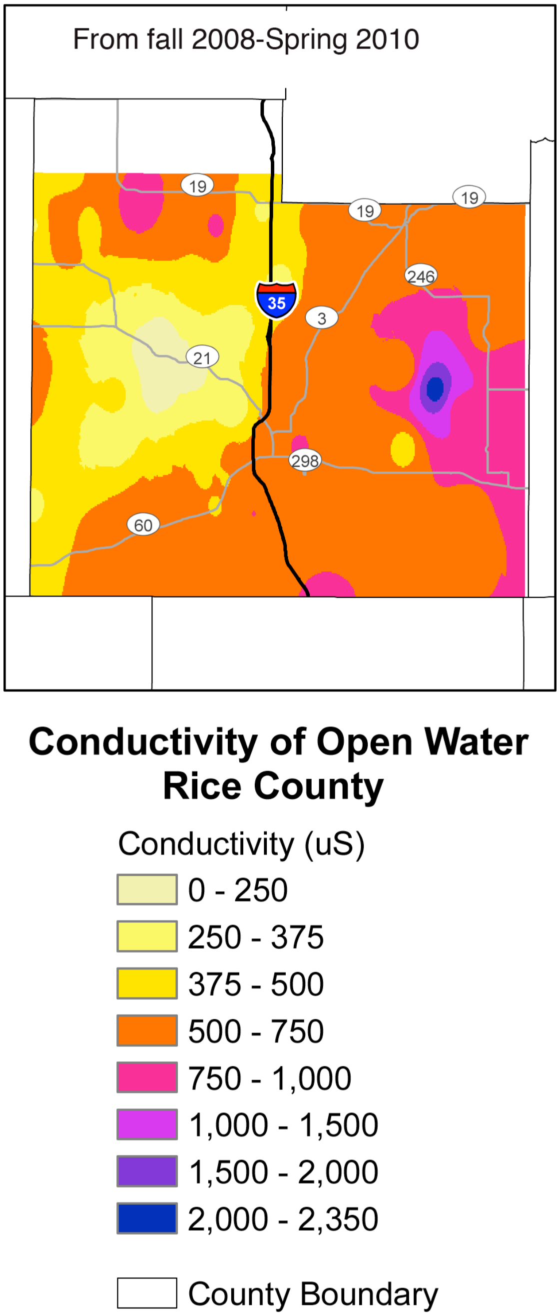
# Introduction to Geology, Spring 2010 Final Projects

# Study of Open Waters and Aquifers in Rice County, Minnesota



## Professor Bereket Haileab

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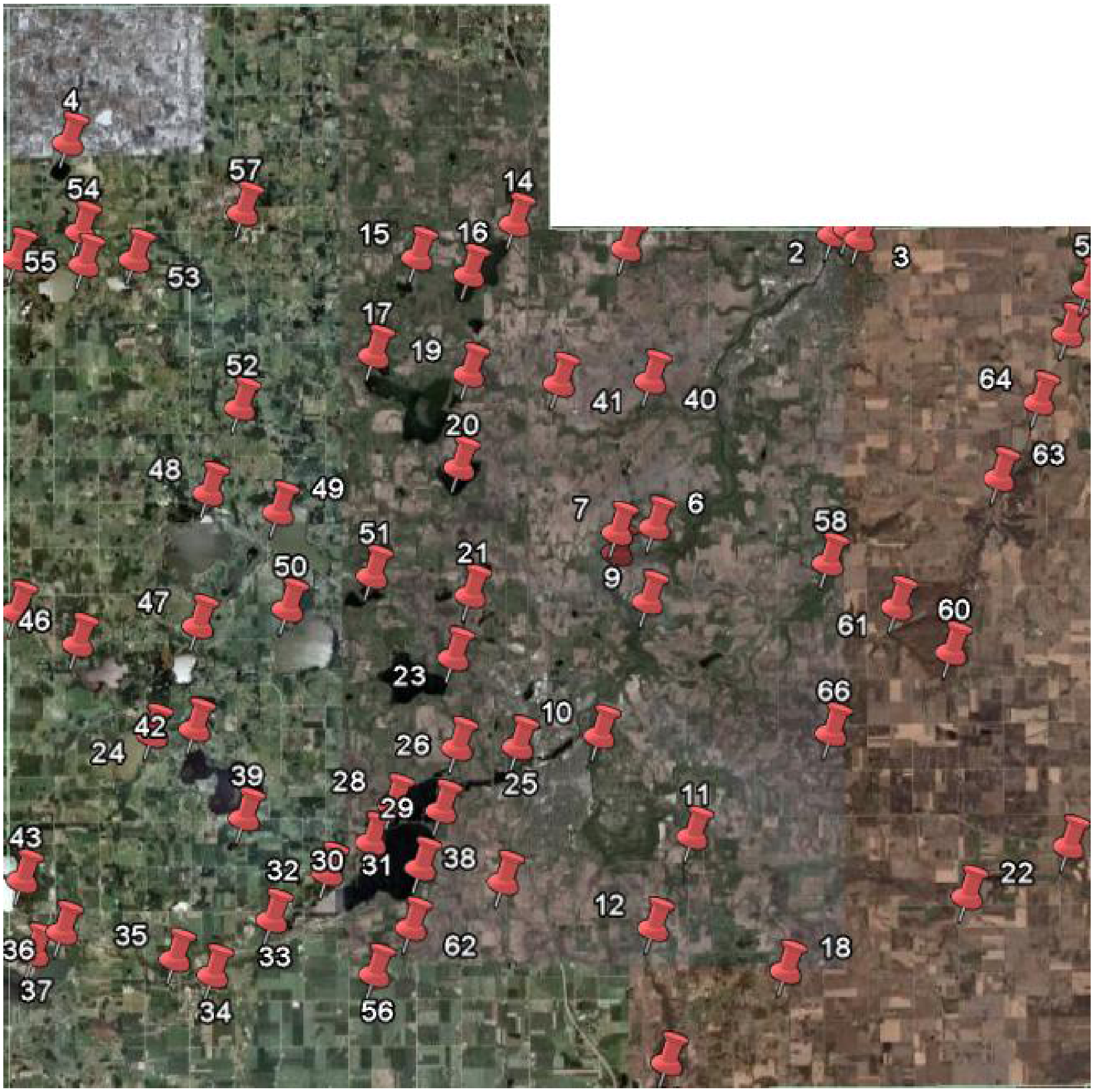

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## Introduction:

In the spring of 2010, thirty-nine students were enrolled in my introduction to geology course. Four were seniors and the rest were freshman and sophomores. In addition to lectures, labs and other assignments that go with the class, the students conducted several research projects. The class was divided into 11 groups with each group having three or four students. This year, the main theme was water and water issues in South Western Minnesota, in particular, Rice County. At the moment, water is not an issue in this part of the state, but, with more development, more agricultural practice and not having enough knowledge about ground water, there is definite a need to know more about our water and our aquifers. The research projects include, conductivity, nitrate, calcium, and turbidity of open waters in Rice County. Some also measured the porosity and permeability of the common rock formations in the county. Others, studied, Turkey manure composts site, fractures and joints of the common rock formations and distribution of feed lots in the county.

