CHARACTERIZATION OF GROUNDWATER FROM RICE COUNTY, MINNESOTA

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ABSTRACT

A report on the quality of well water was compiled for Rice County, Minnesota, using data from the Minnesota Department of Natural Resources (DNR), the Minnesota Pollution Control Agency (MPCA), the Minnesota Nitrate Volunteer Monitoring Network (VNMN), and data collected by the authors of this study. The Minnesota County Well Index (CWI) was used to find wells with a variety of depths, geologic units, and distances to nearest feedlots. A variety of well uses was sought, but wells in Rice County are primarily domestic, and this is reflected in our dataset. After linking the datasets together, the most comprehensive data set was on nitrate. There was also data on other ions such as, iron, sodium, calcium, potassium, arsenic, and lead. Field data was also collected by the authors of this study and the DNR for pH, conductivity, salinity, and temperature. Generally, the eastern part of the county has a higher elevation, more farmland, higher nitrate levels, and lower pH levels. Throughout the county all reliable measurements of nitrate and trace metals were below the maximum contaminant level.

INTRODUCTION

Over one million Minnesotans get their drinking water from private wells, an estimated 23% of the state (Lewandowski et al., 2008). Rice County alone has an estimated number of 16,000 of private wells (Wei-Hsin Fu, personal communication). Within the county, high oxidation levels in the Prairie du Chien, Jordan and Franconia aquifers make the drinking water particularly contaminated by chemicals such as nitrate and lead (MPCA, 1999). Furthermore, because of the county's agriculturally dominated landscape, local groundwater systems are more likely to be contaminated by animal waste, fertilizer runoff, and chemical pollutants used in large-scale farming operations, all of which are linked to higher levels of nitrates and phosphates.

Located in south-central Minnesota, Rice County has an area of 496 square miles and varies in elevation from about 270 meters to 390 meters above sea level (Fig. 1; DNR, 1995). The total population of the county is 63,034 residents, predominately concentrated around the two largest cities, Faribault and Northfield. Much of the land in Rice County land is used for agricultural purposes (Fig. 2; DNR, 1995) and there are 1640 feedlots evenly distributed throughout the county (Fig. 3; DNR, 1995).

In order to keep local residents informed and better characterize the hydrogeology of the region, the Carleton College Geochemistry of Natural Waters class conducted a ten-week study on groundwater quality in Rice County, Minnesota. The main focus of the study is the spatial analysis of groundwater trends in the county, through the use of a combination of data sampled by the geochemistry class and well water data from government agencies and other non-profit organizations.

GEOLOGIC SETTING

The bedrock below Rice County is primarily comprised of sandstone, limestone, and shale. These sedimentary formations are the result of deposition during alternating periods of transgression and regression in Cambrian and Ordovician epieric seas. Major rock formations represented in Rice County include the Franconia Formation, the St. Lawrence Sandstone, the Jordan Sandstone, the Prairie Du Chien Group, the Platteville Limestone, the Decorah Shale, the

Galena Limestone, and the St. Peter Sandstone (Fig. 4; Berg, 1954; Smith et al., 1993; Runkel, 1994).

The major hydrologic unit in our study area is the Cambian-Ordovician Aquifer system (Olcott, 1992). This aquifer complex consists of the St. Peter Aquifer and the Prairie du Chien-Jordan Aquifer (Ruhl and Wolf, 1983b). It is bounded below by the St. Lawrence Formation, which is largely composed of dolomite and dolomitic siltstone, and above by the Maquoketa confining unit, which consists of the Galena Limestone, Decorah Shale, Platteville Limestone, and Glenwood Shale, among other units (Fig. 5; Olcott, 1992). The St. Peter and Prairie du Chien-Jordan Aquifers are separated by the St. Peter confining bed, a layer of siltstone and shale at the base of the St. Peter Sandstone (Ruhl and Wolf, 1983a). The County Well Index differentiates between the Prairie du Chien and Jordan aquifers; however, there are no confining features separating the two stratigraphic units (Fig. 6; Ruhl and Wolf, 1983a), meaning that water is able to flow between them. Therefore, we claim that the Prairie du Chien and Jordan aquifers should be thought of as one larger aquifer.

Aside from the Cambrian-Ordovician Aquifer system, the only other aquifer that we sampled from was the Quaternary Buried Artesian Aquifer (“Buried Confined” aquifer in western Rice County in Fig. 7). The Quaternary Buried Artesian Aquifer is the uppermost aquifer, and consists of lenses of fine- to coarse-grained sand and gravel confined and separated from other units by till and clay (Ruhl and Wolf, 1983a).

PREVIOUS WORK

The Minnesota Department of Natural Resources (1995), the Southeast Minnesota Volunteer Nitrate Monitoring Network (Network, 2009) and the Minnesota Pollution Control Agency (1999) have all conducted recent studies on the groundwater of Rice County (Fig. 8).

Similar studies on groundwater in Dakota County have been conducted by the University of Minnesota, in conjunction with the Minnesota Department of Agriculture (Lewandowski et al., 2008). The results of this survey were published in the spring of 2008 and were primarily geared towards evaluating the cost of water treatment amongst Minnesotan well owners, particularly those whose aquifers show nitrate contamination. Dakota County itself produced the Dakota County Ambient Groundwater Quality Study, which was geared towards analyzing the chemical components of the region's groundwater in order to establish a baseline and potentially reevaluate environmental policy in the area (County, 2006). The study was conducted over the course of five years, and primarily concentrated on well water drawn from aquifers located in the Prairie du Chien Group and the Jordan Sandstone. The final study consulted for this paper is the 2004 Carleton College Geochemistry of Natural Waters class survey conducted on 19 private wells throughout Rice County (Haileab et al., 2004).

The Environmental Protection Agency maximum contamination level of nitrate in drinking water is 10 mg/L, due to the health effects that can occur in infants with a higher level (EPA, 2009). In the 2004 Geochemistry of Natural Waters class study, 14 out of 19 well water samples possessed nitrate levels above the drinking standard in Rice County (Haileab et al., 2004). The Dakota County study showed that 30% of private wells tested had an elevated level of nitrate and/or pesticides, while 18% of wells showed no signs of nitrates in the groundwater (County, 2006). Lewandowski et al. (2008) found approximately one-third of wells surveyed to be vulnerable to contamination for a myriad of reasons, and though the majority of wells did not show elevated levels of nitrate, the risk of nitrate contamination was increased if the well was in close proximity to a predominantly agricultural area.

In order to start building a database of Rice county groundwater, the 2004 Geochemistry of Natural Waters class also analyzed each well water sample for ion content, stable isotope ratios, and CFC concentrations. Bromide and phosphate were not found to be present in the groundwater, while chloride, fluoride, and sulfate were found to be present, but in amounts within the concentration guidelines set by the Minnesota Department of Health. Cation levels in Rice County groundwater do not exceed any of the drinking water concentration standards set up by the Minnesota Department of Health. The CFC concentrations that were analyzed in Rice County indicate that surface to groundwater percolation times range from several months to 50 years (Haileab et al., 2004). The stable isotope ratios agree with the CFC concentration dates and suggest a local or regional recharge area in the Rice County groundwater (Haileab et al., 2004).

METHODS

Field Methods

Data was used from an ArcGIS database of well and boring records for Rice County from the Minnesota Department of Health. The six aquifers which supply water for the most wells were selected for study: the Jordan (CJDN), Prairie du Chien (OPDC), St Peter (OSTP), Quaternary Buried Artesian Aquifer (QBAA), Prairie du Chien-Jordan (OPCJ), and St Lawrence (CSTL). Using GIS, 365 of these wells were selected by location to ensure a wide distribution across the county. Well owners and addresses were found by spatially joining the selected wells to a parcel dataset provided by the county. A letter explaining the project and requesting permission to sample residents' water was sent to each household (Appendix 1). One week later, residents were called for permission and to schedule a time for sampling. We were given permission by 108 residents, and we visited 70 sites.

Teams of two to three students drove to approved sites and sampled water from the closest available tap to the well (before the water had gone through softeners). At each site, two 125 ml (4 oz) Boston round clear glass sample bottles were filled and capped using size 22-400 white plastic caps with an aluminum foil liner. On site, YSI Meter Model 60s were used to measure pH and YSI Meter Model 30s were used to measure water conductivity (µS), salinity (ppt), and water temperature (°C). At 11 sites, 1 L Pyrex bottles samples were filled for Tritium samples. In 9 cases, three 125ml sampling bottles were filled without trapped air to allow for future CFC sampling. Due to time constraints, CFC and Tritium were not taken into account in this study. In total, 61 wells were visited and sampled.

Laboratory Methods

Tests for Ca, Na, K, and Fe were performed with a Perkin-Elmer 1100B Atomic Absorption Spectrometer (AA) using Perkin-Elmer Intensitron (for Ca, Na, K) and VWR Scientific Inc. (for Fe) Hollow Cathode Lamps. Sets of standards were made for each element using Ultra Scientific Analytical Solutions concentrated stock standards so that each set fell within the linear range of absorbance vs. concentration, and spanned the sample data set evenly. These standards were used to calibrate the AA to measure concentration in milligrams per liter. A portion of each of the water samples for each metal to be tested was removed and diluted based on the expected concentrations so that the resulting concentration would fall within the linear range of absorption vs. concentration for that particular metal. Because the particulate matter that had settled to the bottom of many of the collected samples was suspected to contain iron, these samples had to be treated with nitric acid before being run through the AA. The samples were agitated to create a homogeneous mixture, and a portion was extracted. One percent by volume concentrated nitric acid was added (15.7 M) to dissolve the precipitated iron, and the resulting solution was diluted to an appropriate concentration (see above). Nitrate tests were performed with a Nexsens WQ Nitrate ISO Probe. No dilution was necessary for nitrate tests; the probe was inserted directly into the sample.

GIS Analytical Methods

GIS software was used to compare the data collected and analyzed by the authors of this study with previous work by the Minnesota Department of Natural Resources (MNDR) and the Minnesota Department of Health. The County Well Index (CWI), run by the Minnesota Department of Health, stores a plethora of data on every registered well in Minnesota. In the CWI data file, every well has a unique identification number. This number is used by multiple agencies within Minnesota to correlate their own data. Some well owners visited by the authors of this study had multiple wells on their property, which led to confusion when classifying the correct well identification number. Such an issue should not have a large impact on the results because multiple wells on the same property are close together and therefore likely to be drilled into the same aquifer.

Using the CWI unique identification numbers, we joined the data collected for this study to data from the MDNR, MPCA, and the VNMN. In the CWI data file, each well was classified by the aquifer from which the well draws. Point-based well chemistry data was interpolated across Rice County using an ordinary kriging algorithm. The values in each of the resulting concentration surfaces were classified into five geometric intervals.

The feedlots and well layers were spatially joined to calculate the minimum distance from well to feedlot. This operation was performed multiple times, once for all feedlots, once for cow and swine feedlots, and once for feedlots with more than one animal. Scatter plots of feedlots vs. nitrate concentrations were generated from the resulting attribute tables. In order to determine the correlation between the quantity of feedlots and nitrate concentration of a well a distance to point function was run using two buffer distances of 0.5 miles and 1.0 mile. The results were exported to a spreadsheet, and summarized in MATLAB.

RESULTS

Field Data

Temperature values ranged from 4.0 to 18.0 °C, with one outlier of 28.6 °C. The mean temperature was 9.60 °C and the standard deviation was 3.75 °C (Table 1). In most cases, both low and high conductivity values were collected at each well; rarely, only high values were recorded. Most low conductivity values fell between 400 and 700 µS, with a mean of 504 µS and a standard deviation of 175 µS. High conductivity values ranged from 370 to 1045 µS, with one outlier of 15 µS. The mean high conductivity was 693 µS and the standard deviation was 181 µS. Wells sampled varied relatively evenly between 7.0 and 9.7 pH, with a mean value of 8.0 pH and a standard deviation of 0.8 pH.

Laboratory Data

Sodium

Within our sampled wells, Na concentration exhibits low variability, with a minimum value of 0.1 mg/L and a maximum value of 1.7 mg/L. Most values fall between 0.2 and 0.8 mg/L. The mean concentration is 0.4 mg/L and the standard deviation is 0.4 mg/L (Table 2).

Potassium

The concentration of K measured within the sampled wells was marked by relatively low variation, with an evenly distributed range between 0.0 and 1.0 mg/L. The mean of K concentration is 0.4 mg/L and the standard deviation is 0.2 mg/L (Table 2).

