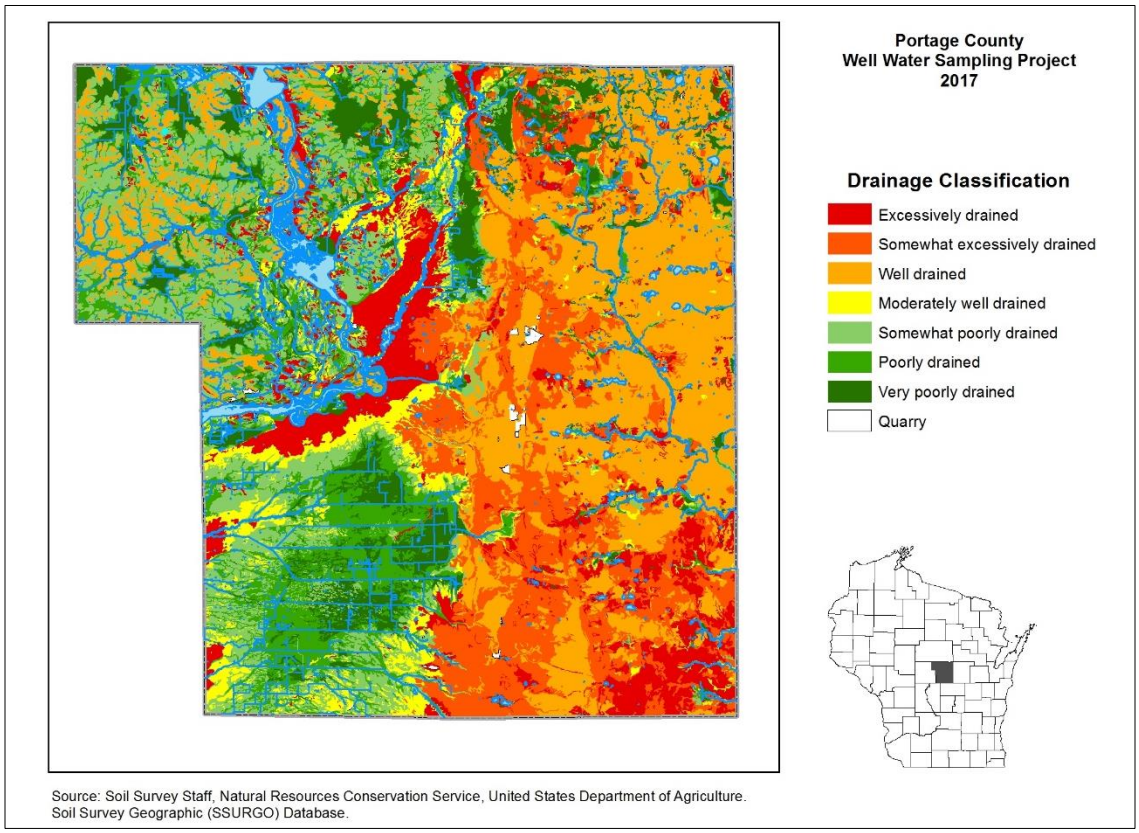


Figure C.

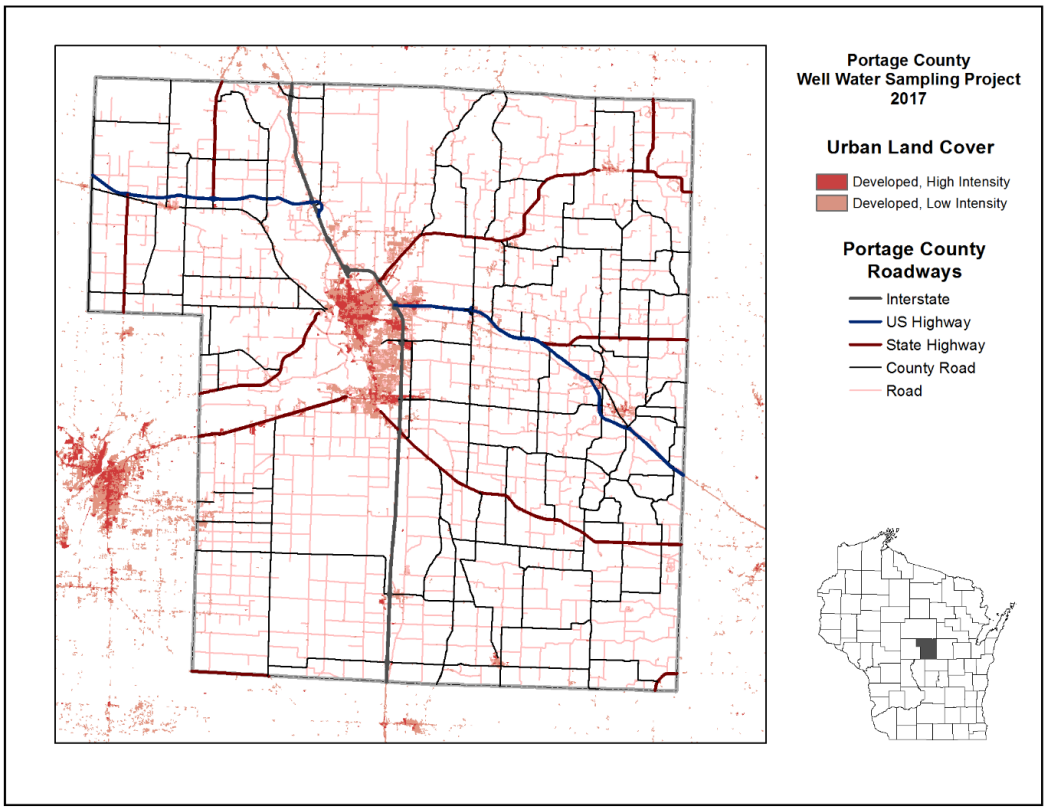


Figure D.