Each group was assigned a project by the second week of the term and started collecting data for their final projects. Students went to the field weekly and read relevant articles and started analyzing their data. By the midterm, many of the projects were in a good shape. Those that were having trouble collecting data were assisted by the TA's for the course and caught up soon.

The teaching assistants were of great help from driving the students to the field; helping with chemical analysis and GIS. Ms. Wei-Hsin Fu an adjunct Instructor and GIS Specialist in Environmental Studies also helped with GIS.

Bereket Haileab, Spring 2010.

# Final Project: Conductivity as a proxy for dissolved ions in open waters of Rice County, Minnesota

By: Jake Devereux, Cassie Mullen, Anna Swanson and Meg Tuta

Geology 110: Introduction to Geology
Professor Bereket Haileab
23 May 2010

**Abstract:** A study of water conductivity levels in bodies of water throughout Rice County, MN, in April 2010. A YSI meter was used to collect hydraulic conductivity and water temperature at various locations, which were recorded using GPS, and compared to data collected in a similar study by Nick Holschuh in four previous seasons in 2008 and 2009. Correlations to nitrate concentration by location, rainfall by season, and geographical features (such as glaciation) of the area are sought.

**Keywords:** hydraulic conductivity, YSI meter, GPS, nitrate, rainfall, glaciation

## Introduction

Rice County is located in the southeastern portion of Minnesota, and its surface water system is divided into two regions. The western region of the county consists mainly of lakes, while the east is covered with streams and rivers (Figure 1). In this study we examine spatial variation of conductivity in Rice County, Minnesota using conductivity as a proxy for water contamination.

Conductivity measures the presence of inorganic dissolved solids in water and gives an indication of how well water conducts electricity. It is measured in microsiemens and detects dissolved solids including sulfate, phosphate anions, sodium, magnesium, calcium, chloride, nitrate and sulfate. Wide variation in conductivity indicates changes in ion content in water bodies. Thus, increased conductivity can be used as an indication of water contamination. High levels of conductivity are often associated with high nitrate levels (Holschuh *et al*). The Environmental Protection Agency defines acceptable conductivity measurements as between 50 and 1500 micromhos (EPA).

Previous studies have mapped hydraulic conductivity to measure water and soil contamination (Naudet *et al*., 2004). Other studies have attempted to discern differences in conductivity of streams, noting the importance of stream water velocity and physical channel characteristics (Ryan and Packman, 2006). Seasonal variation and conductivity has also been studied in Cambodia, where considerable variation was noted between the dry and monsoon seasons (Okumura *et al*., 2007). In Rice County, studies conducted by

Carleton student Nick Holschuh and Professor Bereket Haileab in Rice County indicated high nitrate levels in the streams and rivers in the southeast.

The purpose of our lab is to determine the condition of the groundwater in Rice County by measuring the conductivity of the streams, lakes and rivers of Rice County. Specifically, we examine the effects of seasonal weather variation, geological factors, and human influences that may contribute to variation in conductivity. Our compilation of data from over five seasons provides an important look at the conditions of water in Rice County.

While there have been numerous studies that have measured changes in conductivity in different kinds of bodies of water, and in relation to seasonal variation, none have yet mapped this variable in a comprehensive fashion in Rice County, Minnesota over such a wide time span. As a class project in the spring of 2010, we collected 32 samples and used previous data collected by Nick Holschuh for a total of 99 measurements over five different seasons from the summer of 2008 to the spring of 2010.

Our results indicate the highest conductivity levels in the east of Rice County. There was some seasonal variation in conductivity levels, but the general trend remained constant throughout all five seasons of data collection.

## Methods

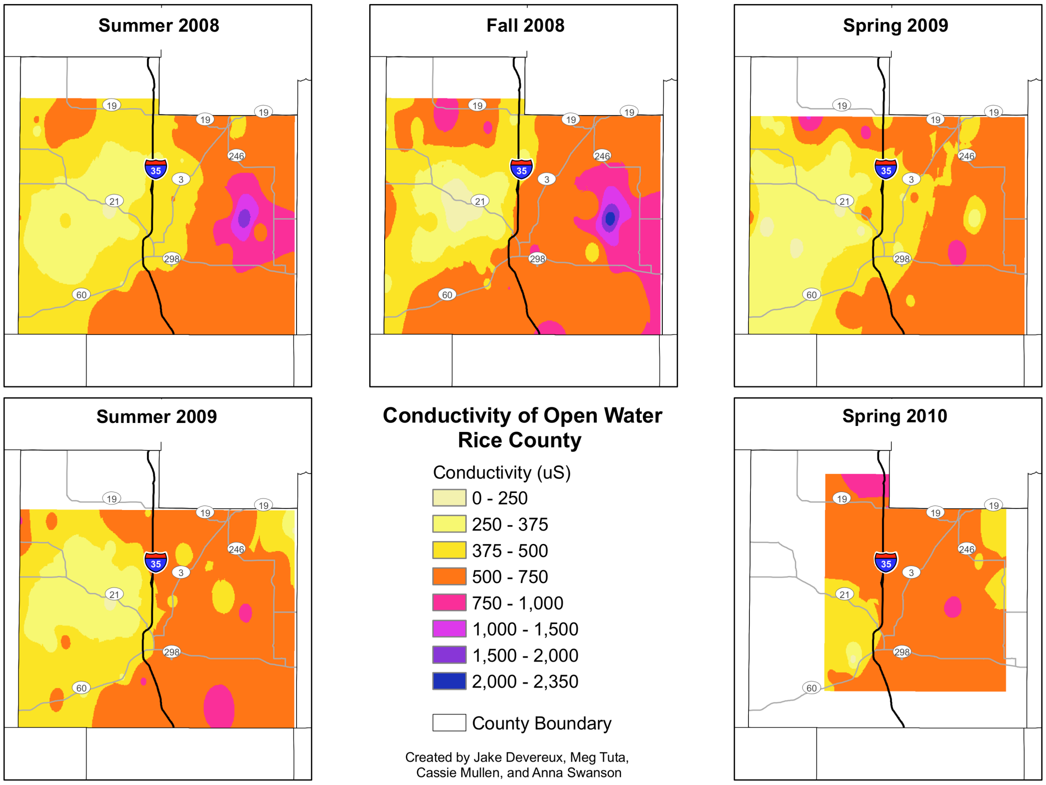
Fieldwork for this study was conducted between 2008 and 2010. At each location, the hydraulic conductivity was measured using a YSI 85 instrument by submerging the sensor completely in the body of water and constantly agitating it until a steady reading in microsiemens was registered. Between readings taken with the meter, the sensor was rinsed with distilled water to prevent residual water from one site affecting the measured conductivity of a later site. The longitude and latitude of the each site was determined and recorded using a GPS meter. The date of collection and temperature (in degrees Celsius) of the water were also recorded, as well as field notes regarding the type of body of water and any notable features of the area (i.e. presence of a culvert, dead animals, etc.). At each site, a sample of the water was also bottled for further study at a later date.