Calcium

Marked by slightly higher values, the concentration of Ca in the sampled wells ranges from 0.1 to 3.5 mg/L, with most falling between 1.0 and 2.5 mg/L and one large outlier of 4.5 mg/L. The mean concentration is 1.8 mg/L and the standard deviation is 0.8 mg/L (Table 2). There is a potential source of error in the calcium data due to a known atomic absorption chemical interference between calcium and phosphate. Phosphate can bind to calcium ions and make them unable to be atomized by the flame in the Atomic Absorption Spectrometer. This results in a measured concentration of calcium that is less than the actual concentration. Due to the fact that most of the water samples were taken from agricultural land, it is likely that they contain phosphates, and for this reason, it is possible that the reported calcium concentrations are lower than the actual concentrations in the water.

Due to these errors, the Calcium map was interpolated from DNR well data, which yielded results ranging from 1.0 to 62.5 mg/L (Fig. 6). The pattern observed in this map features generally high calcium values concentrated in the northwestern half of the county and lower values in the south-central and northeastern parts of the county.

Nitrates

The analysis of nitrate concentrations in this study included data from the DNR, VNMN, the MPCA, and our sampled wells for a total 158 sampled wells. This data yielded a range of results from 0.01 to 2.59 mg/L (Table 2). The relationships between concentration and spatial variables of aquifer, depth to bedrock, land use, distance from a feedlot, and direction of groundwater flow. The concentration of Nitrate did not show a significant relationship to distance from a feedlot at distances of 0.5 miles and 1.0 mile (Fig. 3b,c), nor did the mean concentration show a significant relationship to type of land cover.

The interpolated nitrate concentration surface shows higher nitrate levels in the eastern half of Rice County. The nitrate concentrations generally increase in the direction of groundwater flow, with the highest concentrations at the intersection of ground and surface water.

Iron

Within our sampled wells, Fe concentration exhibits high variability, with a minimum value of 0.0 mg/L and a maximum value of 13.6 mg/L. The mean concentration found is 3.3 mg/L and the standard deviation is 3.3 mg/L (Table 2).

Arsenic and Lead

Samples were not tested for lead and arsenic as Carleton does not own sophisticated enough technology to analyze in the parts per billion.

DISCUSSION

Sodium and Potassium

Sodium and potassium in well water present no health risk and were dropped from our investigation.

Calcium

Calcium (Ca^{+2}) is a common cation in natural waters. It, along with magnesium (Mg^{+2}), is a main contributor to water hardness. Elevated levels of calcium in water may precipitate as calcium carbonate and cause scaling of pipes, although there are currently no known health risks associated with calcium and magnesium (Ohio Department of Natural Resources, 1997). Calcium is abundant in many rocks and soils, particularly limestones and dolostones, and dissolves as water passes through these rocks. Calcium carbonate disassociates (1) and interacts with water and carbon dioxide (2) in the following reactions (Minnesota Pollution Control Agency, 1999b):

$$CaCO_{3(s)} \leftrightarrow Ca^{2+}_{(aq)} + CO_3^{2-} \qquad (1)$$

$$\begin{aligned} CO_{2(g)} + H_2O &\leftrightarrow H_2CO_{3(aq)} \\ H_2CO_{3(aq)} &\leftrightarrow H^+ + HCO^-_{3(aq)} \\ HCO^-_{3(aq)} &\leftrightarrow H^+ + CO_3^{2-}{}_{(aq)} \end{aligned} \qquad (2)$$

Figure 9 shows average calcium concentration by aquifer. Figure 10 displays the relationship between carbonate content in aquifer geology and Ca^{2+} concentration in that aquifer’s contained groundwater. The three aquifers with the highest concentration of calcium are all part of the same hydrogeological unit, the Prarie du Chien-Jordan aquifer (Fig 9). As shown in Figure 10, the Prarie du Chien-Jordan aquifer has high carbonate levels since the Prarie du Chein group is largely composed of dolomite. The dissolution of this dolostone has created karst conditions in Rice County and the rest of southeastern Minnesota. This creates increased aquifer permeability, allowing contaminants to quickly pass unfiltered into the aquifer system. Low calcium concentrations in the St. Peter sandstone can be explained by low carbonate content in the rock (Fig. 10). The low concentrations in the Decorah Shale and Franconia Formation can be explained in the same way. In the Quaternary Buried Artesian Aquifer does not really follow the expected trends, but since the aquifer is so shallow, it is less influenced by geology than by surface contaminants. Calcium is found in many construction materials and household products, which when dissolved into rainwater could explain the elevated calcium levels in the Quaternary Buried Artesian Aquifer.

Nitrate

The lack of a relationship between nitrate concentration and distance of the well from a feedlot could be due to several factors. One possibility is that the infiltration time of the aquifers we sampled was longer than some of the feedlots have been in operation, and therefore the concentrations have not yet been reflected in-situ at the well site. Unfortunately, controlling for infiltration time is difficult because it depends on many variables, elevation, aquifer depth, and permeability of overriding strata. Another possible explanation is that the nitrate is extremely mobile, and rather than accumulate in the areas that are sourcing the nitrate, it accumulates in areas where ground and surface water are concentrating. This second explanation fits better with our results also not showing a correlation to type of land cover, as most of the farms have been in operation for the length of the aquifer infiltration times. In this case, the highest concentrations of nitrate correspond to the locations of the cannon and straight rivers, which is the destination of the potentiometric surface (and ultimately most of the ground water) in Rice County (Fig. 11).

Previous studies have shown nitrate does not accumulate in aquifers that are below more than 70 feet of sediment (MPCA, 1999). Our own results show only a single well above .5 mg/L nitrate with more than 85 feet of overlaying strata (Fig. 12), though the general correlation between nitrate concentration and depth to bedrock is extremely weak (r = .03).

The MPCA found the range of nitrate concentrations to be small within any given aquifer, implying that the mobility of nitrates within aquifers is high (Fig. 13; MPCA, 1999). The highest average concentrations of nitrate were found in the Galena-Decorah formation, in a well, but only one well was tested. The second highest concentrations from our data were found in the Jordan Aquifer. This agrees well with results from the MPCA showing the highest concentrations of nitrate in the Jordan. In both studies, however, average nitrate concentrations in the Jordan were still significantly below the health standard.

Our interpolation map agrees with the results of the 1999 MPCA study showing higher concentrations in the east of the county (Fig. 14). The MPCA was not able to detect any significant nitrate (values were less than 0.5 mg) in wells in the western two thirds of the county.

pH

Water pH is primarily controlled by a series of equilibrium reactions between water and carbon dioxide, (see equations 3). These reactions show that the pH of water is positively correlated to the amount of carbon dioxide the water is exposed to. An increase in CO_2 increases the concentration of H_2CO_3, which disassociates to form H^+ ions (lowering the pH).

$$\begin{aligned} &H_2O + CO_2 \leftrightarrow H_2CO_3 \\ &H_2CO_3 \leftrightarrow H^+ + HCO_3^- \\ &HCO_3^- \leftrightarrow H^+ + CO_3^{2-} \end{aligned} \tag{3}$$

The well water data shows a high pH in the northwest part of the county and a low pH in the southeast part (Fig. 15). This is most likely due to interactions between the ground water and the surface water through the large number of lakes in the western part of the county. These lakes would be alkaline for two reasons. During the summer, there would be decreased concentrations of CO_2 due to plant productivity (i.e. photosynthesis), and in accord with Equation 3 this would decrease the concentration of H^+, and raise the pH. In the winter, this pH would remain high because although plants are no longer consuming CO_2, the water does not interact with the atmosphere (an interaction that would decrease pH) because the surface is frozen (Bereket Haileab, personal communication). Since the majority of the wells on the western part of the county are shallow, they most likely have more interaction with the lakes at the surface, which would explain their higher pH.

Iron

Iron is a naturally occurring element widely present in groundwater. It is gradually released from soil and rocks, causing older aquifers to tend to have higher concentrations of iron than younger aquifers. Iron concentrations are higher in igneous rocks, and lower in limestone and dolomite (Minnesota Pollution Control Agency, 1999a). Iron concentrations in Rice County were highest in the St. Peter and Prairie du Chien-Jordan aquifers. The Jordan formation has high amounts of the iron-containing mineral glauconite, which could explain these elevated levels. In the St. Peter, since iron concentrations are low (Odom, 1975), we believe higher concentrations could be a result of anthropogenic sources. Common sources are the dissolution of ferrous well pump components. There is no known health risk to dissolved iron in drinking water.

Arsenic and Lead

Lead is extremely immobile in soil and therefore has a low average concentration in groundwater of less than 0.5 μg/L in southeast Minnesota (MPCA, 1999). All of the data collected by the MPCA in Rice County was below the EPA health standard. The spatial distribution of MPCA and DNR data throughout the county does not show a distinct pattern (Fig. 16). Arsenic occurs naturally in groundwater and concentrations are especially high in areas of glacial clay deposit—a feature that characterizes western Minnesota much more than eastern Minnesota (Minnesota DNR, 1995). As with lead, all of the Rice county wells analyzed by the MPCA in their 2004 baseline study were below the standard for arsenic. The Spatial distribution of MPCA and DNR arsenic data show the concentration of high values on the western margin of the county, and an otherwise flat distribution of moderate value in the rest of the county with the exception of a few low values in the center (Fig. 17).

CONCLUSIONS AND INTERPRETATIONS

The concentrations of various ionic species in the wells sampled were dependent on three main factors: the direction of groundwater flow, the elemental composition of the aquifer, and the depth of well casing. The direction of groundwater flow primarily influenced the concentration of nitrate in the water. Nitrate is extremely mobile, and rather than accumulate in the areas that are sourcing nitrate, it accumulates in areas where ground and surface water are concentrating. The highest concentrations of nitrate correspond to the locations of the Cannon and Straight Rivers, which are where the majority the groundwater in Rice County flows towards (Fig. 11).

The concentration of calcium in the groundwater was directly affected by the carbonate content of each aquifer. This explains why there is a higher calcium ion concentration in the Prairie du Chien-Jordan Aquifer, since the Prairie du Chien is a carbonate unit. The calcium concentrations measured in the other aquifers studied follow this trend as well. An exception is the Quaternary Buried Artesian Aquifer, but this can be explained by the fact that these wells are generally shallower and ground water in them is more likely to be affected by surface conditions than by the composition of the aquifer.

The concentration of sodium and the pH of the groundwater deviated from our original hypotheses, so we concluded that the well water was more influenced by interactions with the surface than by other factors. For both pH and sodium, we expected higher levels in the southeast but found higher levels in the west and northwest parts of the county. Because the wells in the western part of the county are primarily shallow (Fig. 18), we believe the surface conditions there were magnified, negating any contrary trends.

FUTURE WORK

The number of wells sampled for this study was restricted by time constraints. Aquifers are unequally represented in this study. The aquifer with the largest sample pool, the Priaire du Chien-Jordan aquifer (PDCJ) provided us with 21 wells, but most of the aquifers were represented by only a few samples. Fewer wells were sampled in southeast corner of Rice County than other areas. Sampling of additional wells would create a clearer picture of overall groundwater trends in Rice County. Geochemistry data from aquifers poorly represented in this study would further the understanding of the character of those aquifers. Conductivity and pH data were not collected in the field at all sites, due to either human or machine error. Future studies could include conductivity and pH data from more wells.

Chemical interference between calcium and phosphate could have affected the calcium ion concentration data collected with the atomic absorption spectrometer. Future work on calcium ion concentrations in Rice County well water should add lanthanum chloride solution to the standard solutions to prevent the interference of phosphates from altering the data. Eleven water samples were collected with the intent of conducting tritium analysis and nine well water samples were collected for CFC analysis. Tritium and CFC tests on these samples could be run because of time restraints. These tests could be conducted in the future in order to determine the amount of exposure that people in Rice County have to tritium (which is radioactive) from their drinking water, and to better constrain the recharge age of the groundwater in this region.

ACKNOWLEDGEMENTS

This project would not have been possible without the help of the Rice County residents who allowed us to visit their homes and sample their well water. We would like to thank all residents who gave us permission to sample water from their property, including those residents who we did not have time to visit.

Funding for this project was provided by the Carleton College Geology Department. Rice county well data was provided to us by the following groups: the Minnesota Pollution Control Agency, the Minnesota Department of Natural Resources and the Southeast Minnesota Volunteer Nitrate Monitoring Network project. A template for an introductory letter to mail to residents was provided to us by Bruce Montgomery from the Minnesota Department of Agriculture. Finally, we would like to thank Wei-Hsin Fu whose help with GIS was invaluable to this project, as well as Tim Vick and Tsegaye Nega.