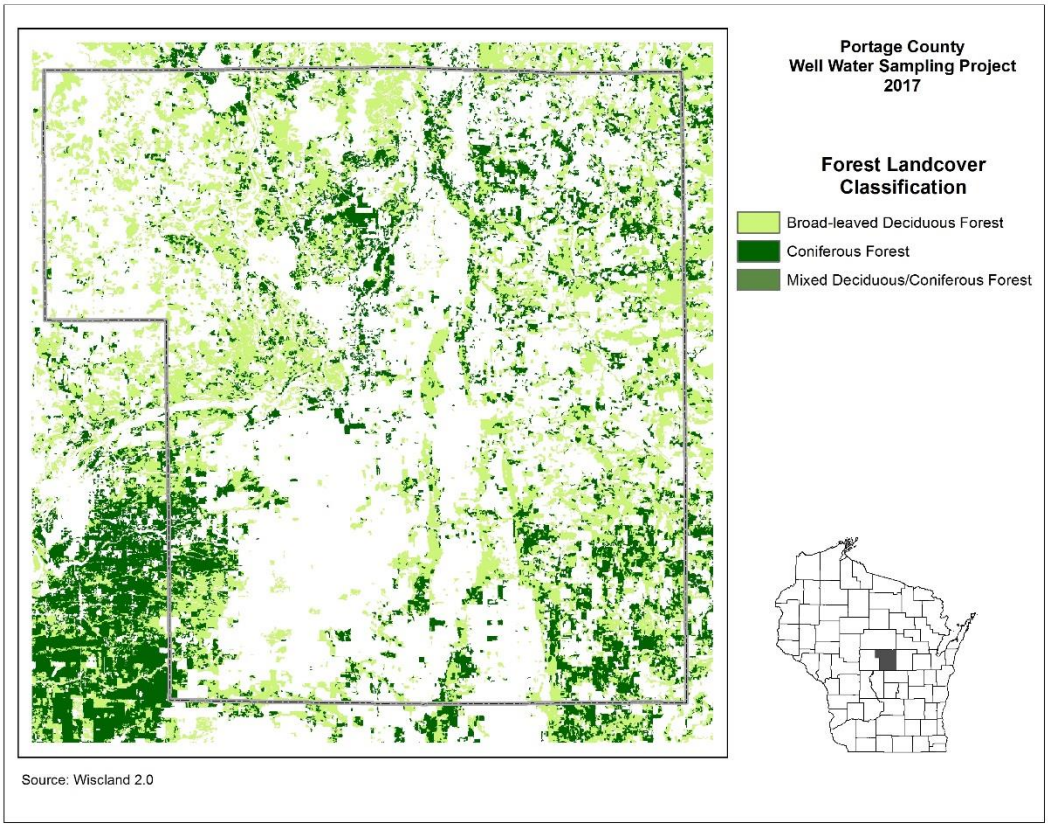


Figure E.

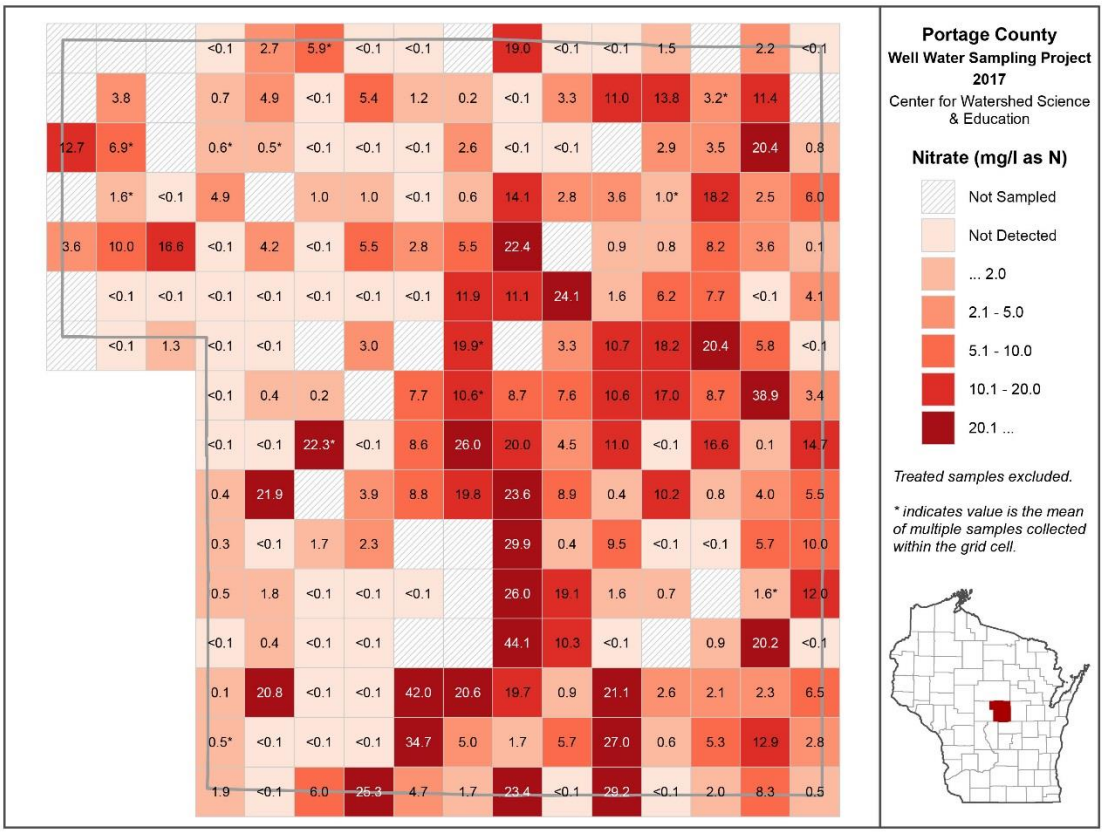


Figure F.