Conductivity sampling was conducted by Nick Holschuh and Bereket Haileab at 67 individual sites in Rice Country, each of which he revisited once during five seasons over 2008 to 2009 (Summer 2008, Fall 2008, Spring 2009, Summer 2009) (Figure **). Additional sampling was conducted by four introductory geology students and teaching assistants Liz Lundstrom and Nate Evenson.

In analyzing our data, we sorted the samples in ArcGIS and used Kriging interpolation to compare the variation in conductivity from summer of 2008 to Spring of 2010. We then reviewed weather data about the amount of rainfall using the Carleton Weather Database.

## Results

Based on our maps for the five seasons measured, there is a significant difference in the level of conductivity between the eastern and western regions of Rice County (Figure 1). Within this overall trend, there is some seasonal fluctuation, but these variations do not seem significant and could arise from measurement error, slightly different sample groups between seasons, differing levels of rainfall prior to measurement collection, and other environmental fluctuations. Conductivity measurements from the spring of 2010 fell between and 201 and 858 uS.


Summer 2008
Fall 2008
Spring 2009
Summer 2009
Spring 2010

Conductivity of Open Water
Rice County

Created by Jake Devereux, Meg Tuta, Cassie Mullen, and Anna Swanson

**Figure 1** displays seasonal variation in conductivity of Rice County, Minnesota. Although there is some variation between seasons, the Eastern half of the county has conductivity measurements that range from 375-2000 uS for the summer and fall of 2008. Conductivity measurements for spring of 2009, summer of 2009, and summer of 2010 fall between 375 uS and 1000 uS.

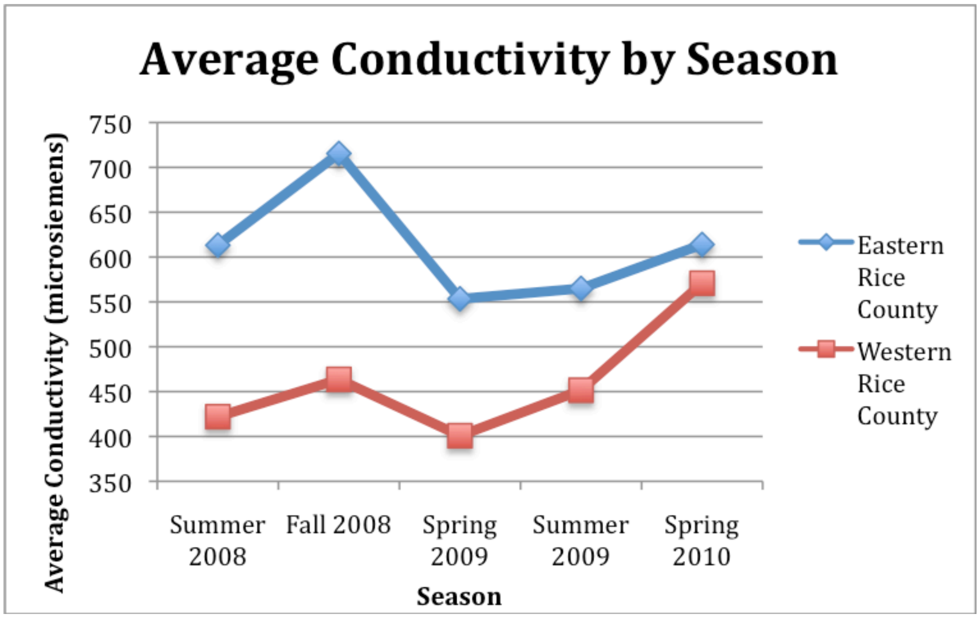


**Figure 2** displays the average conductivity data by season for summer of 2008 through spring of 2010, separated into Western and Eastern Rice County at the longitude 93°16" N. The two halves of the county seem to follow the same general trend, but the trend itself does not seem to be correlated to specific seasons.

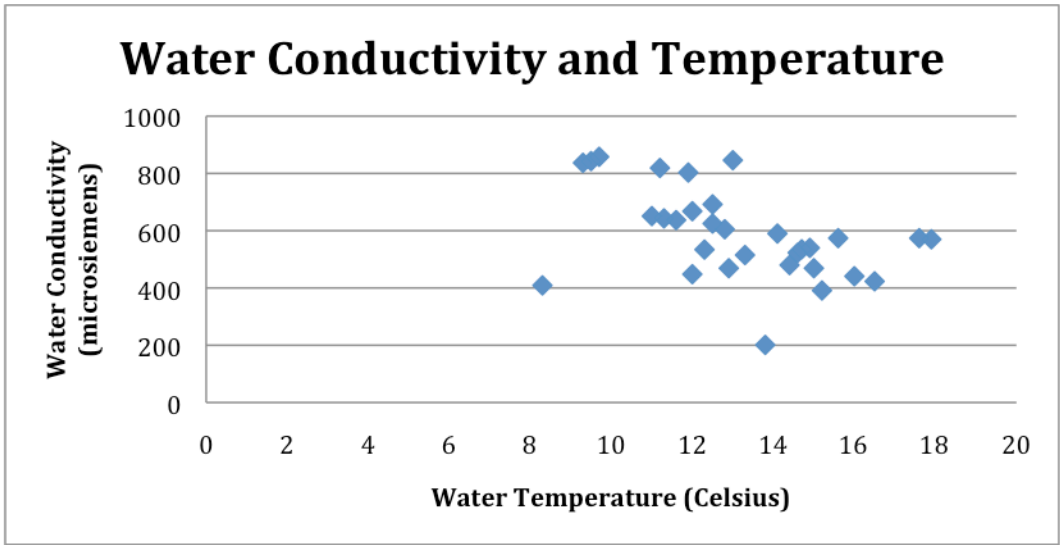


**Figure 3** displays a scatter-plot of conductivity measurements taken during April of 2010, comparing conductivity with corresponding water temperature measurements. No correlation appears to be represented by our data.