Rice County Elevation

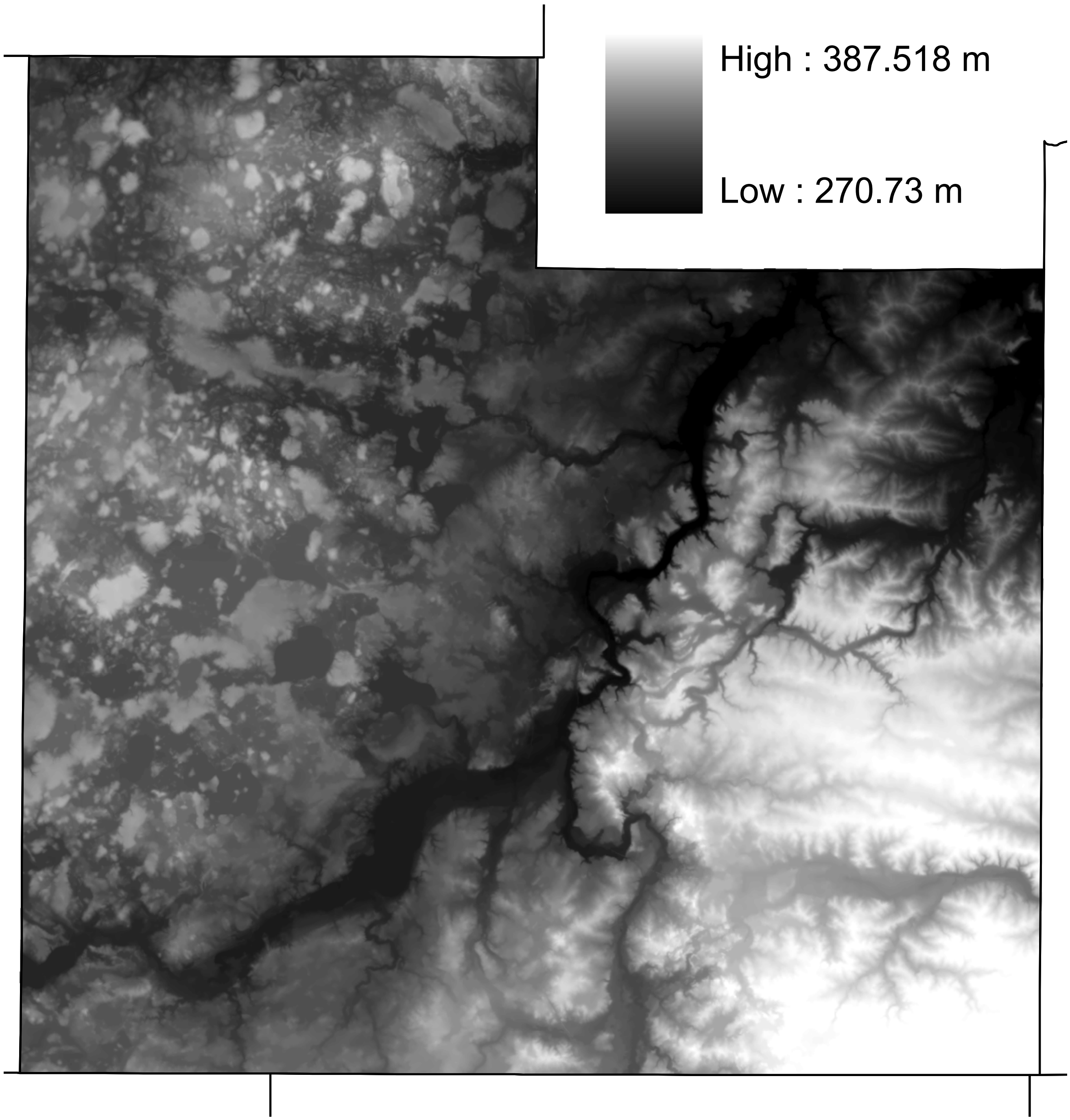


Figure 1: Elevation of Rice County. Note the visible drainage pattern of the Cannon river running from sounth west to north east. Also note the generally higher elelvation in the south east corner of the state. Modified from USGS national elevation dataset.

Land Usage in Rice County

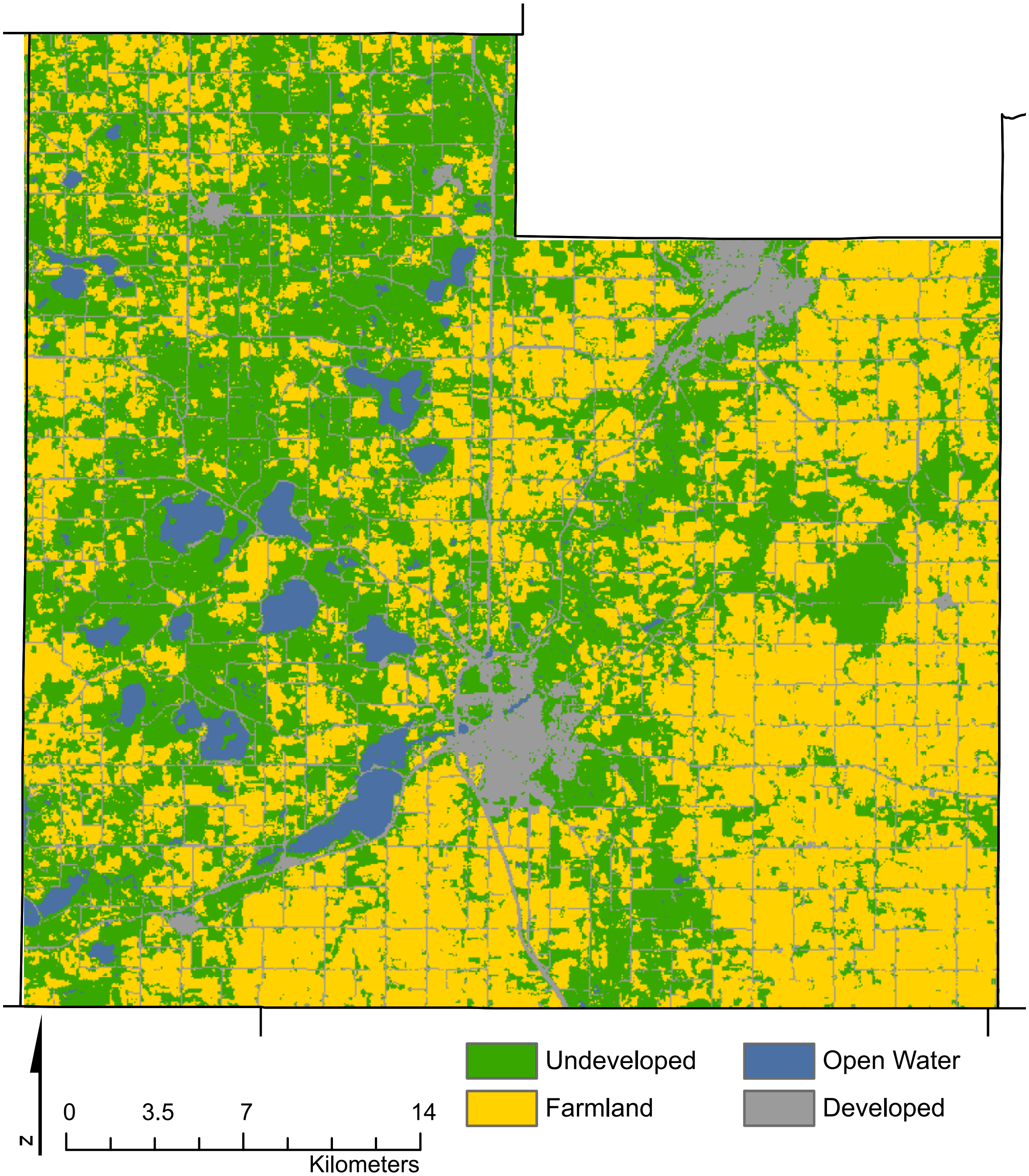


Figure 2. Land use cover within Rice County. Undeveloped land includes woods, prairie, and grass land. Farmland includes agricultural land and pasture lands. Developed land used for residential and comercial purposes or roadway. Open water includes lakes, streas, and rivers.

Rice County Feed Lots

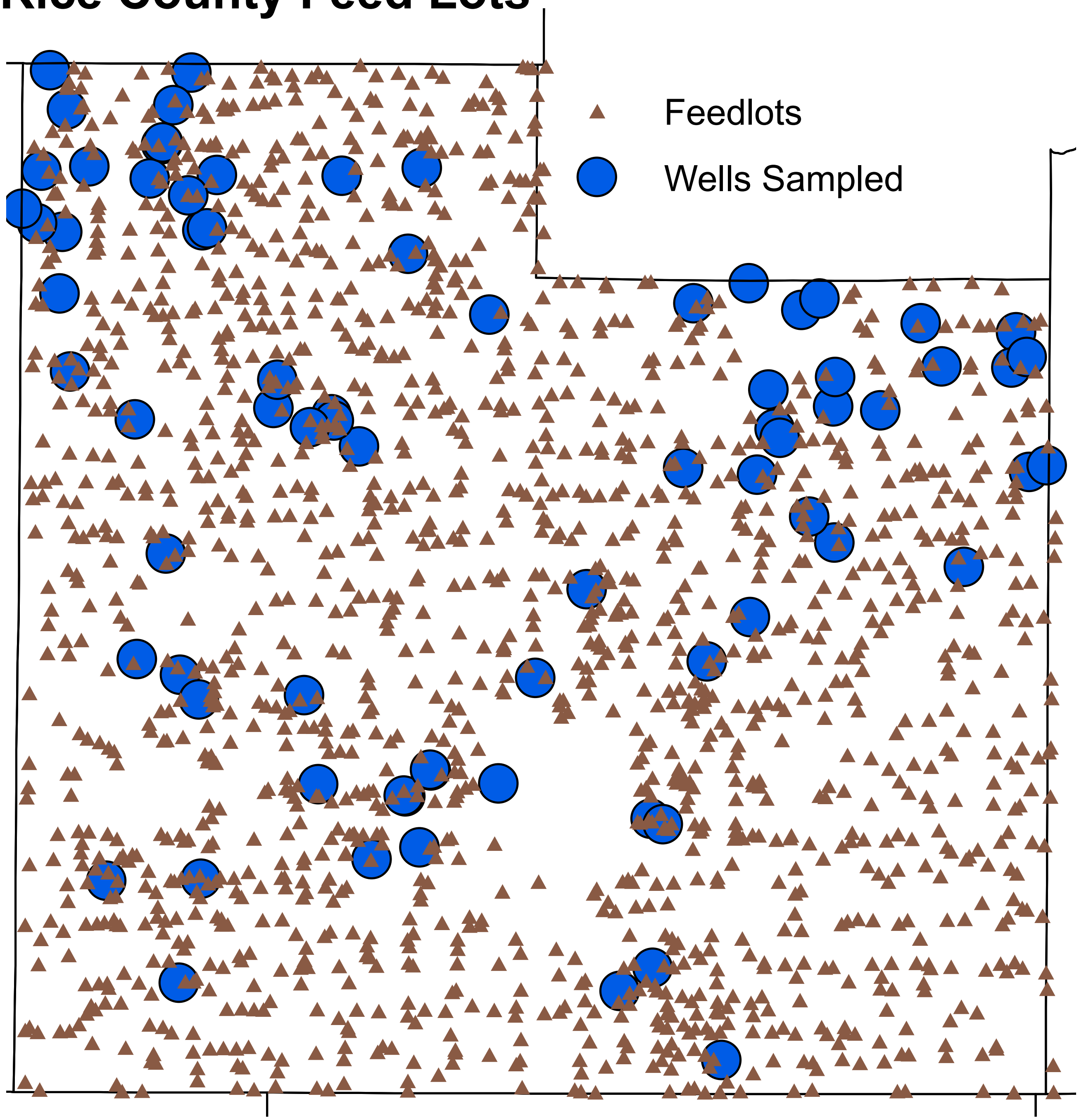


Figure 3: Cow, pig, poultry and other feed lots in Rice County.

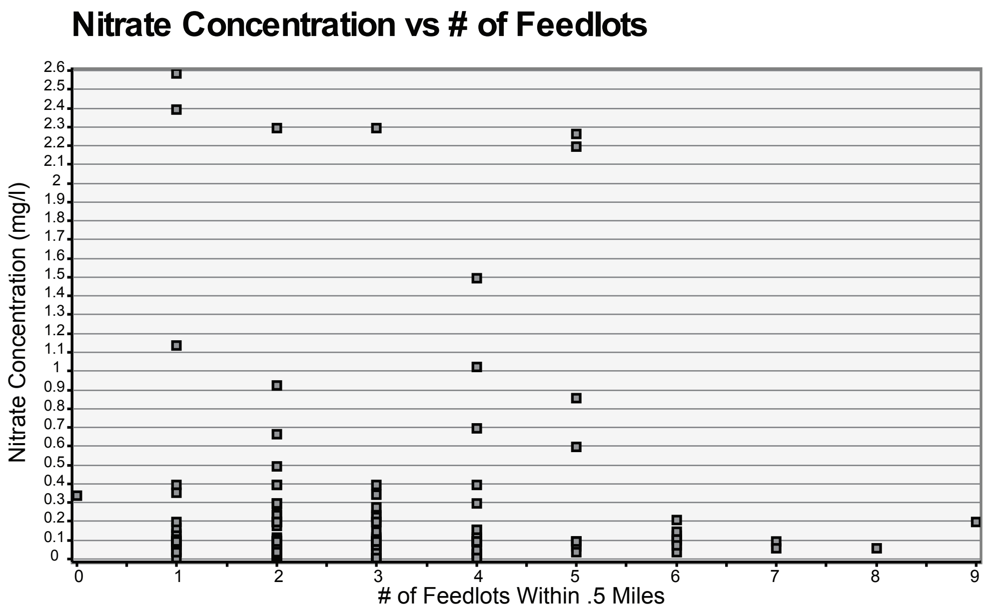


Figure 3b. Nitrate concentrations (mg/L) sampled from wells in Rice County plotted against the number of feedlots within a .5 mile radius. Data represents 158 wells sampled by the DNR, VNMN, the MPCA, and the Carleton College Geology Department.