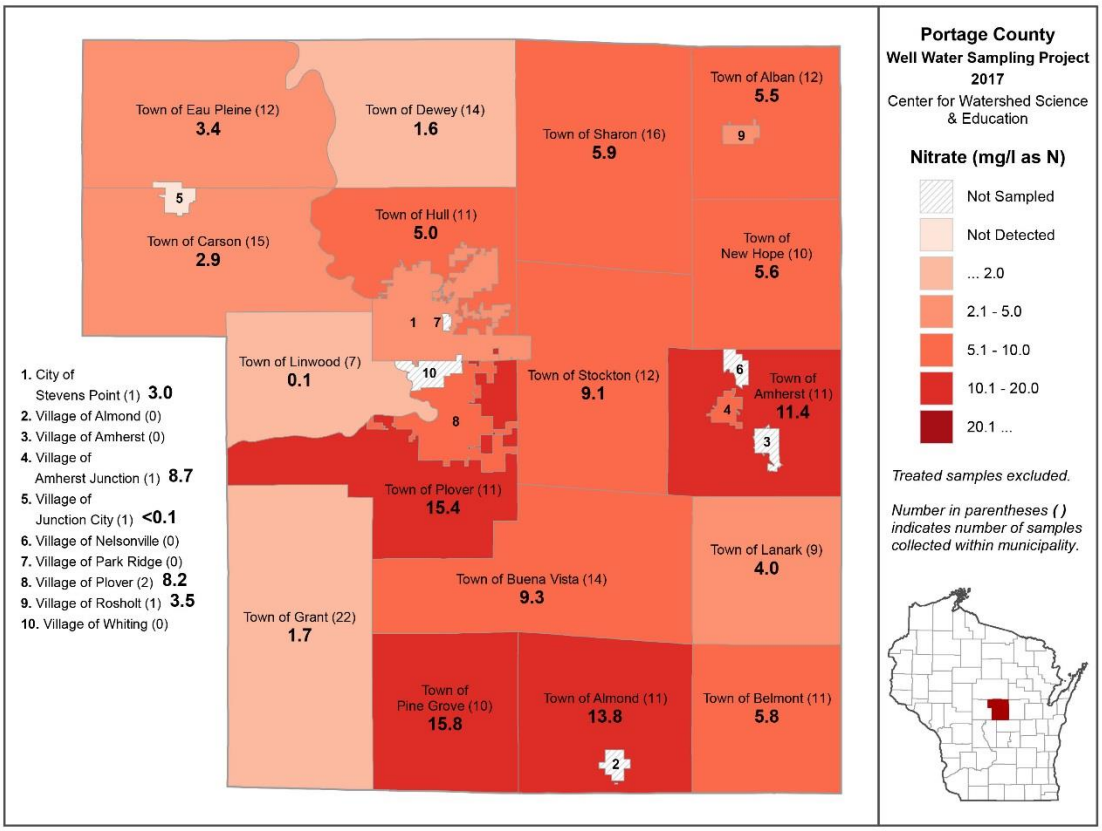
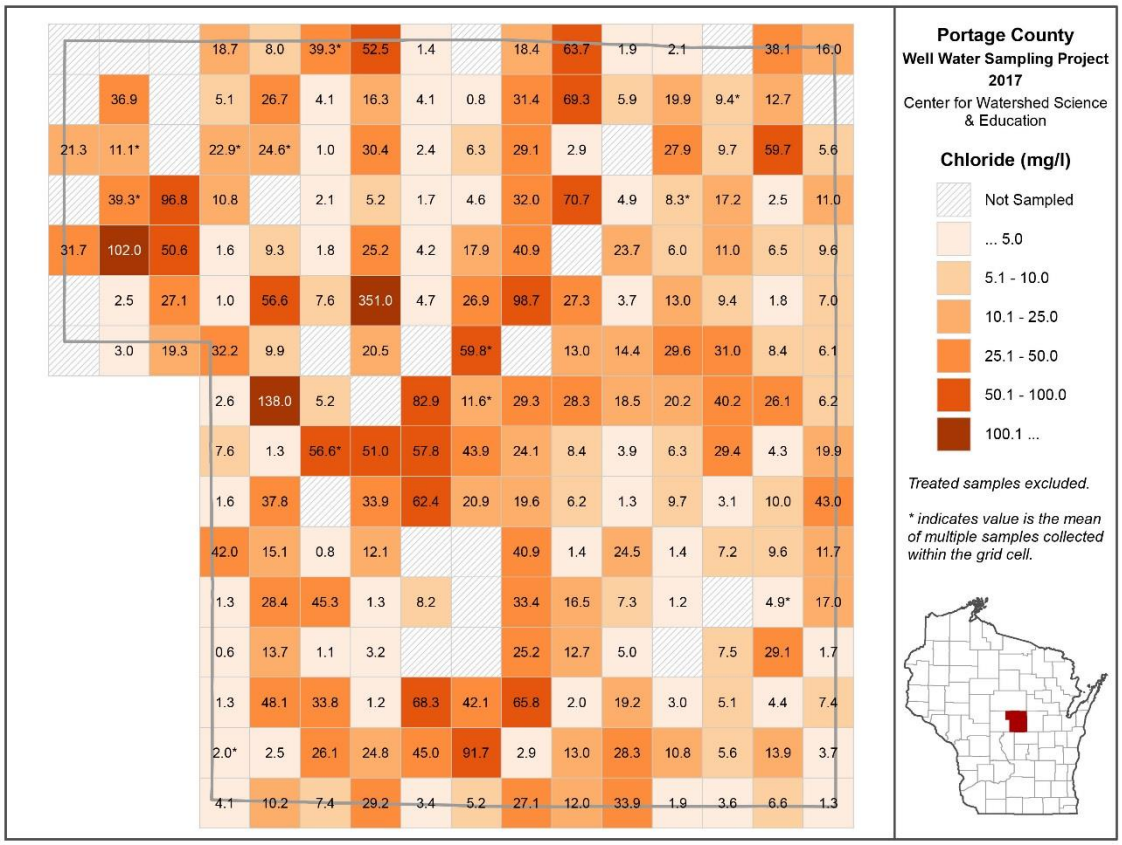


Figure G.