Table 1. Spring 2010 Conductivity Measurements for Rice County, Minnesota.

| | | | | **Spring, 2010** | |
|---|---|---|---|---|---|
| Sample # | Longitude | Latitude | Temp (C) | Conduct (uS) | Date |
| 68 | -93.344790 | 44.282040 | 13.8 | 201.2 | 17-Apr-10 |
| 69 | -93.356930 | 44.279540 | 16.5 | 423.2 | 17-Apr-10 |
| 70 | -93.393710 | 44.253560 | 15.2 | 391.2 | 17-Apr-10 |
| 71 | -93.383220 | 44.259740 | 14.7 | 535 | 17-Apr-10 |
| 72 | -93.356960 | 44.254740 | 12.5 | 625 | 17-Apr-10 |
| 73 | -93.308210 | 44.254620 | 12.5 | 692 | 17-Apr-10 |
| 74 | -93.303050 | 44.242210 | 12 | 668 | 17-Apr-10 |
| 75 | -93.084979 | 44.273359 | 15.6 | 574 | 18-Apr-10 |
| 76 | -93.085875 | 44.274472 | 17.6 | 574 | 18-Apr-10 |
| 77 | -93.09088 | 44.274853 | 17.9 | 570 | 18-Apr-10 |
| 78 | -93.09208 | 44.275586 | 14.6 | 523 | 18-Apr-10 |
| 79 | -93.2001 | 44.38494 | 14.1 | 590 | 18-Apr-10 |
| 80 | -93.20126 | 44.38494 | 14.9 | 540 | 18-Apr-10 |
| 81 | -93.28665 | 44.47231 | 13 | 846 | 24-Apr-10 |
| 82 | -93.28909 | 44.47231 | 12 | 448.1 | 24-Apr-10 |
| 83 | -93.28944 | 44.49869 | 9.3 | 837 | 24-Apr-10 |
| 84 | -93.29007 | 44.49873 | 9.5 | 843 | 24-Apr-10 |
| 85 | -93.28502 | 44.5143 | 9.7 | 858 | 24-Apr-10 |
| 86 | -93.17014 | 44.30846 | 12.3 | 534 | 24-Apr-10 |
| 87 | -93.17113 | 44.3174 | 11.3 | 643 | 24-Apr-10 |
| 88 | -93.171018 | 44.31749 | 11 | 651 | 24-Apr-10 |
| 89 | -93.17088 | 44.34563 | 11.2 | 819 | 24-Apr-10 |
| 90 | -93.17052 | 44.34427 | 11.9 | 803 | 24-Apr-10 |
| 91 | -93.14487 | 44.41474 | 12.8 | 605 | 24-Apr-10 |
| 92 | -93.1249 | 44.40618 | 12.9 | 469 | 24-Apr-10 |
| 93 | -93.10191 | 44.4066 | 11.6 | 637 | 24-Apr-10 |
| 94 | -93.07798 | 44.4072 | 13.3 | 515 | 24-Apr-10 |
| 95 | -93.08518 | 44.38255 | 14.4 | 480 | 24-Apr-10 |
| 96 | -93.08421 | 44.37825 | 16 | 441 | 24-Apr-10 |
| 97 | -93.08036 | 44.41733 | 15 | 469 | 24-Apr-10 |
| 98 | -93.09703 | 44.42841 | 8.3 | 409 | 24-Apr-10 |

Table 1 displays the specific longitude, latitude, water temperature (in degrees Celsius), conductivity (in uS), and date of each sample measured during April of 2010. Temperatures range from 8.3-17.9 degrees Celsius, and conductivity ranges from 201.2 to 858 uS.

## Discussion

Our results from the spring of 2010 in Rice County indicate much higher levels of conductivity in the eastern regions than in the western regions (Figure 1). This finding supports previous research conducted by Nick Holschuh and Bereket Haileab from the summer of 2008 to the spring of 2009. Regions of high conductivity in the east correlate with regions of high nitrate measurements (Appendix 4). There does not appear to be any correlation between population centers and increased conductivity, most likely because of proper water treatment (Appendix 2). High nitrate and conductivity levels in the east indicate significant agricultural input, since the southeast regions show the highest conductivity levels.

The complex geology of Rice County has also played a role in the variance of its conductivity. Between 10,000 and 15,000 years ago, the western half of the county was subject to glaciation, making lakes the dominant bodies of water in that area, while the eastern half remained untouched by glaciers, leaving streams as the dominant feature today. As streams are better suited for irrigation, the eastern half is much more conducive to agricultural use. Consequently, nitrates used for farming in the more fertile eastern half have entered the bodies of water there and resulted in both increased nitrate concentration and hydraulic conductivity, as compared to the western half of the county.

Our data collected during the spring of 2010 did not cover the entire sampling region from the previous four seasons. However, nitrate concentration and conductivity levels in the area we examined correspond with the previous findings of Nick Holschuh and Bereket Haileab between summer of 2008 and spring of 2009.

In comparing seasonal fluctuations (Figure 2) in conductivity with seasonal rainfall averages, there does not seem to be an appreciable correlation between the two variables; however, given a longer span of time for more consistent sampling (over several years, perhaps), it is possible that some relationship might emerge, but with the data we have, this is not yet apparent.

In comparing temperature and conductivity measurements for the data we collected in the spring of 2010, there is no clear correlation between temperature and conductivity (Figure 3). Although higher conductivity and higher temperature are usually associated (Franco, et al.), there are enough confounding factors (limited sample size, disparities in conductivity based on geographical location) to make this trend not apparent based solely on our data.

## Conclusion

Based on our results from the spring of 2010, streams and rivers in the eastern region of Rice County are characterized by higher hydraulic conductivity levels than lakes in the western portion of the county. Conductivity data over five seasons supports this finding. Agricultural input and the geology of Rice County are the main factors that affect variance in hydraulic conductivity. Although there was some variation between seasons, the changes were not significant and the general trend with higher levels in the east remained constant.