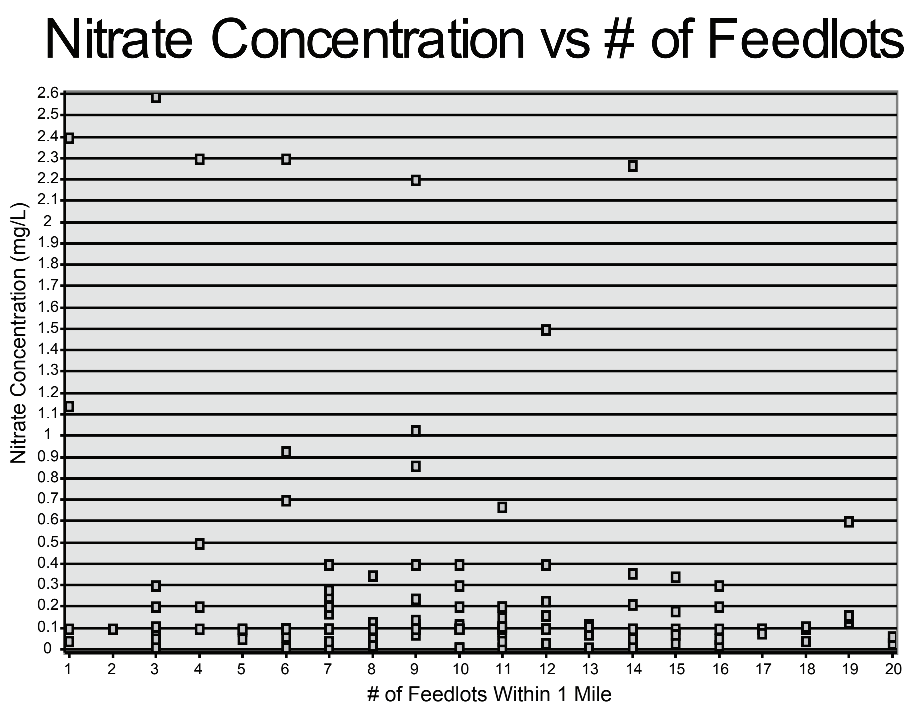
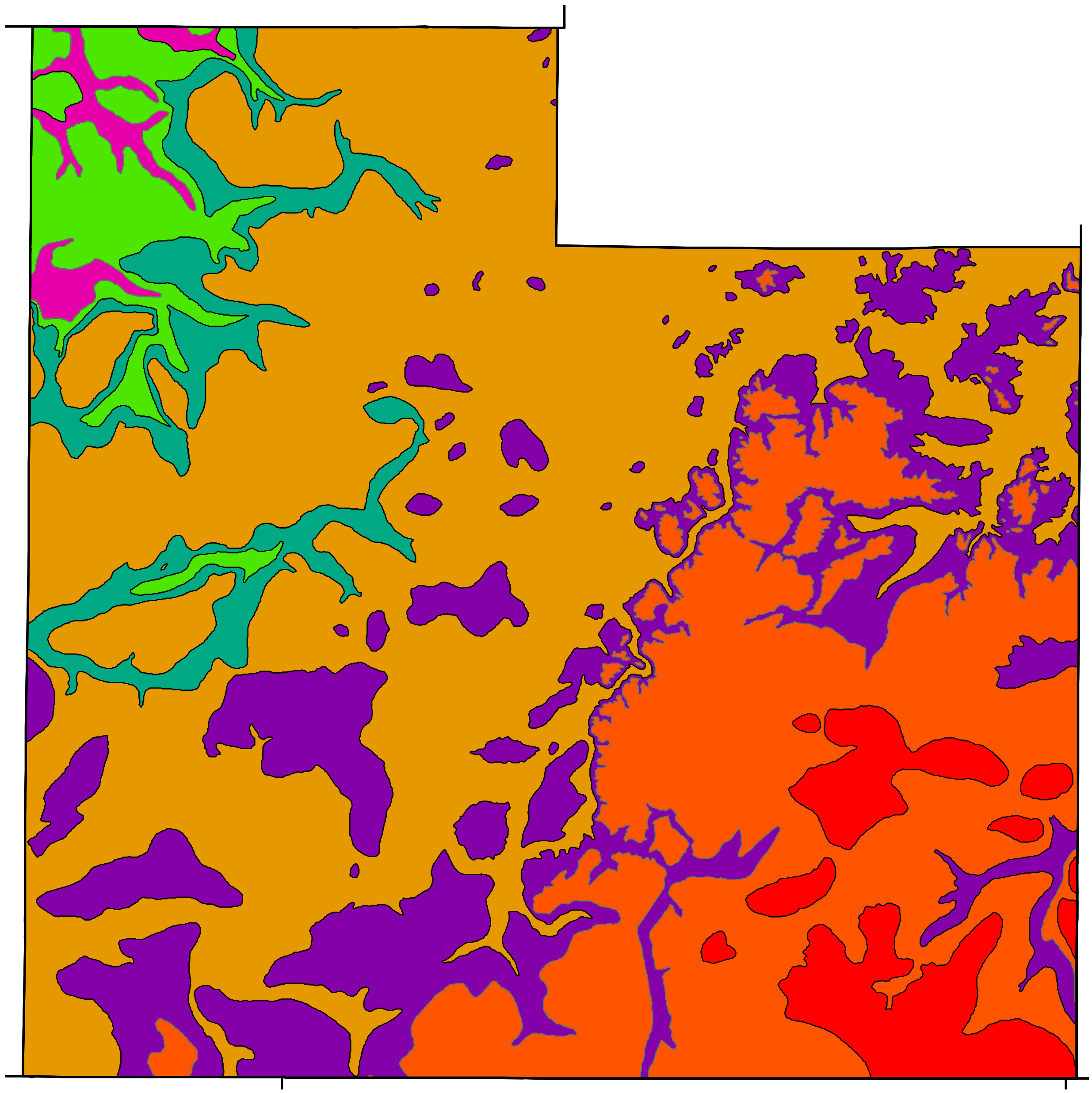


Figure 3c. Nitrate concentrations (mg/L) sampled from wells in Rice County plotted against the number of feedlots within a 0.5 mile radius. Data represents 158 wells sampled by the DNR, VNMN, the MPCA, and the Carleton College Geology Department.

Surficial Geology of Rice County



Rock Unit:
- Galena
- Decorah - Platteville
- St. Peter
- Prairie du Chien
- Jordan
- St. Lawrence
- Franconia

Figure 4. Surfical geology of Rice County.

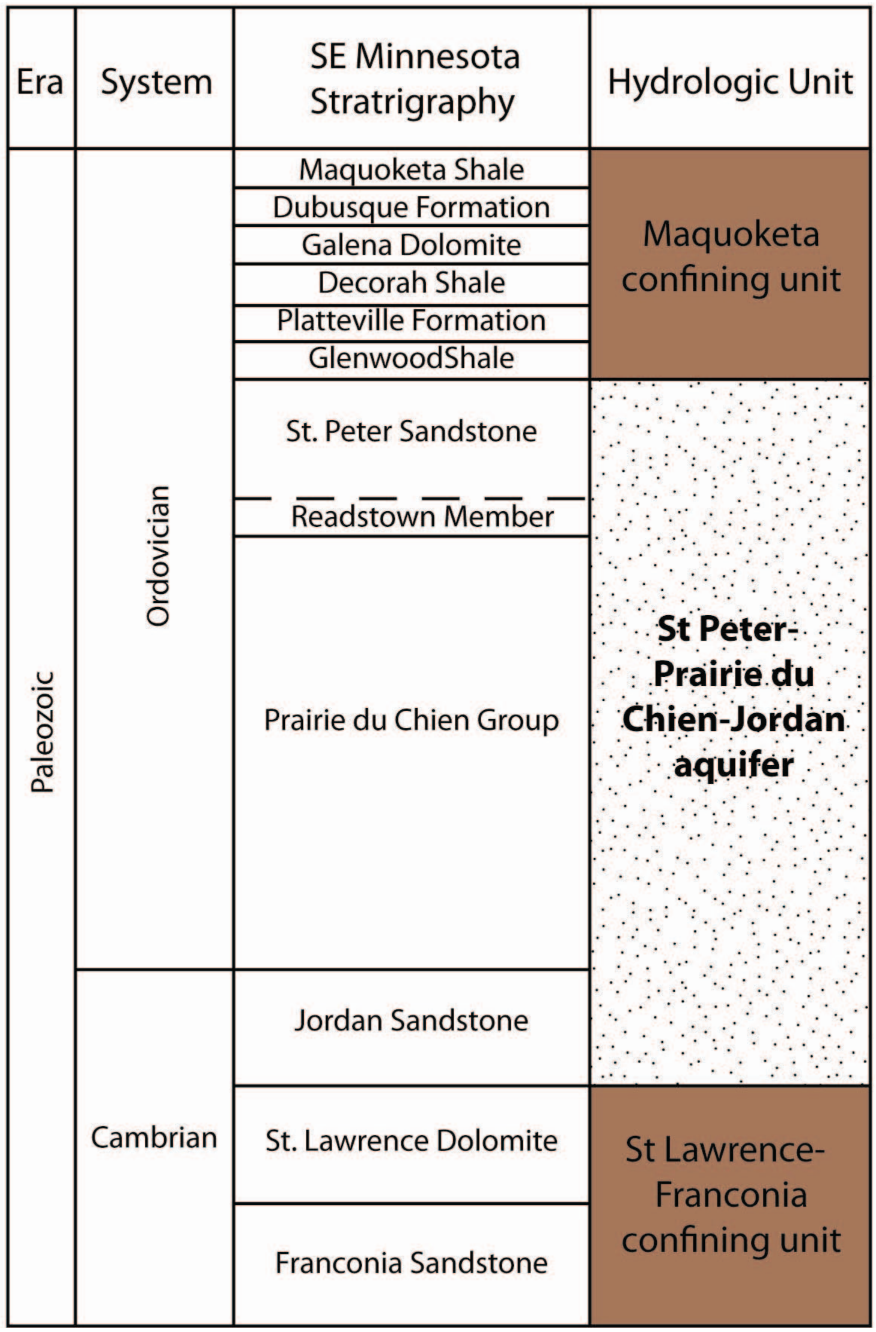


Figure 5. Diagram showing the stratigraphy of Southeastern Minnesota in during the Cambrian and Ordovician systems. The hydrologic units associated with these strata are also displayed next to the stratigraphy units (Adapted from Olcott, 1992)(Adolphson et al., 1981).