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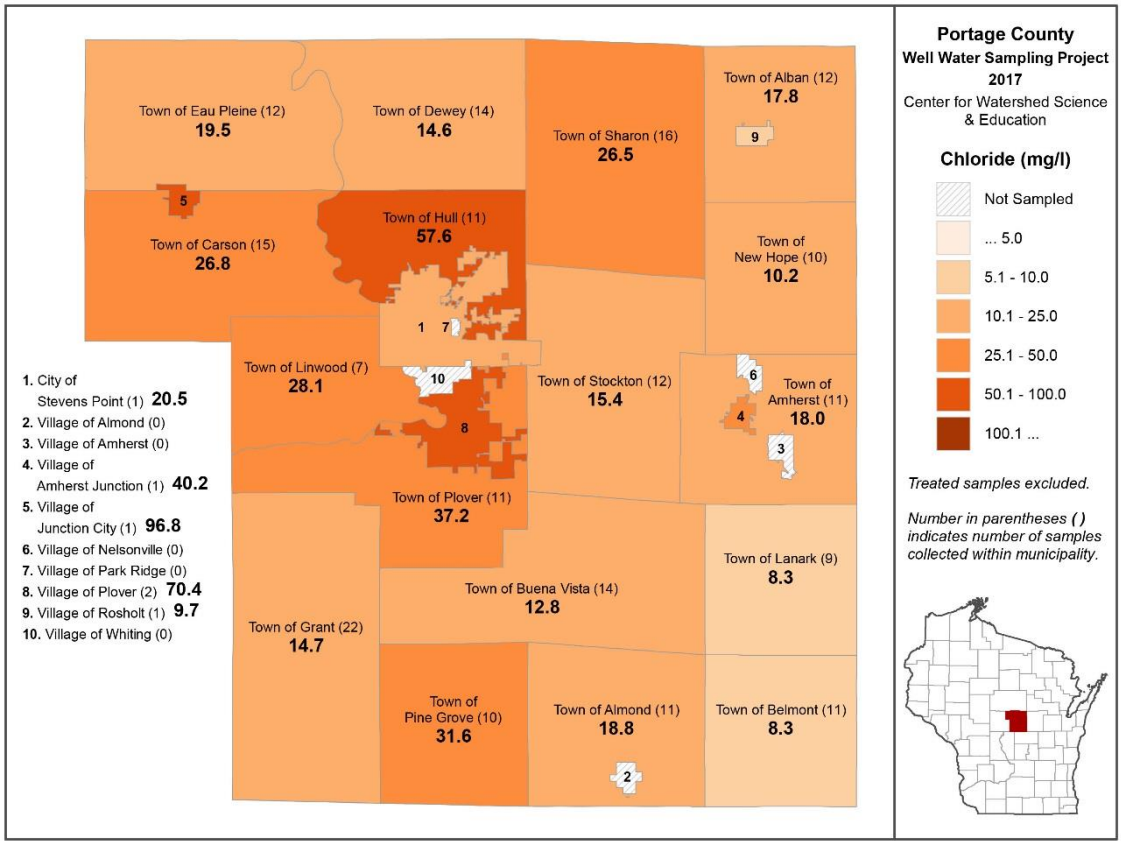
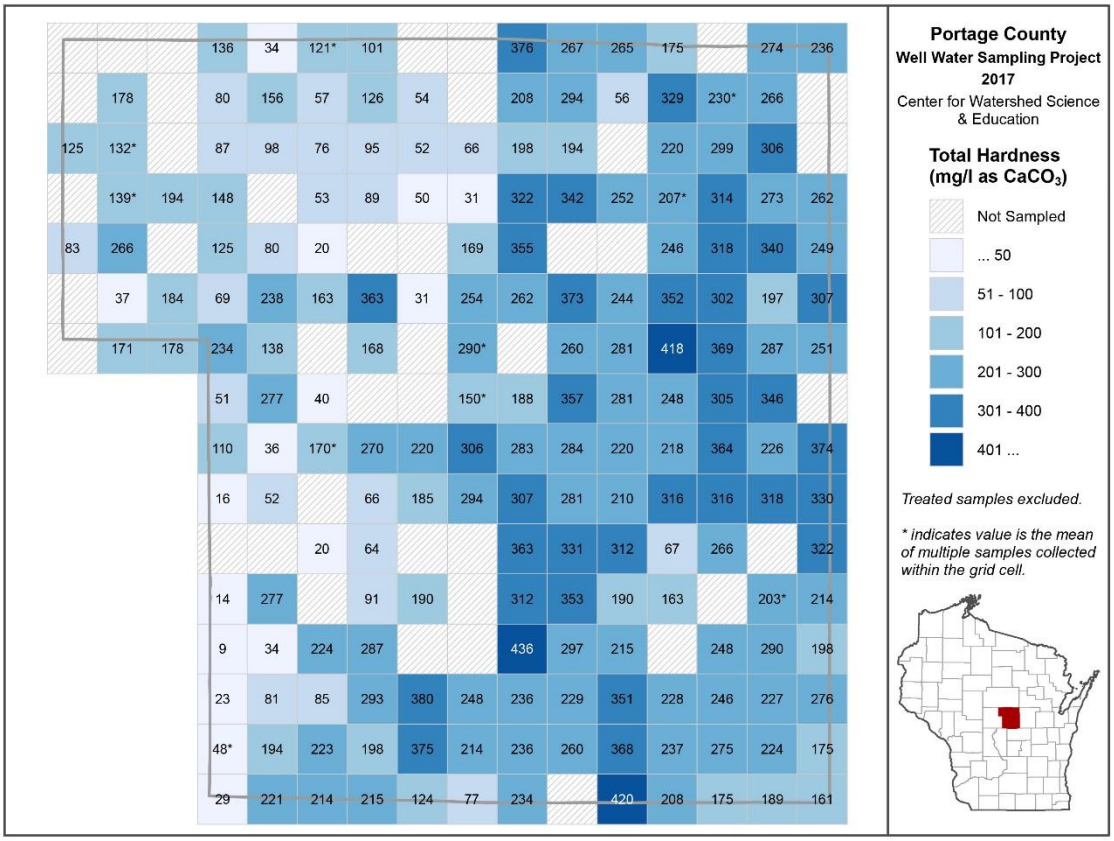


Figure I.



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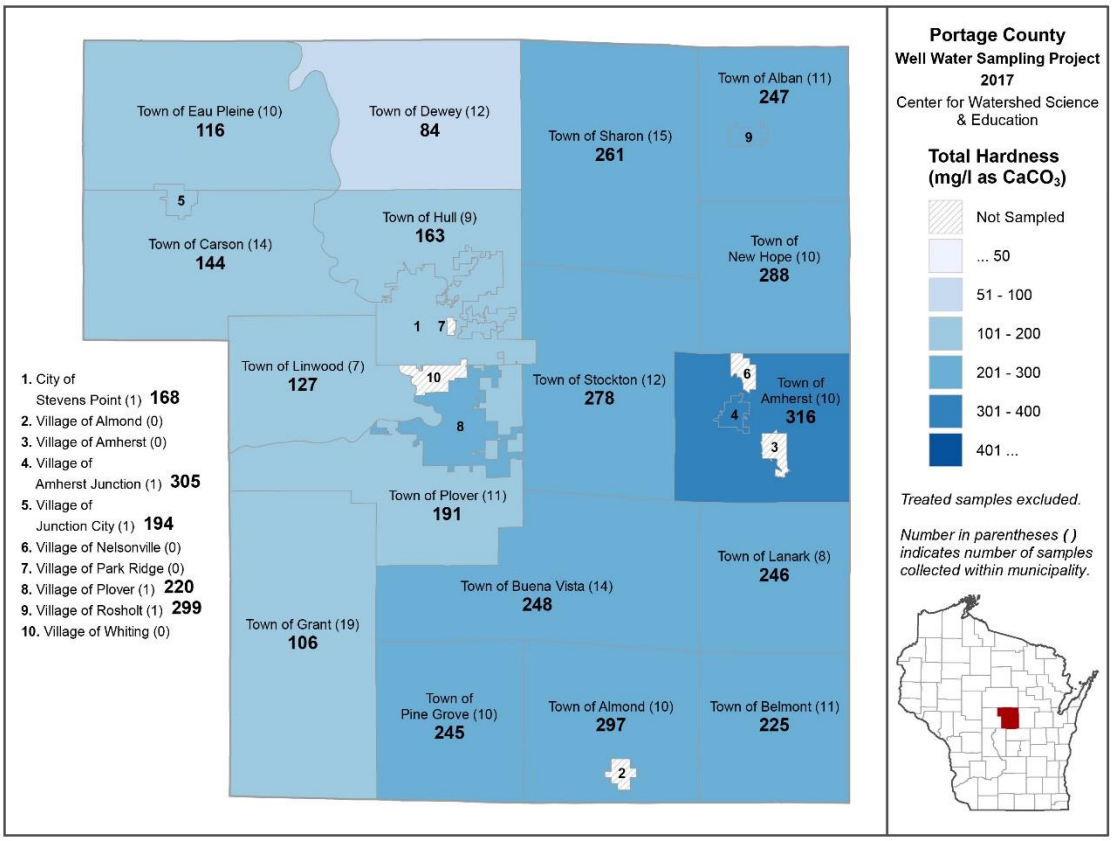