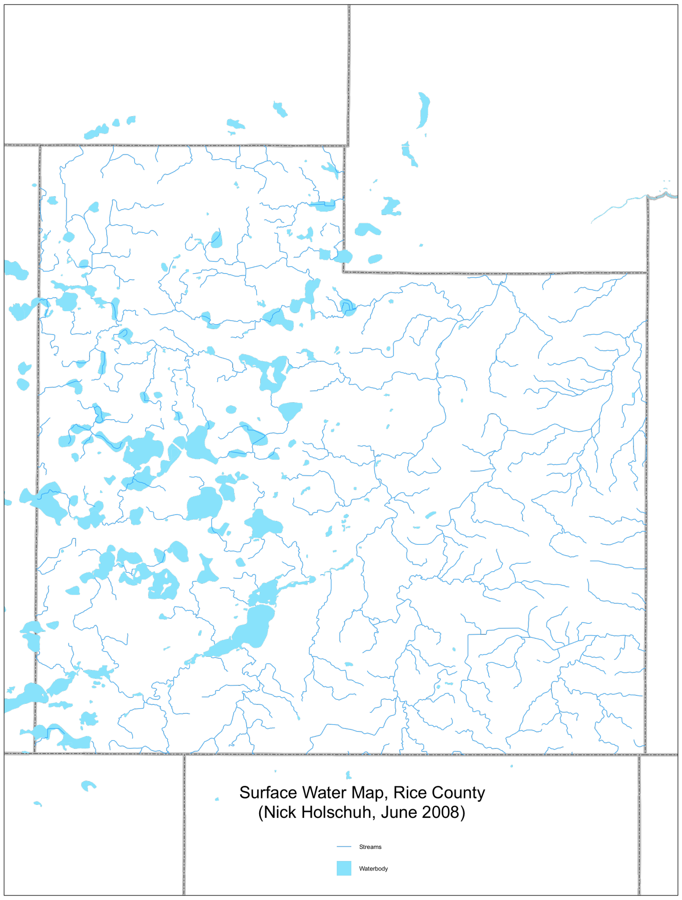
All of our measurements fell beneath the EPA standard of 1000 uS for contamination, so current levels of conductivity are not a cause for concern, in terms of local population health and agricultural issues. Possible sources of error in our study include the small sample size, inconsistent distribution of sampling within the county, and underrepresentation of certain areas of county within our data.

To verify the Spring 2010 data, the sampling region within Rice County should be expanded to cover the county more thoroughly, and sampling should be repeated in subsequent seasons to determine if seasonal trends do indeed exist. Similar studies could be conducted in nearby counties with similar or different glacier-produced geological features, such as Goodhue County.

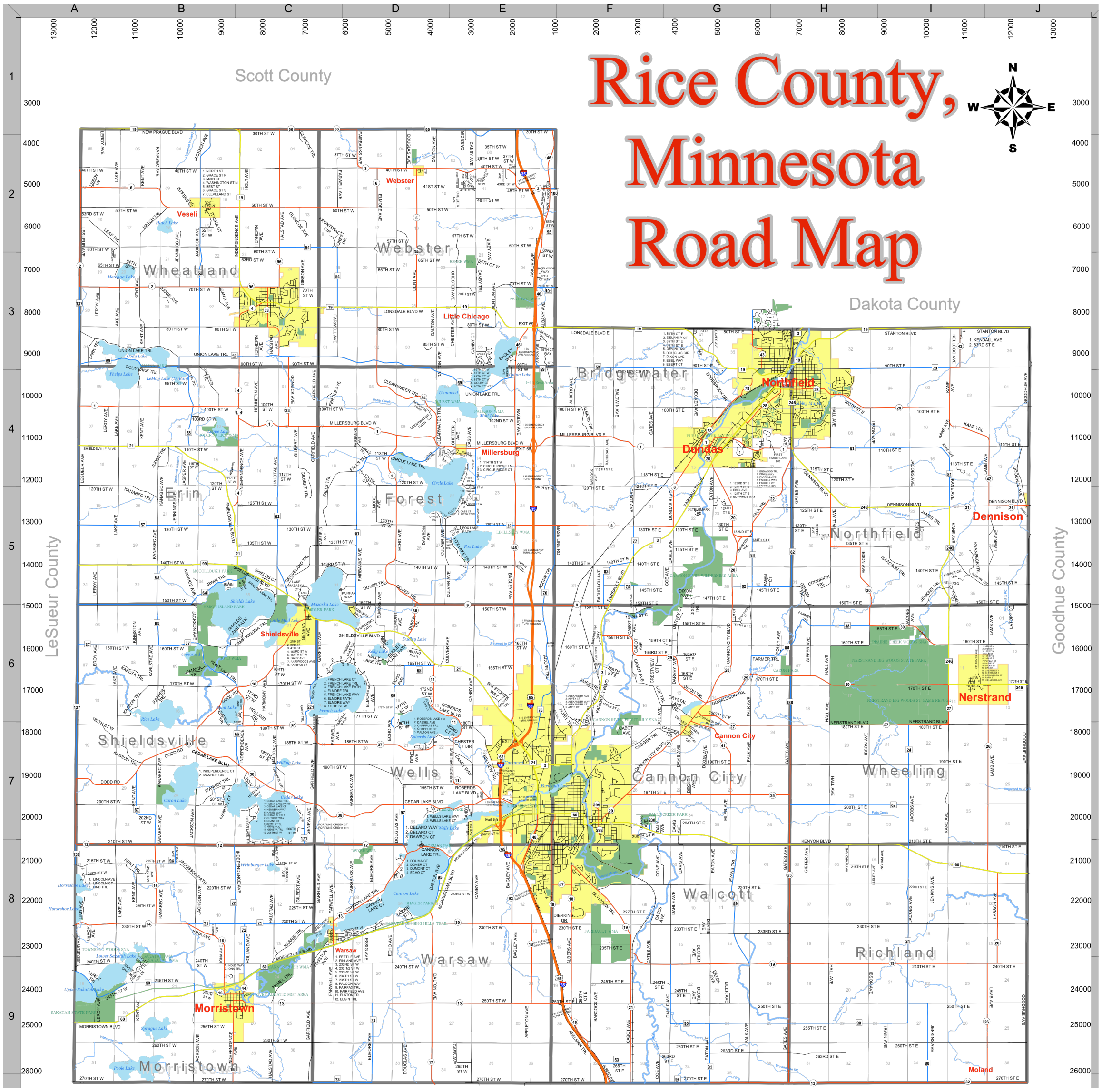
## Acknowledgements

We would like to thank our professor, Bereket Haileab, for his overwhelming encouragement and all his assistance organizing the collection of samples, and directing our efforts with the analysis and paper. Also, we would like to thank our teaching assistants who collected conductivity measurements for us, Adam Denny, Elizabeth Lundstrom, James Bethune, and Nathan Evenson, and additionally thank Adam Denny and James Bethune for discussing our data with us. We would like to thank Nick Holschuh for providing us with the data that he collected from previous seasons, and Wei-Hsin Fu for helping us use GIS to make maps from our data. And finally, we would like to thank the Geology Department for providing funding for our project.