Stratigraphic nomenclature			Hydrogeology	
Era	Period or System	Geologic unit (group, formation, or bed)	Hydrogeologic unit (aquifers or confining beds)	Water-bearing characteristic and dominant lithology
Cenozoic	Quaternary	Drift	Surficial sand and gravel aquifer	Largely outwash, but includes alluvium along major streams and local ice-contact deposits. Slightly used, with additional development of supplies possible. High potential for contamination because the water table is at or near land surface. Yields as much as 1,000 gal/min in places.
			Confining beds	Till and clay of low permeability. Not a source of water to wells.
			Buried sand and gravel aquifers	Outwash and ice-contact deposits confined by till of low permeability. Slightly to moderately developed for water supplies with potential for additional development, especially in butied valleys. Yields ranve from 100 to 1,000 gal/min.
Mesozoic	Cretaceous	Cretaceous beds	Cretaceous confining beds	Shale beds of low permeability. Not a source of water.
			Cretaceous aquifer	Sandstone lenses near base of predominantly shale section. Slightly developed, may yield additional small supplies. Typical yields to wells are 5 to 50 gal/min, but may be as much as 250 gal/min. Water is highly mineralized, particularly in the basal units along the western border of the State.
Paleozoic	Devonian	Cedar Valley Limestone	Upper Carbonate aquifer	Limestone, dolomite, and dolomitic limestone. Major aquiferr in the south-central part of embayment. Wells generally yield 200 to 500 gal/min from solution channels, joints, and fissures.
	Ordovician	Maquoketa Shale		
		Dubuque Formation		
		Galena Dolomite		
		Decorah Shale	Confining bed	Relatively impermeable shale, dolomitic limestone, and limestone. Platteville yields about 25 gal/min from local fractures and solution channels.
		Platteville Limestone		
		Glenwood Shale		
		St. Peter Sandstone	St. Peter aquifer	White, fine- to medium-grained sandstone. A major aquifer, but seldom used for public supply because larger yields are available from wells in other aquifers. Typical yields range from 100 to 250 gal/min.
			St. Peter confining bed	Contains siltstone and shale that restrict vertical flow. Areal extent unknown. Not a source of water to wells.
		Prairie du Chein Group	Prairie du Chein-Jordan aquifer	Mainly dolomite and sandstone. The major aquifer in the area. Commonly yields 500 to 1,000 gal/min. Supplies 75 percent of water in Twin Cities metropolitan area. Karstic conditions are common in extreme southeast.
	Cambrian	Jordan Sandstone		
		St. Lawrence Formation Franconia Formation	Confining bed	Silty, sandy dolomite interbedded with layers of fine-grained sandstone and siltstone. Generally a poor source of water to wells; however, yields from the Franconia in the northwest part of the areaare adequate for domestic use.
		Ironton Sandstone	Ironton-Galesville aquifer	Very fine to coarse-grained sandstone interbedded with shale, siltstone, and dolomite; an important aquifer outside the limits of other major aquifers. Yields range from 250 to 500 gal/min.
		Galesville Sandstone		
		Eau Claire Sandstone	Confining bed	Sandstone, siltstone, and shale; gray to reddish brown. Normally not a source of water, however, sandstone beds may yield small quantities to wells in the south.
		Mount Simon Sandstone	Mount Simon-Hinckley aquifer	Thick sequence of sandstone, siltstone, and shale. The secondary aquifer in Twin Cities area and only bedrock aquifer used in the northern part of the Hollandale embayment. Little used for water supply in extreme southeast. Wells generally yield from 400 to 700 gal/min, but may be as much as 2,000 gal/min.
Precambrian	Proterozoic	Hinckley Sandstone		
		Fond du Lac Formation	Hydrologic properties little known	Fond du Lac Formation, in combination with Hinckley Sandstone, yields water north of the Twin Cities metropolitan area where the Mount Simon is absent. Elsewhere, the Fond du Lac is deeply buried and undeveloped as a source of water supply
		Sedimentary, metamorphic and igneous rocks	Hydrologic properties unknown	Lack of detailed subsurface information precludes eveluation of hydraulic characteristics.

Figure 6. A comprehensive description of the rock units in southeastern Minnesota and the associated hydrologic properties. Comprehensive descriptions of the aquifers and aquitards (confining units) are provided(Ruhl and Wolf, 1983a).

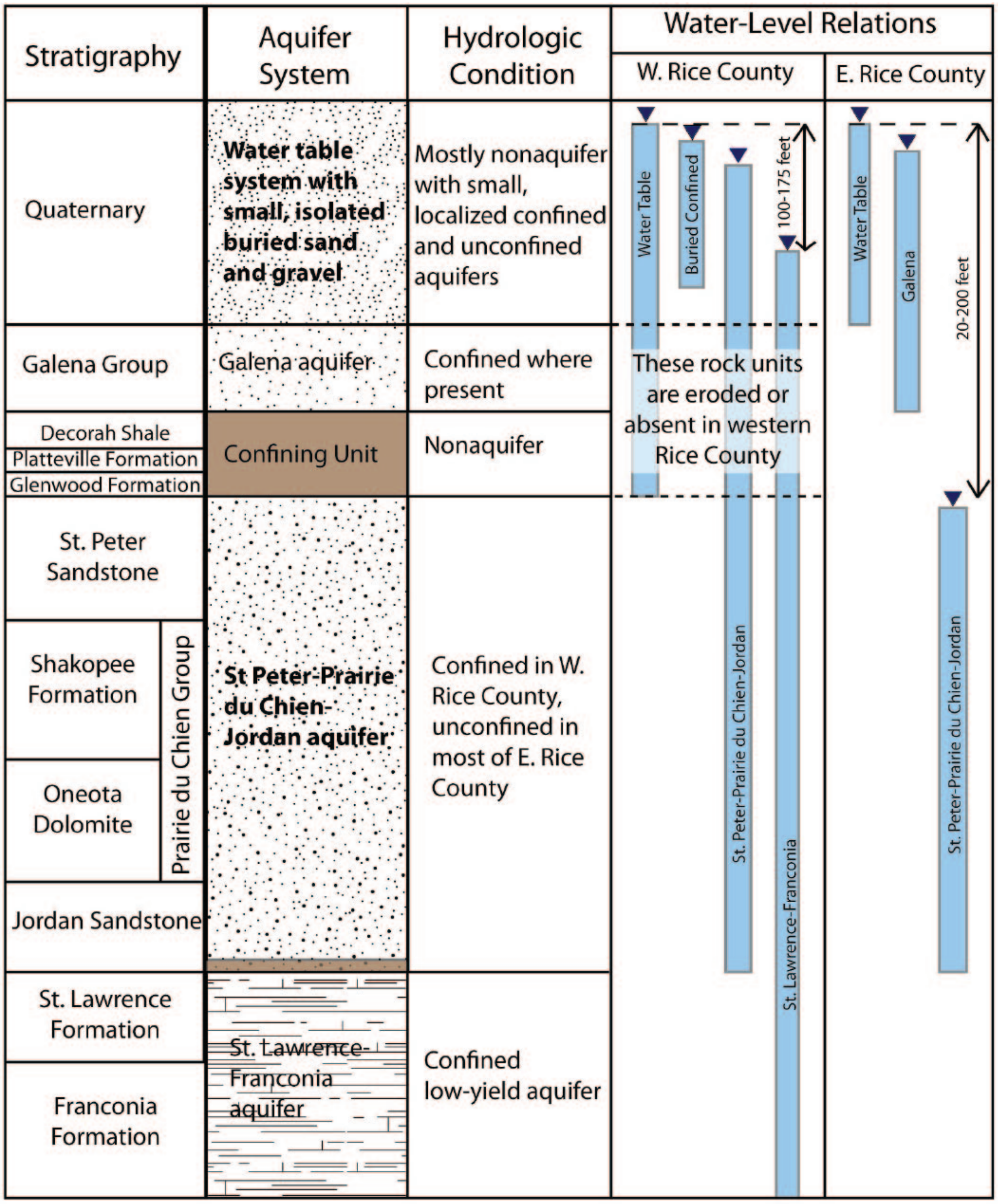


Figure 6. An overview of the relevant aquifer systems and their associated depths in western and eastern Rice County. The stratigraphy of southeastern Minnesota is shown again for reference (Adapted from Olcott, 1992)(Olcott, 1992).

Previous Research Data Sites

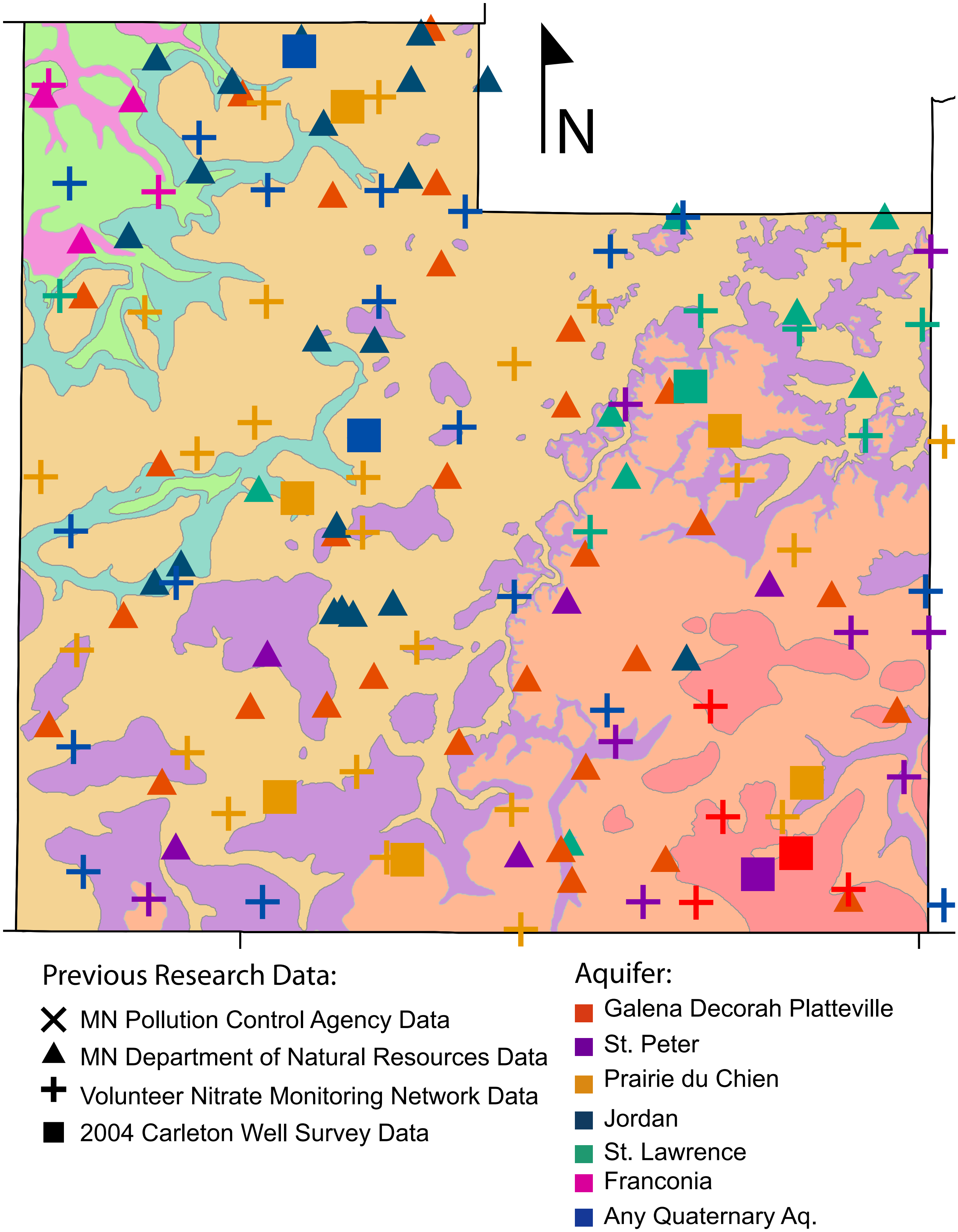


Figure 4. The map displays the locations for wells previously sampled in other research, with surficial bedrock geology mapped as well. Symbols designate the study which sampled the specific well, while colors designate the aquifer that the well draws water from.

Variable	Mean	Range	Standard Deviation
Temp (C)	9.60	4.0 - 18	3.75
Conductivity (High) (μS)	693	370- 1045	181
Conductivity (Low) (μS)	504	400 - 700	175
pH	8.0	7.0 – 9.7	0.8

Table 1: Field Data Results

Ion	Mean	Range	Standard Deviation	Health Risk Standard
Sodium	.4 mg/L	.1-1.7 mg/L	.4 mg/L	--
Calcium	1.8 mg/L	.1-4.5 mg/L	0.8 mg/L	--
Potassium	.4 mg/L	0-1 mg/L	.2 mg/L	--
Iron	3.3 mg/L	0-13.6 mg/L	3.3 mg/L	--
Nitrate	.22 mg/L	.02-2.24 mg/L	.35 mg/L	10 mg/L