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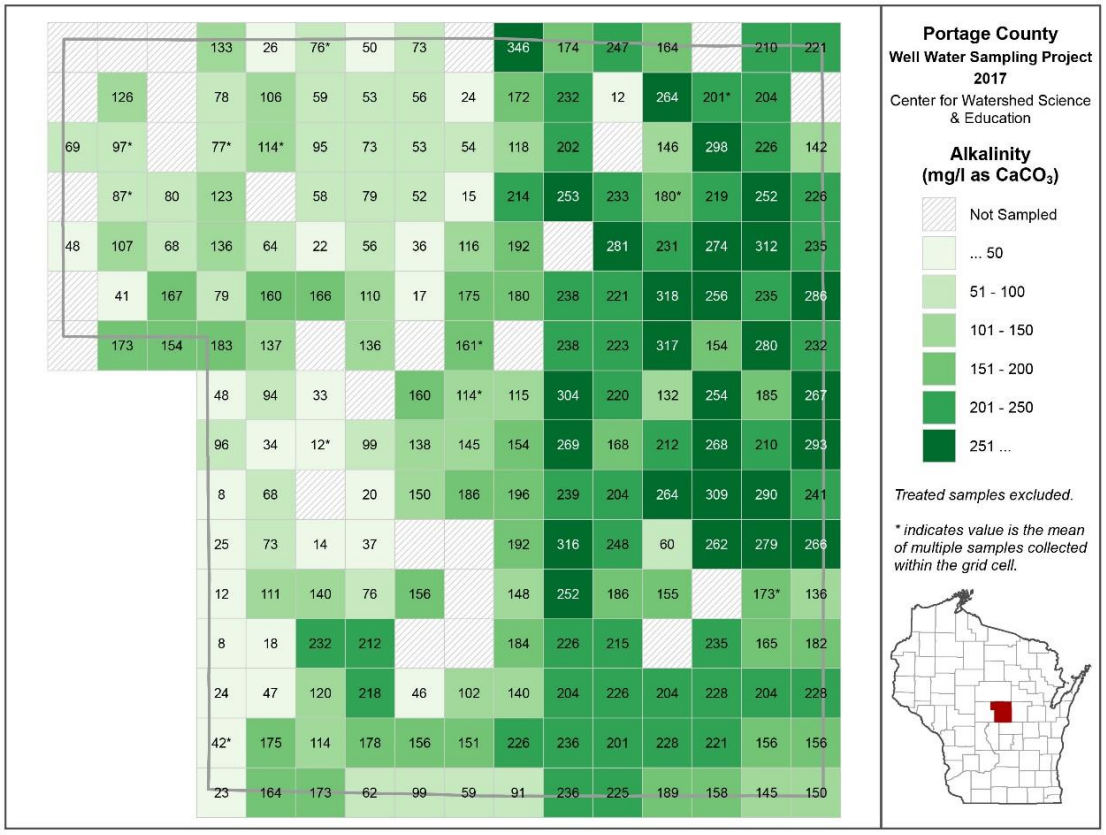

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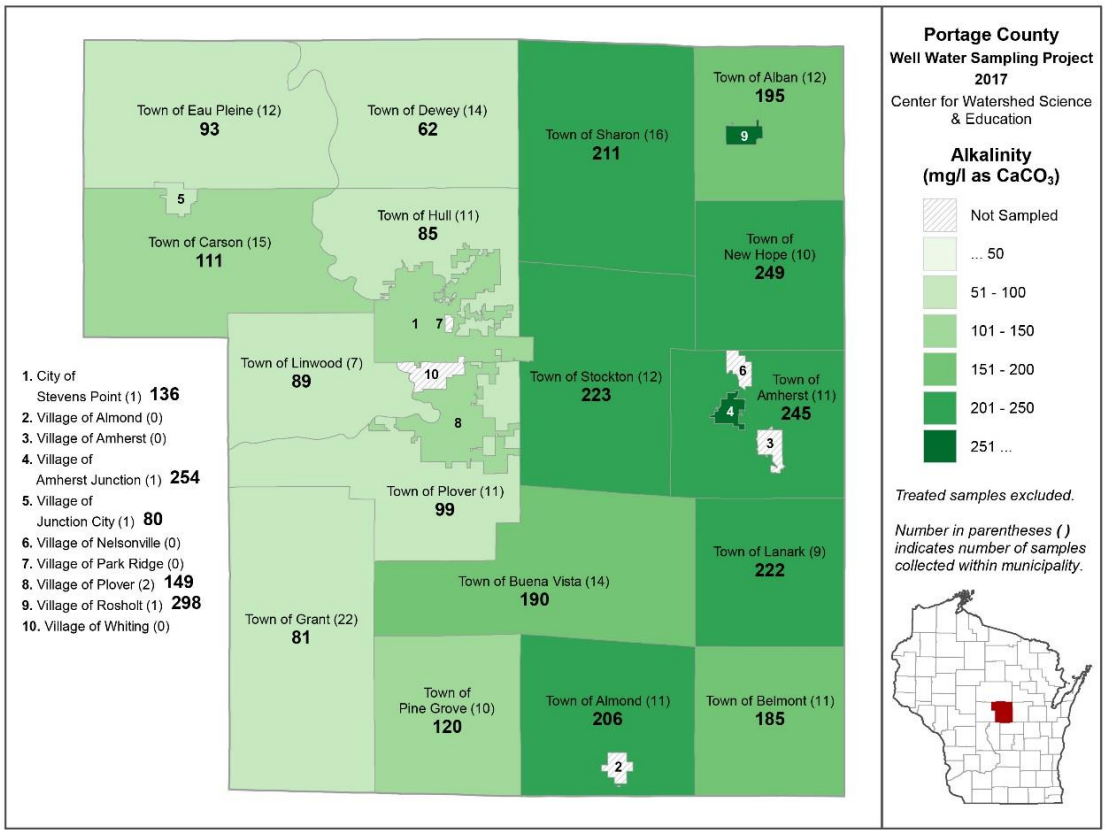