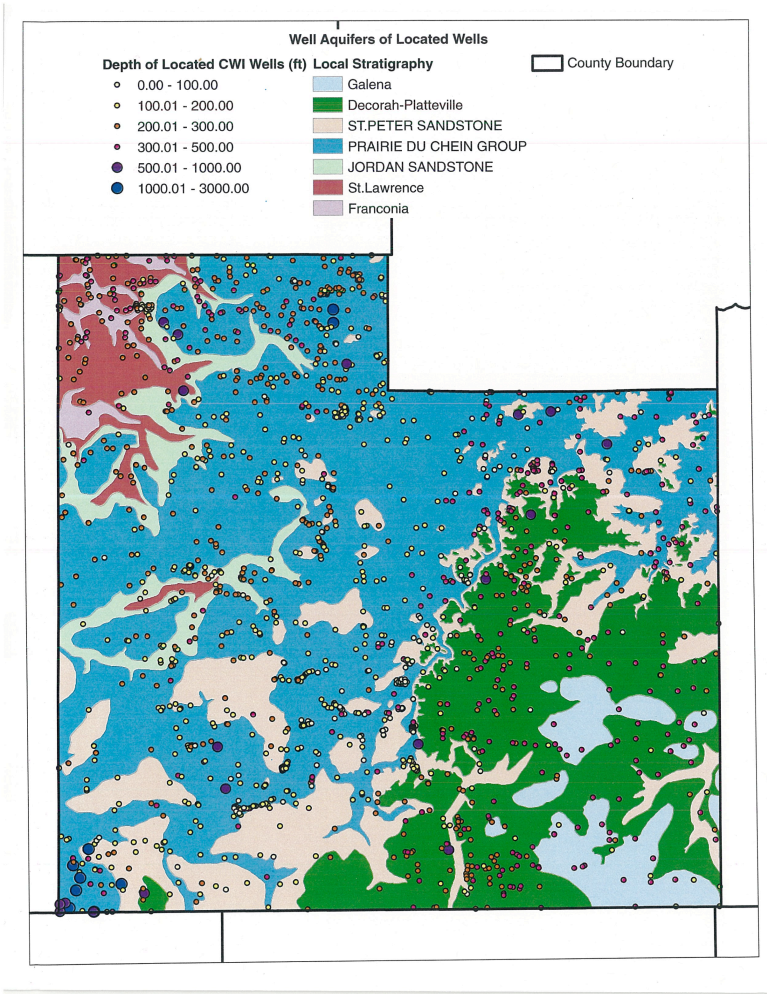
## Appendix



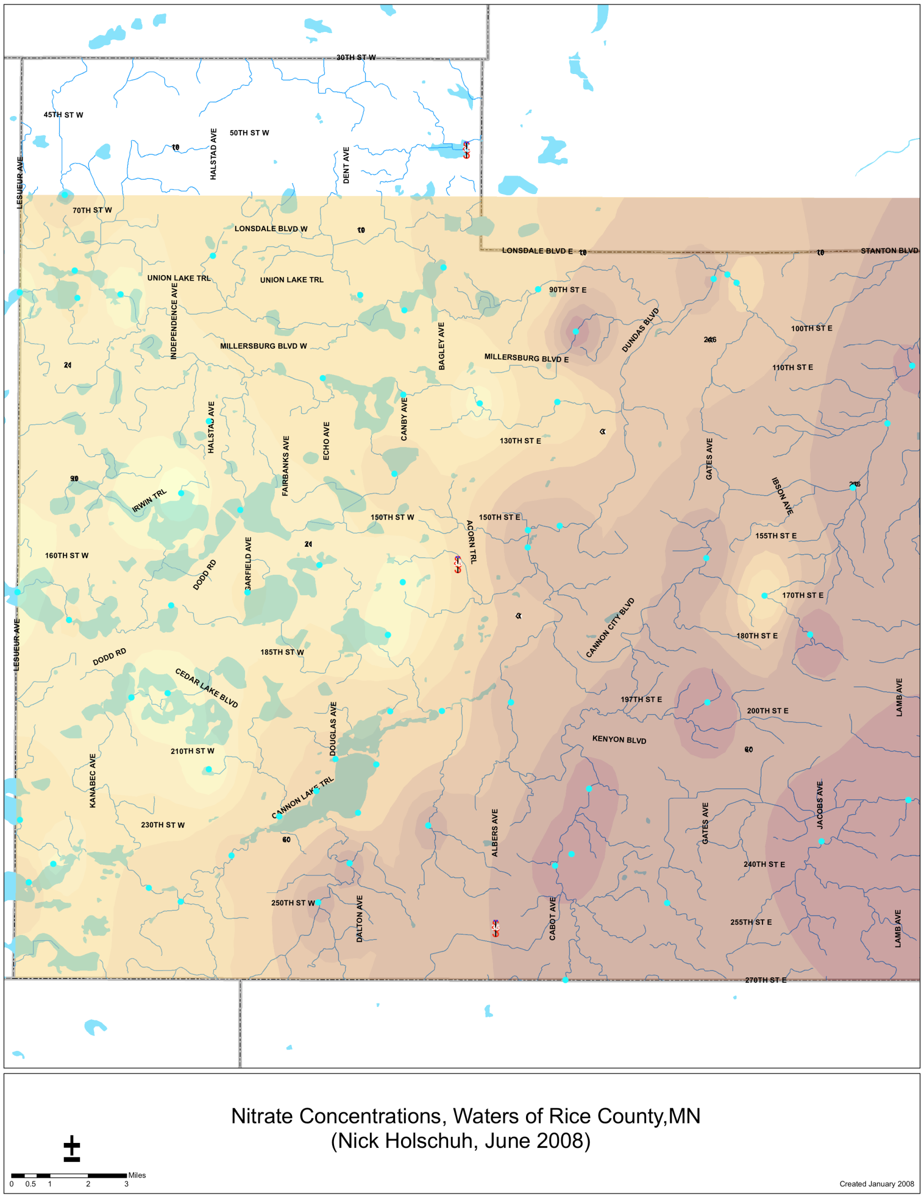
Appendix 1. Surface water of Rice County. Created by Nick Holschuh.