Table 2: Atomic Absorption Results

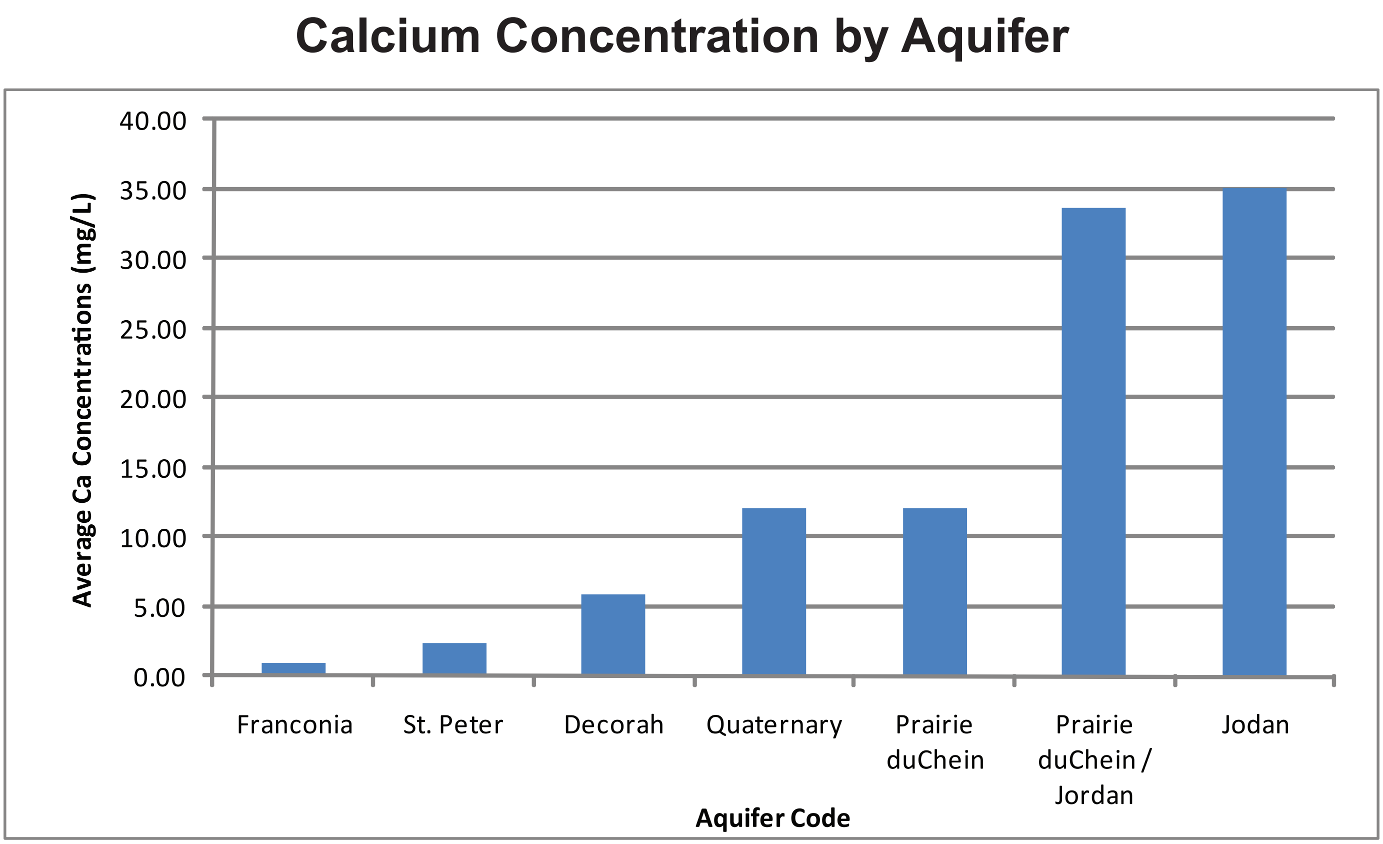


Figure 9: Calcium concentration (mg/L) within sampled aquifers in Rice County.

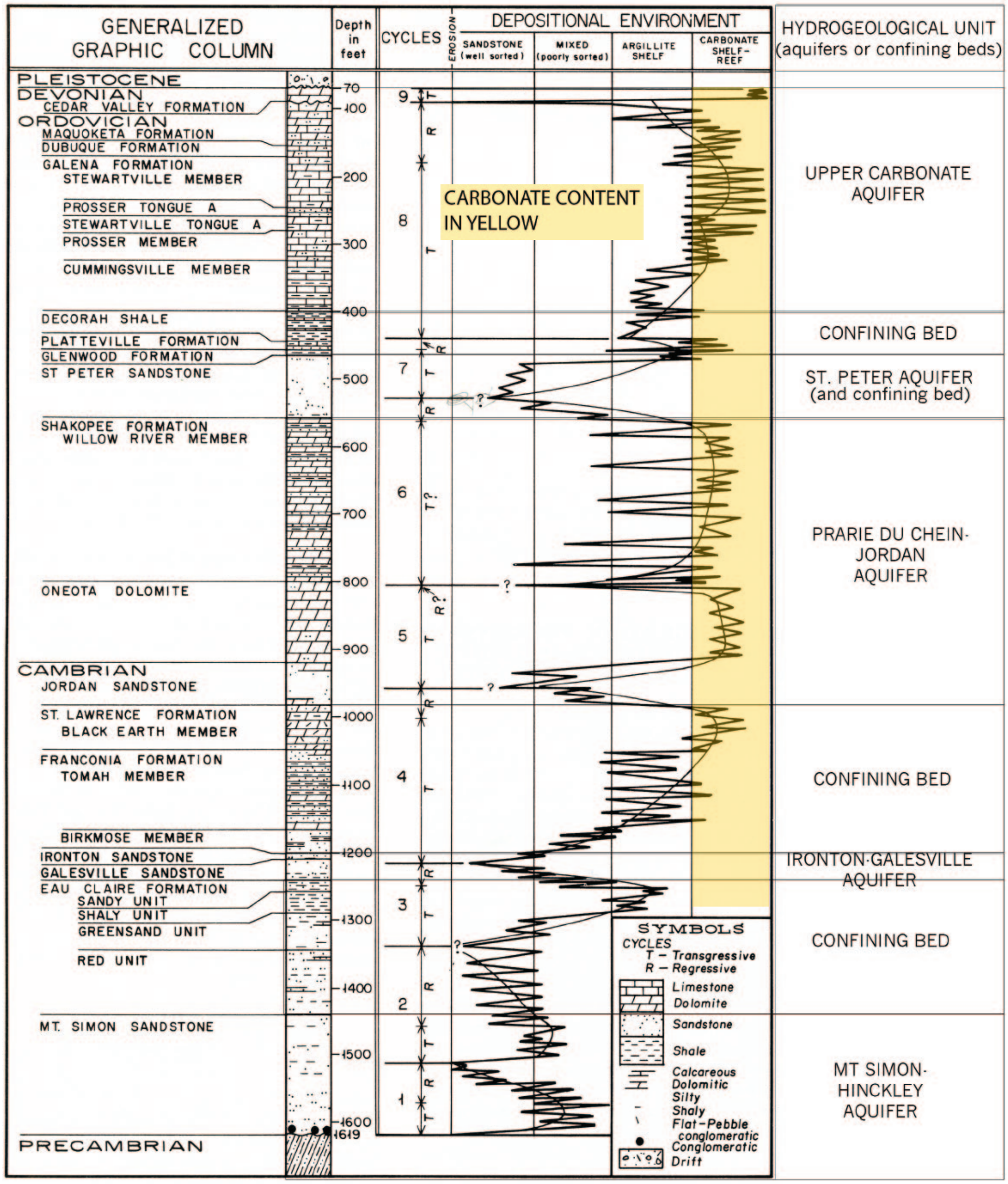
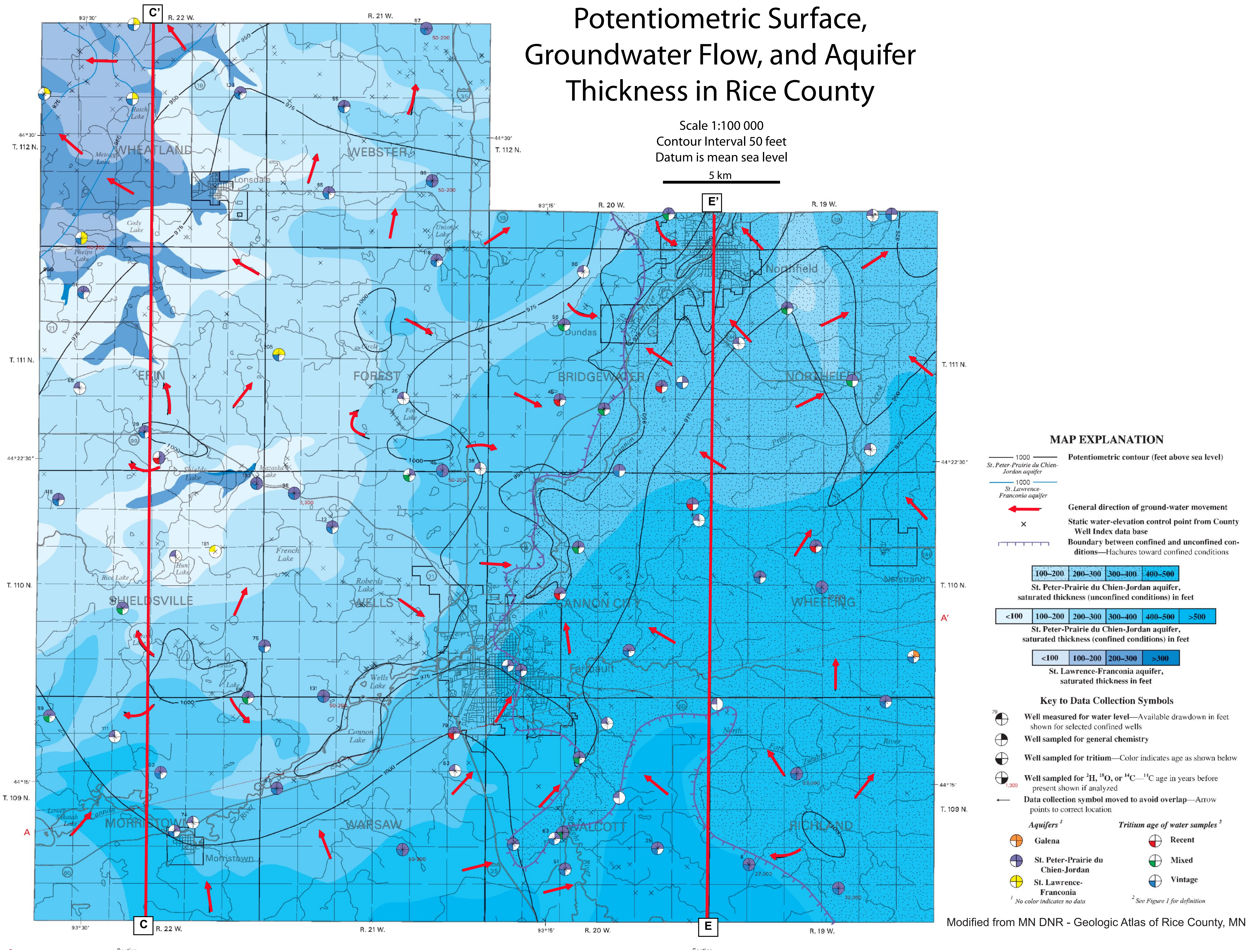


Figure 10. Stratigraphic column of Rice County with carbonate content and corresponding hydrological unit.

Potentiometric Surface, Groundwater Flow, and Aquifer Thickness in Rice County

Scale 1:100 000
Contour Interval 50 feet
Datum is mean sea level
5 km



Modified from MN DNR - Geologic Atlas of Rice County, MN

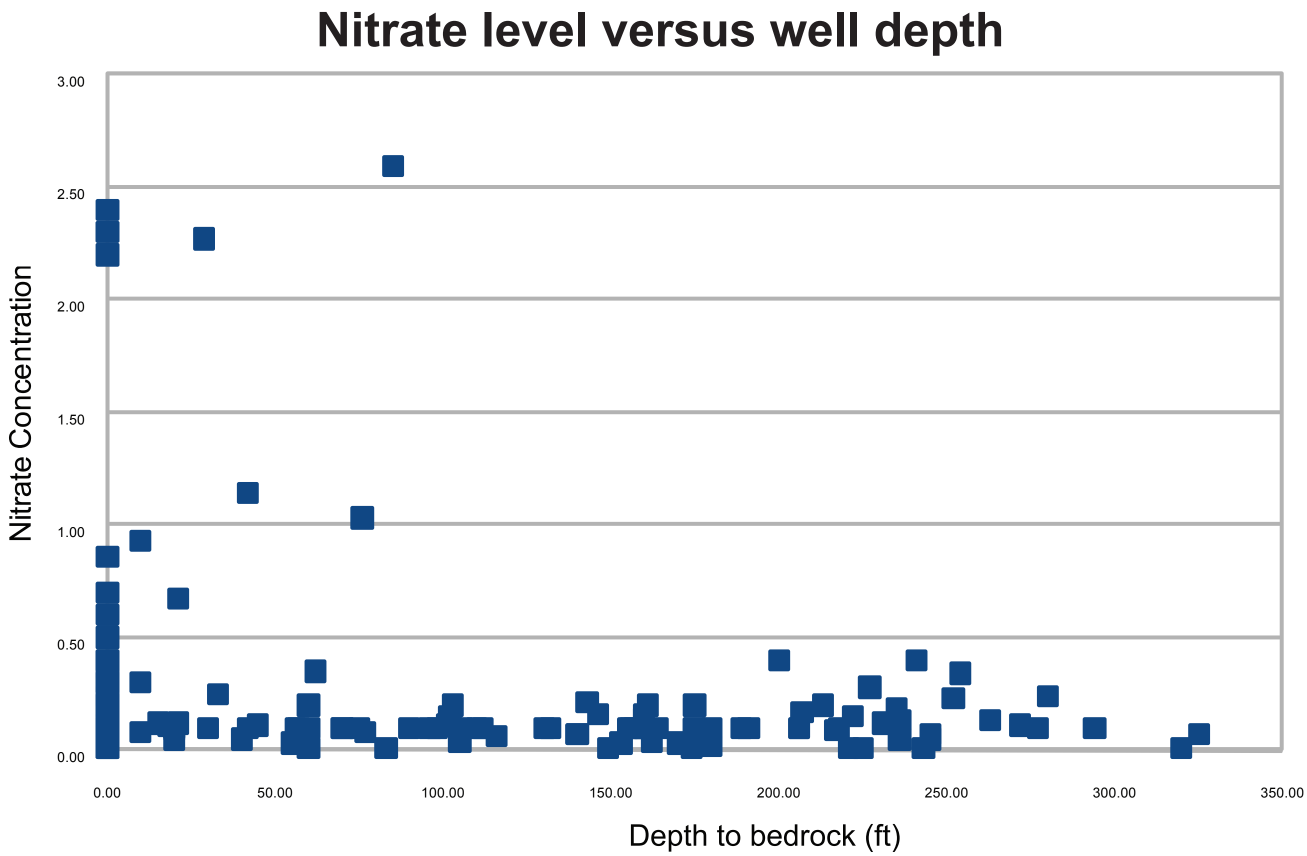


Figure 12: Nitate levels decrease generally as the depth to bedrock increases, with a slight increase around 250 ft.