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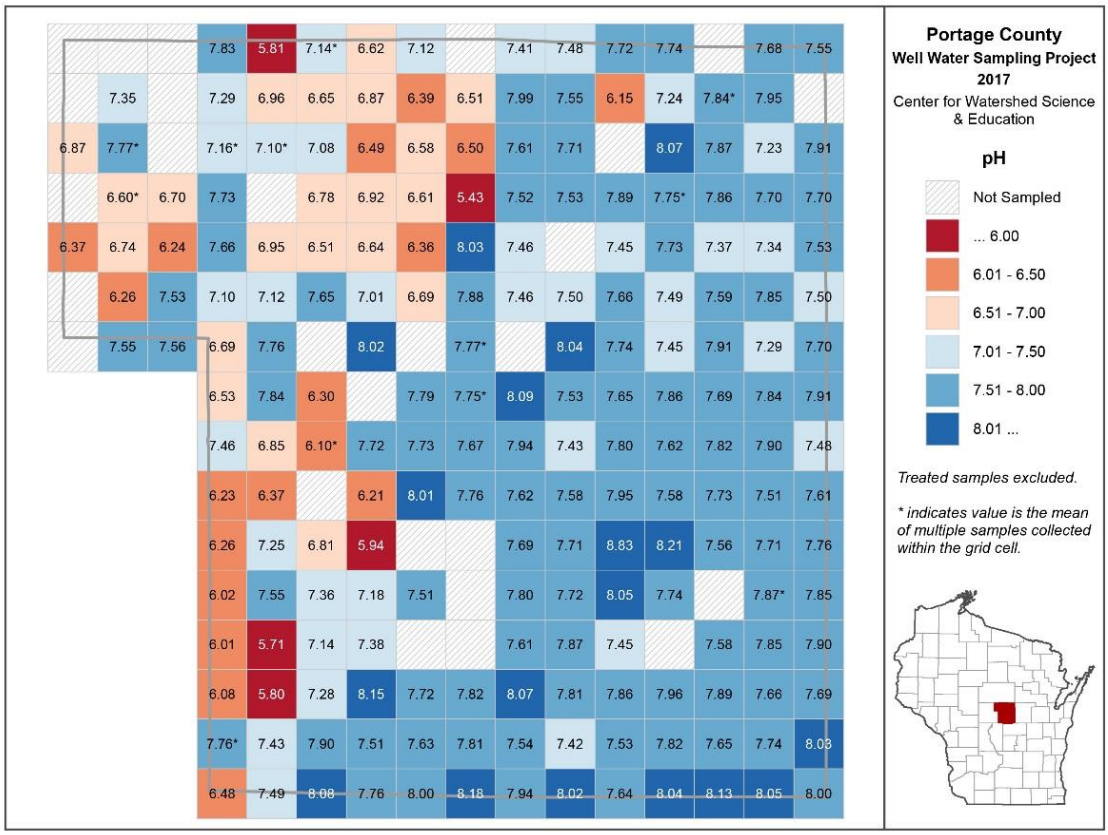

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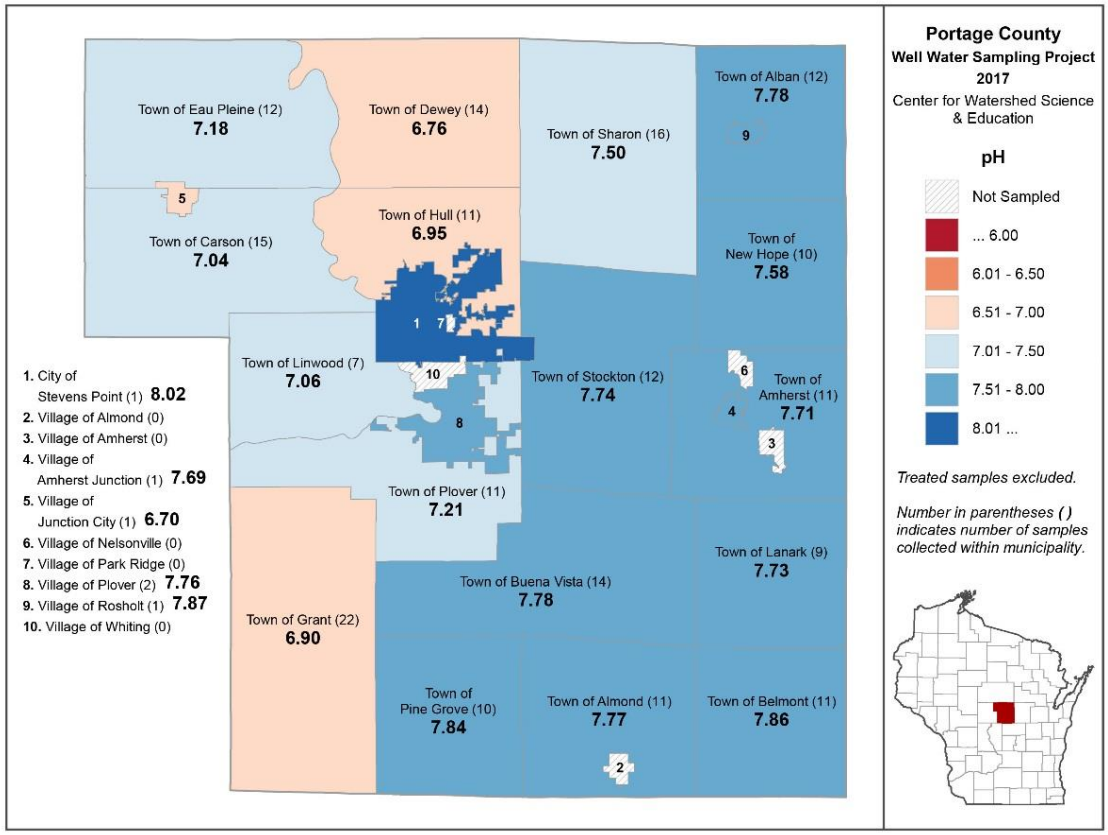
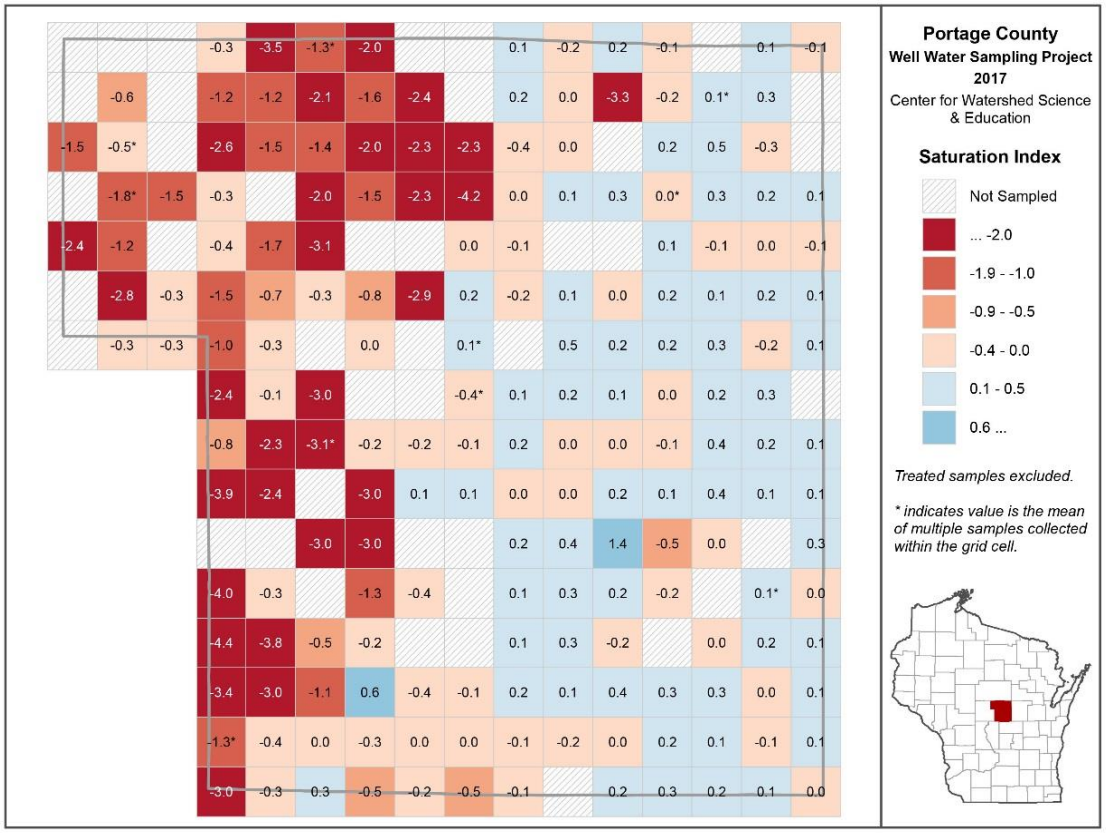