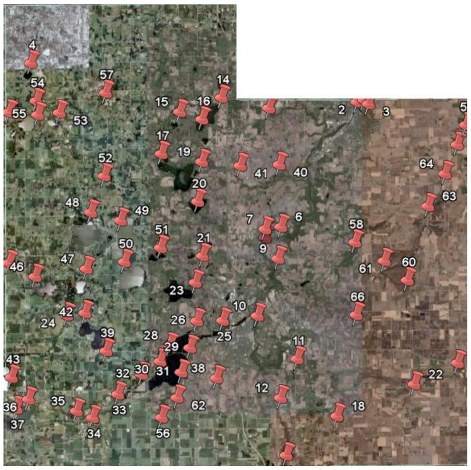
Appendix 2. Rice County Map. City boundaries shown in yellow.



Appendix 3. Geologic Map of Rice County, Minnesota.



Appendix 4. Nitrate Concentrations in Rice County for June 2008. Darker purples correlate to higher nitrate levels. Created by Nick Holschuh.



Appendix 5. Distribution of sampling for data collected by Bereket Haileab and Nick Holschuh for Summer of 2008 through Summer of 2009.

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# Analysis of a Turkey Manure Composting Site
## in Goodhue County

Introduction to Geology, Spring 2010
Jonathan Hughes, Alex Korsunsky, & Rachel June-Graber

## Abstract

We studied the chemistry of water on and near the site of the Sustane Natural Fertilizer Inc. turkey manure composting facility in Dennison, MN. We tested water in the manure runoff holding ponds as well as a nearby stream for nitrates, conductivity, salinity, and oxygen content. We found in all cases that the chemical content of the water in the holding ponds was significantly different from that in the stream, suggesting that the improvements at the site have largely prevented contamination by runoff from the site. However, slightly elevated nitrate and conductivity levels downstream from the site as compared to upstream raise concerns that some leeching may be occurring.

## Introduction

For our research project, we looked at the Sustane Natural Fertilizer Inc. turkey manure composting site and tested to see whether it has had a negative impact on the area through elevated levels of nutrients or fecal matter in nearby bodies of water. The composting site is located in Goodhue County, Minnesota in Dennison (Fig. 1). The site itself is a large pile of turkey manure with three runoff ponds to catch turkey manure runoff from the compost. The site is surrounded by farms on every side, and to the South there was a small stream running from West to East. Most of the manure collected for this site comes from six different families in the turkey business in the Northfield and Cannon Falls area, as well as from other regional farms.

The compost site is permitted to manage 25,000 tons per year; however, the actual amount handled is lower (Holden, 2010). About 5% of the finished compost is sold to a few area farmers; 95% of the finished compost is trucked to a further manufacturing facility in Cannon Falls where the material is processed and shipped around the world.

Very little published research is available on the subject of turkey manure composting facilities and their effects on the surrounding environment. Many articles we found did not specifically address the effects turkey manure composting, but rather the benefits of composting in general.  The article "Composting's a Perfect Fit for a Turkey Producer" discusses the particular benefits of turkey manure compost, stating that "turkey manure composts vigorously" and "[i]t's for the micronutrients and the bacteria that improve the soil… It's also high in calcium," (MSUE, 2000).

Other sources that did look at turkey manure composting discussed the benefits of turkey compost for plants, or the effect of manure runoff that had been applied to fields, rather than the effect that a greater concentration (such as that present at the composting site) might have on the soil and water in the area. Elrashidi, West et. al. (2009) researched runoff from poultry manure applied to fields in West Virginia, finding that volume of runoff varies greatly depending on land usage, with cropland, pastureland, and forests all producing different amounts of runoff. However, that study's focus on nonpoint source polluters means that its relevance to potential major sources such as Sustane is distinctly limited. Another study, Makris (2009), examines animal waste storage ponds and finds that they are significant sources of the greenhouse gas N2O, demonstrating that storage and composting facilities to Sustane are potentially important sources of pollution. Nevertheless, this study, too, is limited in usefulness to this investigation by its focus on atmospheric pollution rather than groundwater contamination.