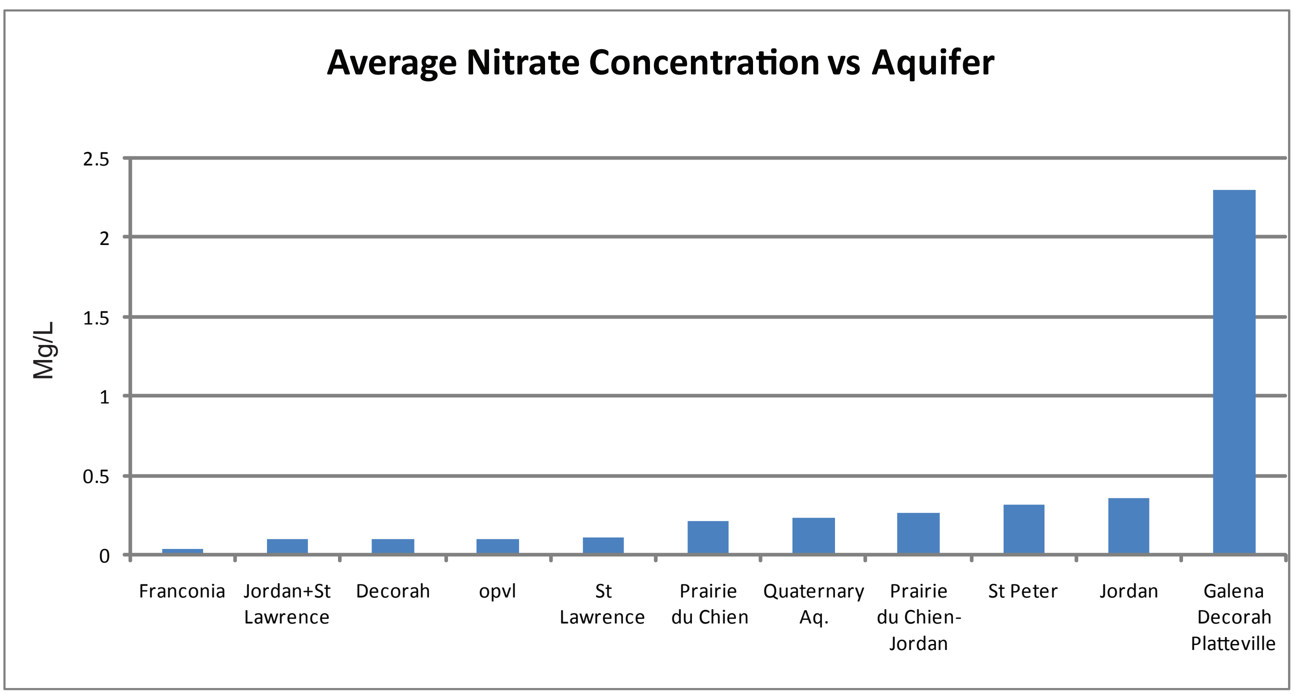


Figure 13: Nitrate Level within each aquifer of Rice County.

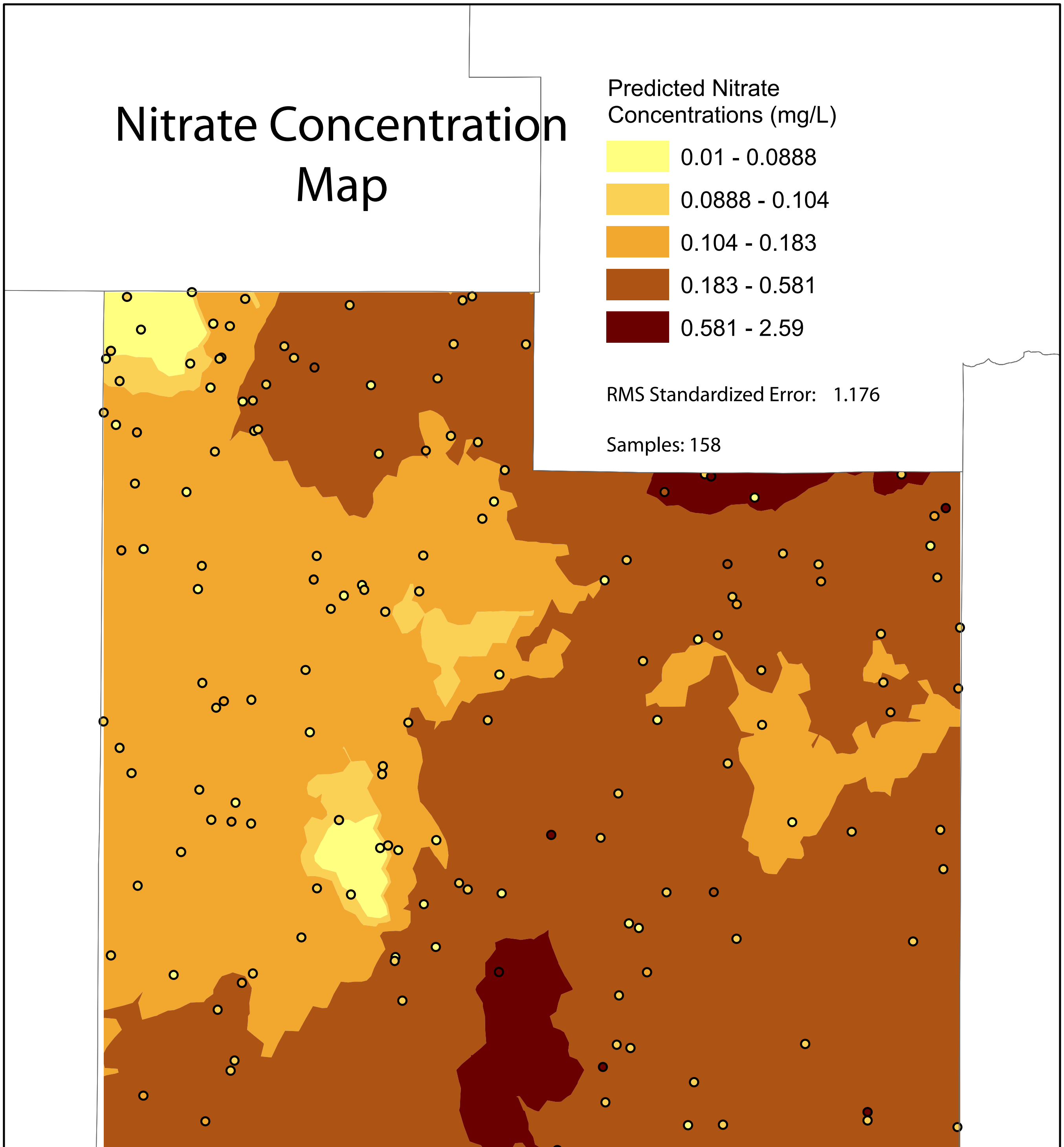


Figure 14. Interpolated groundwater nitrate concentration (mg/L) map of Rice County. Data represents 158 wells sampled by the DNR, VNMN, the MPCA, and the Carleton College Geology Department.

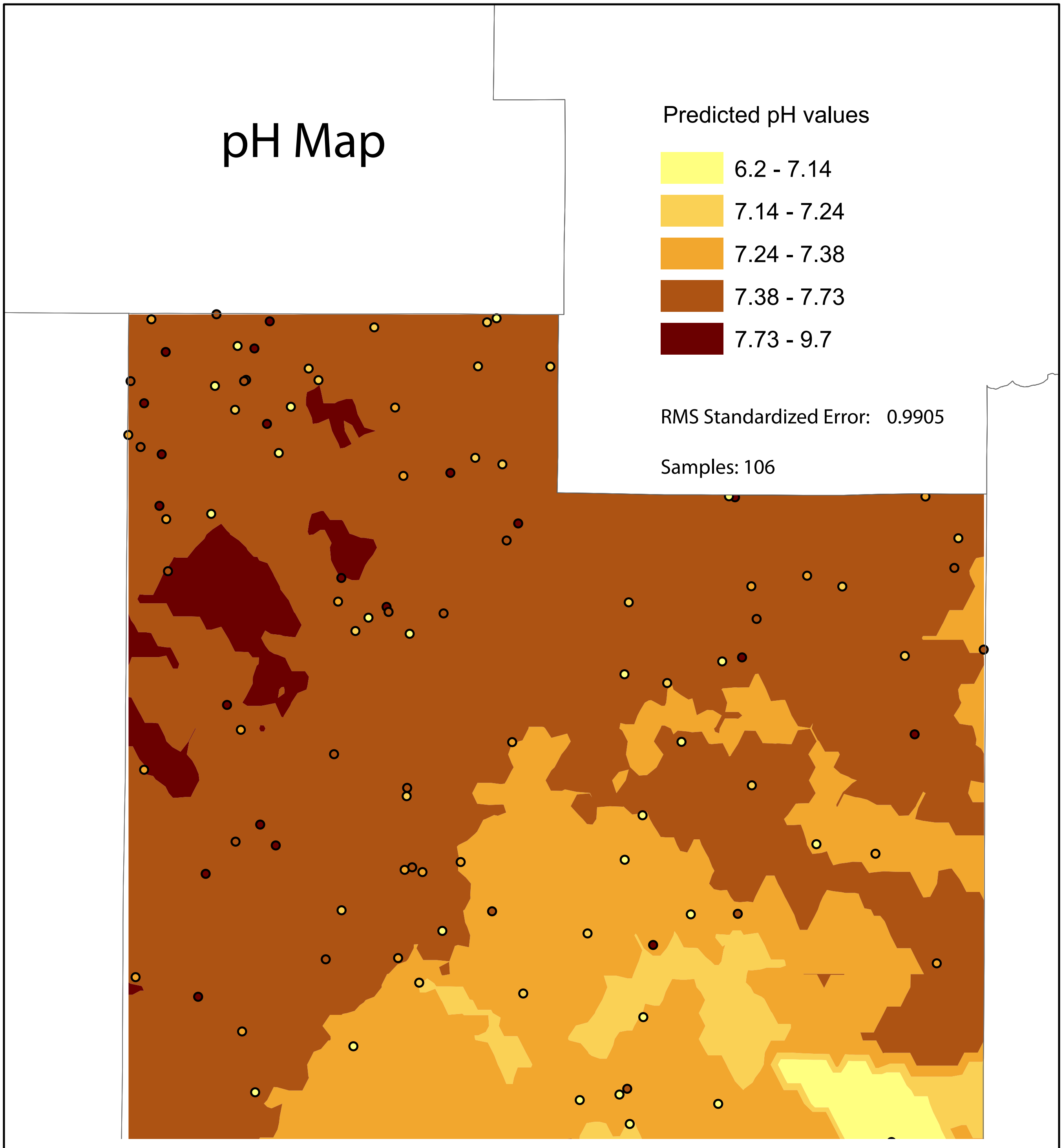


Figure 15. Interpolated groundwater pH map of Rice County. Results were classified with a quantile scheme. Data represents 158 wells sampled by the DNR, the MPCA, and the Carleton College Geology Department.