Figure O.



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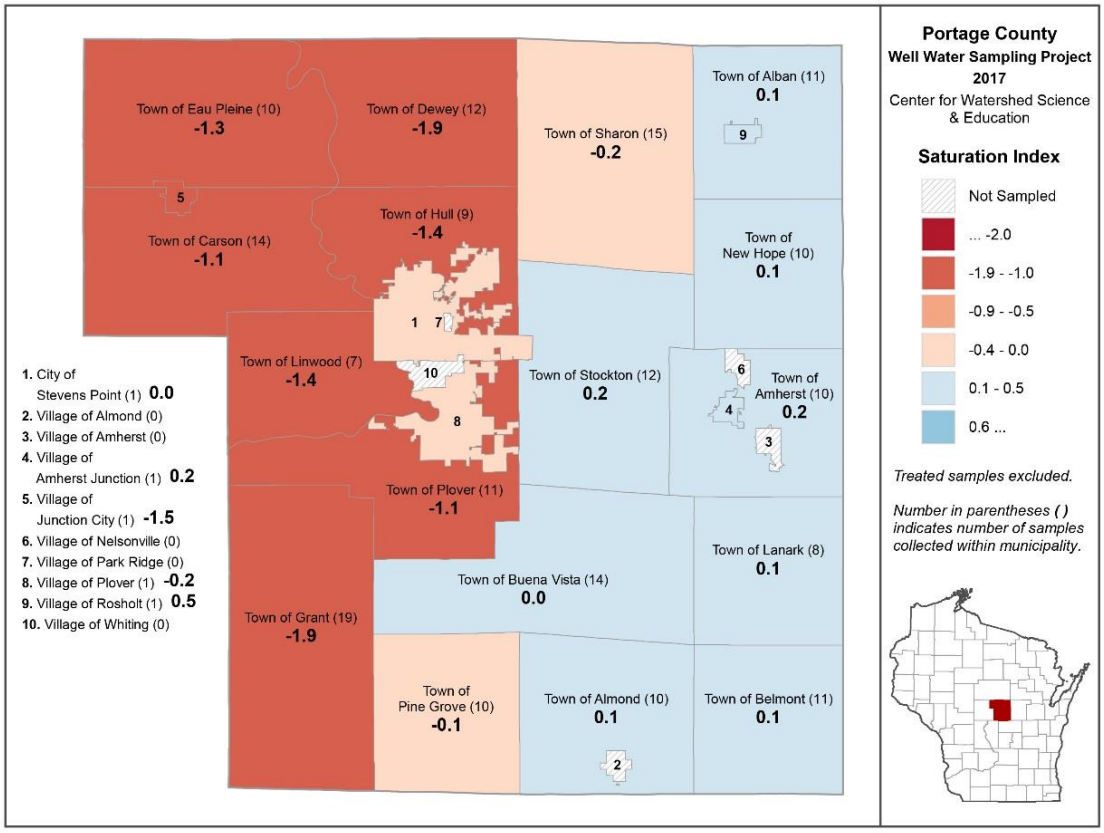


Figure Q.