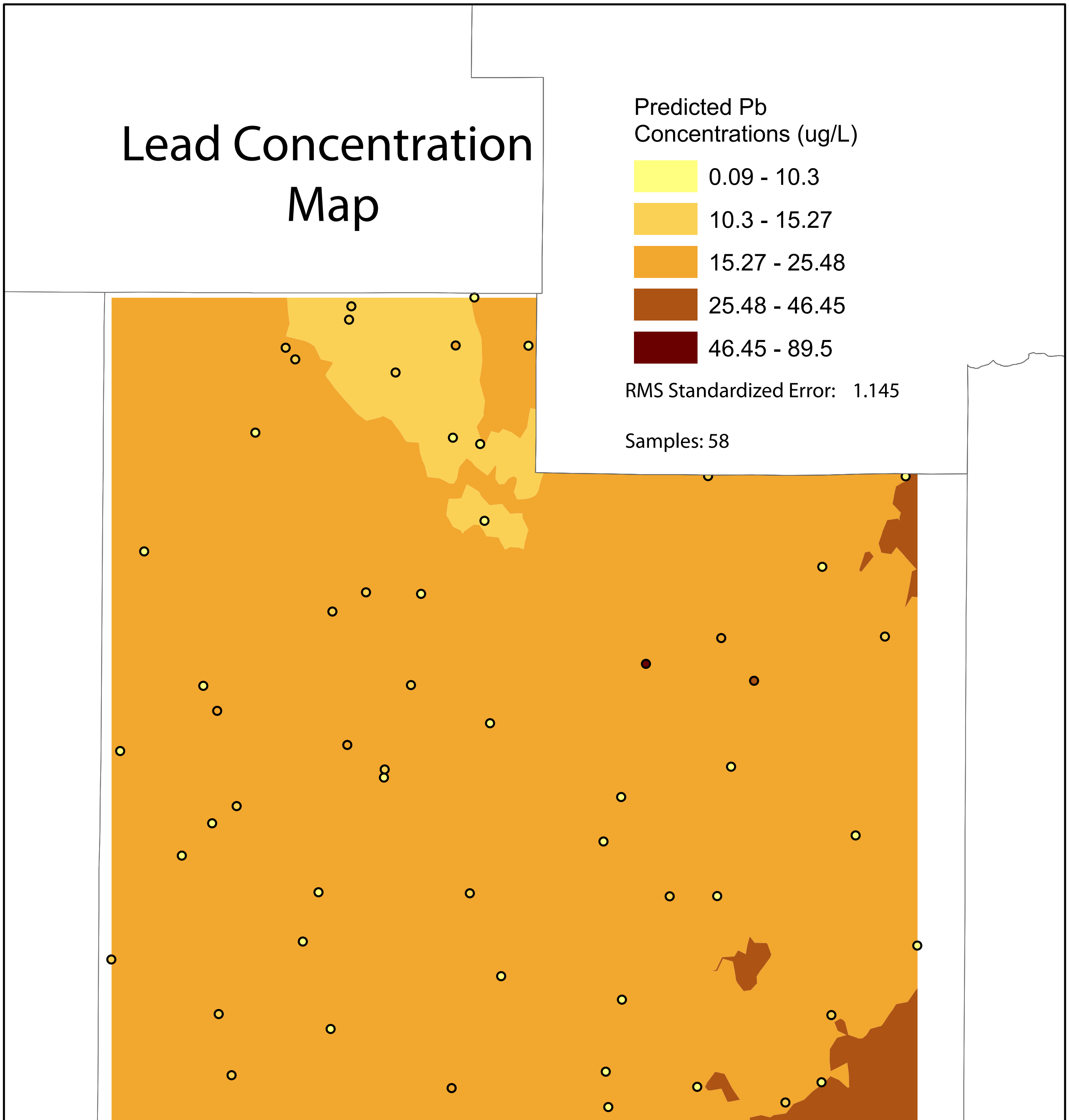


Figure 16. Interpolated groundwater Pb concentration (ug/L) map of Rice County. Points represent sample locations. Data from the DNR and MPCA.

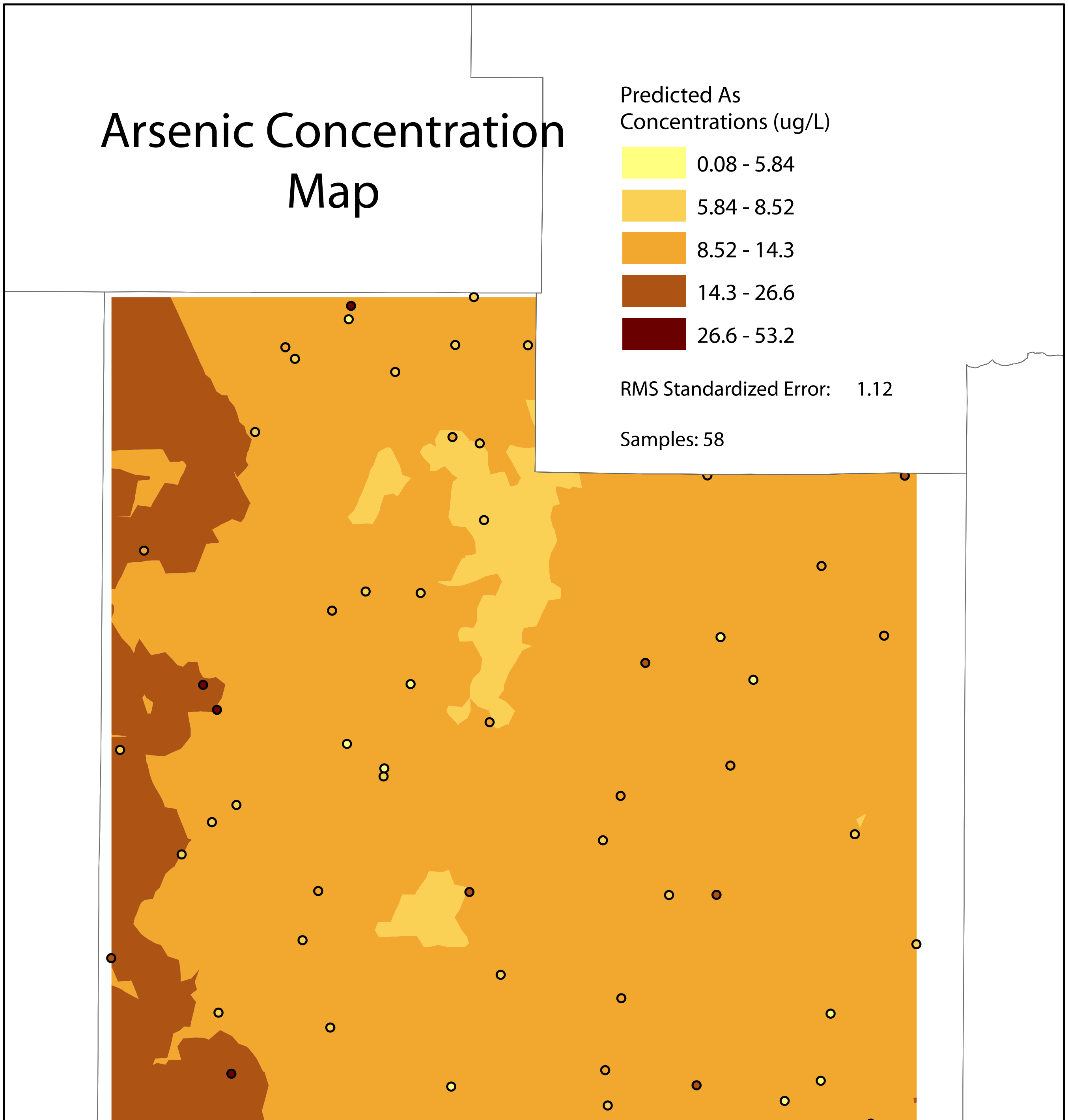


Figure 17. Interpolated groundwater As concentration (ug/L) map of Rice County. Points represent sample locations. Data from the DNR and MPCA.

Rice County well casing depth

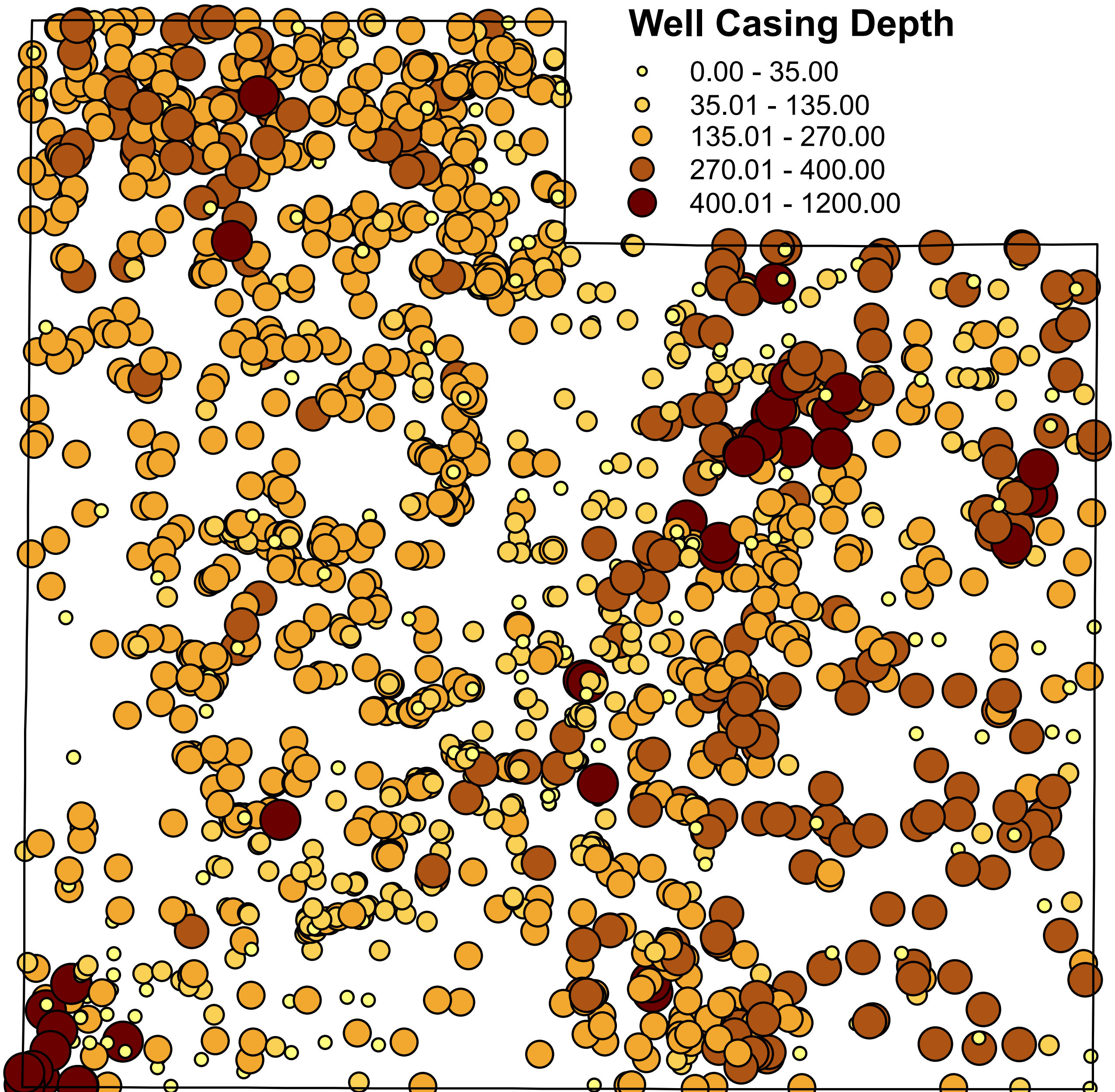


Figure 18. Well Casing depth of all wells within Rice County. Data is from the Minnesota County Well Index.

APPENDIX 1. Rice County Letter

Dear Rice County resident,

We need your help on an important project regarding your drinking water. In conjunction with the Geology Department at Carleton College, students in the Geochemistry of Natural Waters course taught by Dr. Haileab are conducting research in order to better understand the groundwater chemistry of Rice County.

Your participation will consist of granting Carleton students access to your well water in order for them to collect a few small samples. The information will be used in conjunction with data from other wells located throughout the county to draw conclusions about the state of groundwater in the region, which will finally be compiled in a report for the class. Rest assured that none of your personal information (name, address, etc.) will be included in this report. In return for allowing us access to your well, we promise to get back to you promptly with the results of our analysis of your groundwater, as well as our general findings for the county.

We will be calling you shortly after you receive this letter and, with your permission, figure out an appropriate time to stop by your property and briefly conduct our research.

Thank you very much for your assistance with our study. If you have any questions please feel free to contact us using the phone number or e-mail address provided below.

Sincerely,

Students of the Geochemistry of Natural Waters class and Dr. Bereket Haileab

507-222-5746

bhaileab@carleton.edu

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