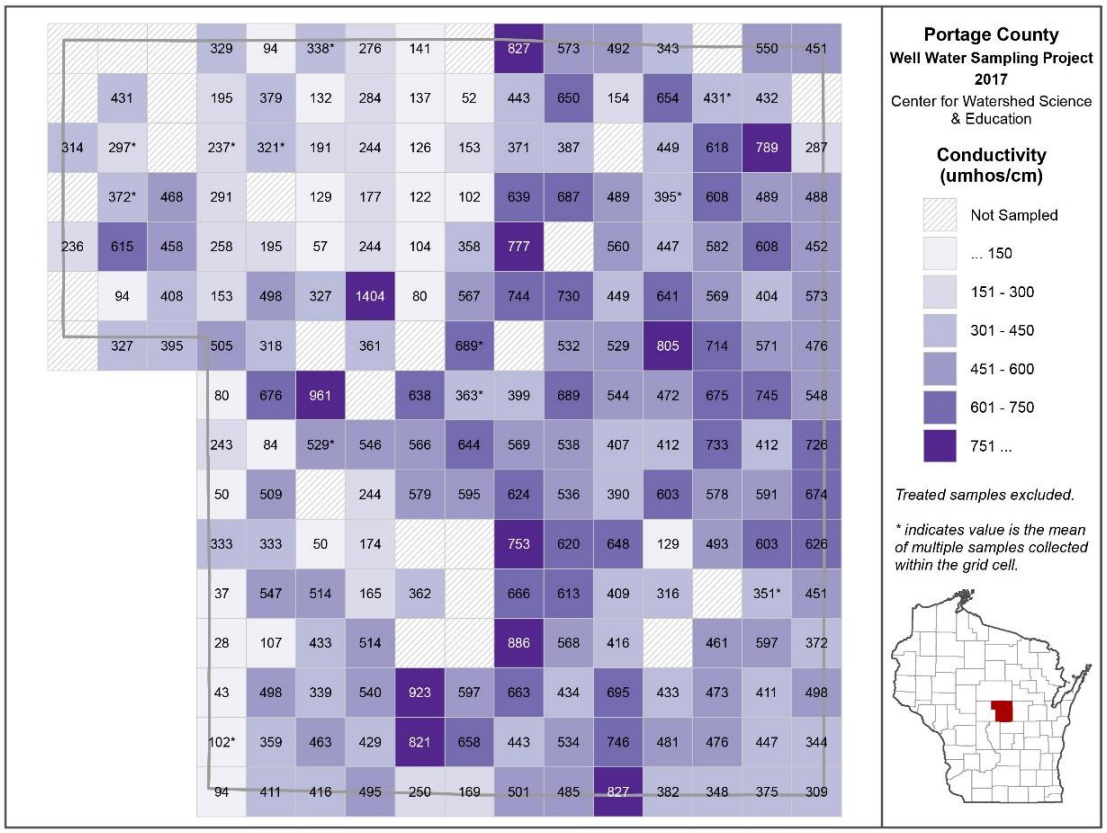
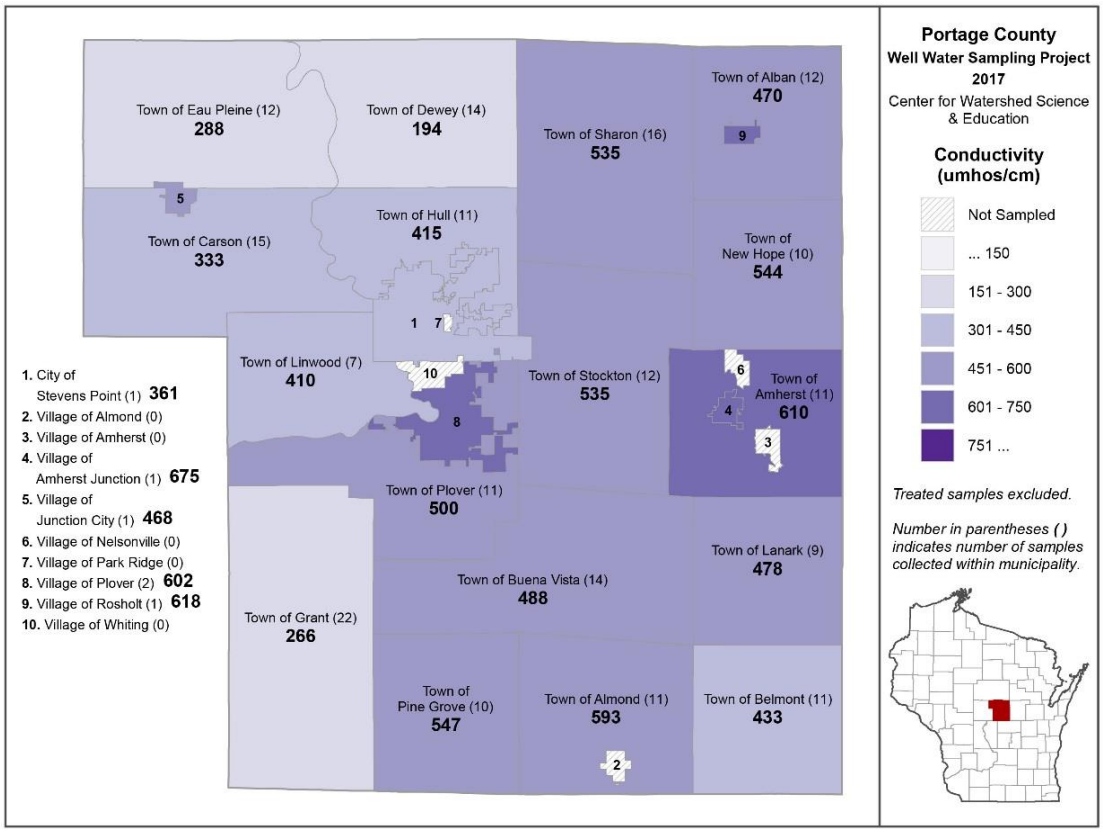


Figure R.



APPENDIX D – Statistical Analysis: Output from R (version 3.4.3)

Multiple linear regression dependent and independent variable explanation:

NITRATE_SQRT: square root transformation of the Portage County well water nitrate concentrations.
LOG_CHLORIDE: log transformation of the Portage County well water chloride concentrations.
IRR_PERCENT: Percent of land within ½ mile radius of well classified as Potato/Vegetable (Class ID- 2140, Wiscland 2.0). After inspecting the data, Class ID 2140 was used as proxy for irrigated land.
WEIGHTED_AVG_RANK: Weighted rank of drainage classification assigned to ½ mile radius around each well (1 = poorly drained, 7=excessively drained)
CORN: Percent of land within ½ mile radius of well classified as continuous corn (Class-ID-2120).
DAIRY: Percent of land within ½ mile radius of well classified as dairy rotation (Class-ID-2130).
S_COUNT_N: Count of parcels with septic system that intersect or are contained within ½ mile radius of well.

```
Call:
lm(formula = NITRATE_SQRT ~ IRR_PERCENT + CORN + DAIRY + S_COUNT_N +
    WEIGHTED_AVG_RANK, data = portage_combined)
Residuals:
    Min      1Q  Median      3Q     Max
-3.2630 -1.0333 -0.1081  0.8896  4.2594

Coefficients:
                  Estimate Std. Error t value Pr(>|t|)
(Intercept)       -0.37920    0.36320  -1.044  0.29767
IRR_PERCENT        3.00392    0.44361   6.771 1.28e-10 ***
CORN               5.61044    2.03259   2.760  0.00629 **
DAIRY              1.62599    0.86032   1.890  0.06015 .
S_COUNT_N          0.57190    0.90994   0.628  0.53037
WEIGHTED_AVG_RANK  0.36048    0.08263   4.363 2.02e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.41 on 208 degrees of freedom
Multiple R-squared:  0.3035, Adjusted R-squared:  0.2867
F-statistic: 18.12 on 5 and 208 DF,  p-value: 6.509e-15

Call:
lm(formula = LOG_CHLORIDE ~ IRR_PERCENT + CORN + DAIRY + S_COUNT_N +
    WEIGHTED_AVG_RANK, data = portage_combined)
Residuals:
     Min       1Q   Median       3Q      Max
-1.12686 -0.39173  0.02948  0.37778  1.68534

Coefficients:
                  Estimate Std. Error t value Pr(>|t|)
(Intercept)        0.87719    0.13669   6.417 9.21e-10 ***
IRR_PERCENT        0.69031    0.16695   4.135 5.15e-05 ***
CORN               0.31579    0.76497   0.413   0.6802
DAIRY              0.60281    0.32378   1.862   0.0640 .
S_COUNT_N          0.74413    0.34246   2.173   0.0309 *
WEIGHTED_AVG_RANK -0.01435    0.03110  -0.462   0.6449
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5306 on 208 degrees of freedom
Multiple R-squared:  0.09039,         Adjusted R-squared:  0.06853
F-statistic: 4.134 on 5 and 208 DF,  p-value: 0.001335
```

APPENDIX E - Corrections

Edited document on November 27, 2018.

Page 16, paragraph 5 incorrectly referred to Figure 8c. The paragraph was corrected to reference Figure 9c.