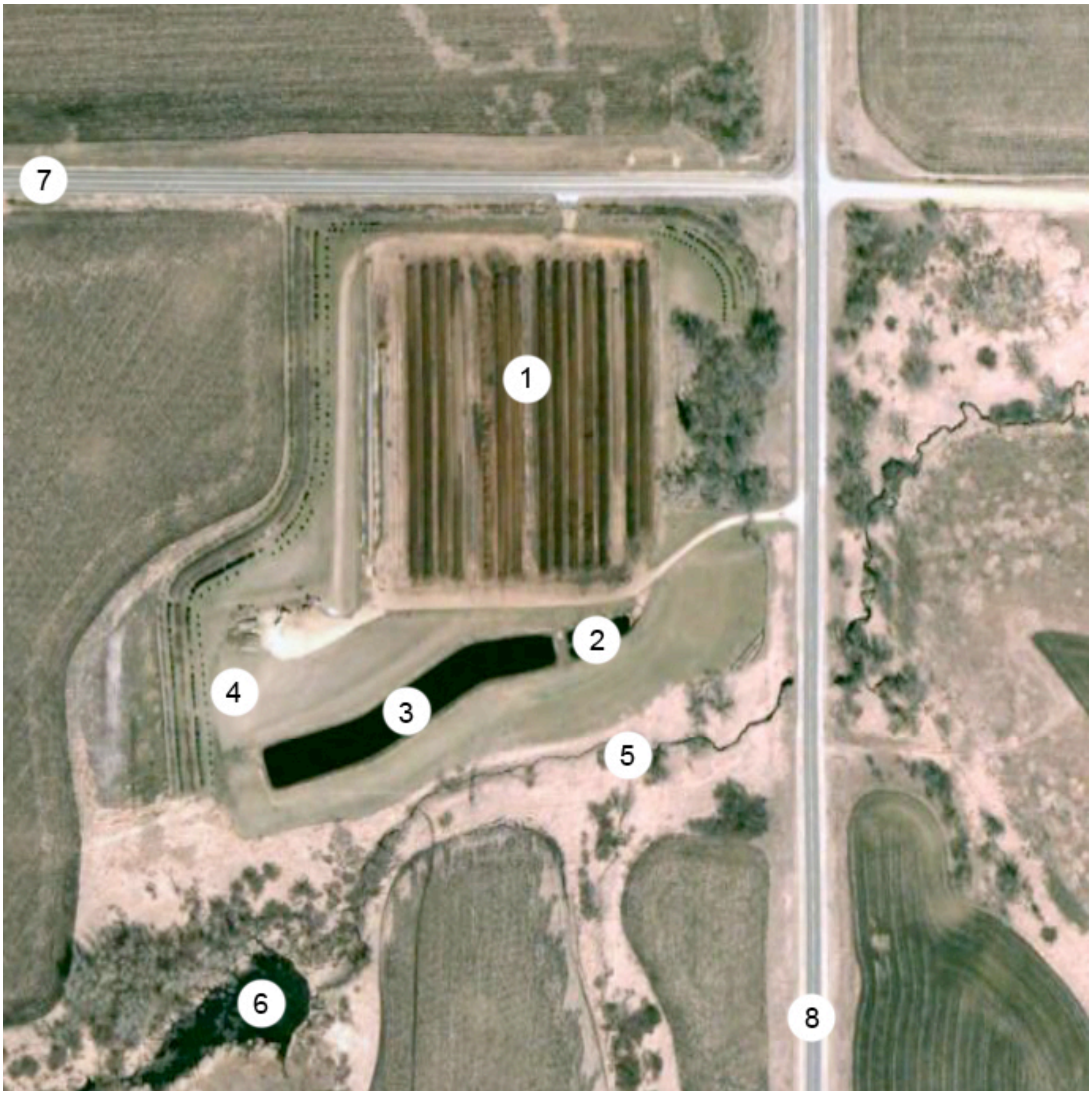

**Figure 1, Aerial view of the composting site. 1) Manure Field, 2) Holding Pond #2, 3) Holding Pond #1, 4) Holding Pond #3 (created since the picture was taken), 5) Stream east – downstream, 6) Stream west – upstream, 7) County Road 49, 8) Blvd Route 56.**

According to Craig Holden, President and CEO of Sustane Natural Fertilizer, Inc, the Sustane compost facility was designed as an alternative treatment process to direct land application of raw manure. Although turkeys produce manure year round, and this manure is valuable in improving soil and crop fertility, in Minnesota fertilizer can only be applied between the thawing of the ground and the first planting and again between the harvest and the first snows, as applying manure to land that is still frozen or covered in snow is both ineffective (the melt carries away many of the nutrients) and potentially hazardous (melting snow can carry fecal matter and e. coli bacteria into streams and groundwater). Consequently, manure must be carefully stored during the rest of the year so as to avoid leeching into the groundwater.

The land at the facility has gone through a number of engineering projects to make it suitable for the storage of large volumes of turkey waste. According to Craig Holden, these modifications include:

A. Shaping and compacting a clay liner of the pad.

B. Runoff control berms surrounding the clay pad.

C. Construction of a concrete-lined solids separation basin.

D. Construction of a compacted clay lined runoff holding basin

E. Engineered holding ponds

F. Eight groundwater monitoring wells (both up-gradient and down-gradient), analyzed by an independent private lab biannually.

G. Up-gradient and down-gradient perimeter tile lines for sampling around both holding ponds.

H. A windbreak around three sides of the site as a visual barrier and dust trap.

I. A pump station to move runoff to windrows or onto cropland. Runoff is pumped back into the windrows or irrigated onto surrounding cropland.

Holden further reports that the site soils were bored and analyzed for permeability prior to development of the site. He states that these revealed that the clay pad is compacted glacial clay and is impervious to leaching. Directly under the 15 foot deep clay pad is about 400 feet of Decorah Shale which is considered an aquatard. The site is also inclined, allowing for natural drainage to the runoff control ponds (Holden, 2010).

In addition to these physical improvements, Sustane employs the following practices to control contamination:

A. The clay composting pad is surveyed in 100 locations twice annually to determine whether any portions of the pad are eroding. If erosion is discovered, the pad is repaired with compacted clay to fill in the low spots.

B. The intermittent stream to the south of the site is also sampled and tested twice annually (Holden, 2010).

Investigation into the success or failure of these improvements is important, not only for the implications it may have for drinking water supplies in southeastern Minnesota, but also because it can help to refine waste management techniques. If the site is succeeding in containing waste, then it will demonstrate that Sustane's model is viable and should be replicated at other sites; if leakage is occurring, then these data may point the way to changes that can be made to this and future sites to make them more successful.

In light of the features of the site designed to contain the runoff from the manure, we hypothesize that, while the holding ponds will contain elevated levels of nitrates, potassium, and other indicators of contamination, the nearby natural water sources will not diverge significantly from regional norms.

**Figure 2, Runoff pond at the composting site.**

# Methods

In order to gain some knowledge about the turkey composting site and its effects on the surrounding area, we decided to do several tests of local bodies of water. We visited the site and took water samples from all three of the run-off ponds (Pond #1: N 44.36845º W 092.98172º; Pond #2: N 44.36858º W 092.98115º; Pond #3: N 44.22085º W 092.59021º). We took water samples from the nearby stream at two different points, one upstream from the facility (N 44.36811º W 092.98089º) and one downstream (N 44.36706º W 092.98308º), approximately 200 meters apart. We ran tests on all water samples for oxygen content, conductivity (a proxy for potassium content), and nitrogen. We also took the conductivity of the water at these same sites.

Furthermore, we took the well numbers of the six wells at the site that we could locate in order to get the public well data from the county. The positions of the wells are as follows:

Well #1: 513636, N 44.36878º W 092.98020º
Well #2: 513635, N 44.36832º W 092.98087º
Well #3: 726984, N 44.36787º W 092.98265º
Well #4: 726983, N 44.36794º W 092.98341º
Well #5: 513634, N 44.36886º W 092.98358º
Well #6: 513637, N 44.37054º W 092.98358º

## Results

Our tests revealed that the range for conductivity in the holding ponds was from ~3400 μS - ~5800 μS. The stream yielded results close to 600 μS for both sites sampled, with the downstream site some 40 μS higher. Salinity was higher in the holding ponds than the stream (~2-3ppt vs. ~0.4ppt), and oxygen content and saturation lower. Nitrates were higher in the ponds than in the stream, although there was considerable variation within both groups.

**Figure 3, The stream on the south side of the site.**

**Table 1**

| | **Pond 1** | **Pond 2** | **Pond 3** | **Stream – east/downstream** | **Stream – west / upstream** |
|---|---|---|---|---|---|
| **Conductivity** | 4510$\mu$S | 5820$\mu$S | 3489$\mu$S | 729$\mu$S | 587$\mu$S |
| **Salinity** | 2.9ppt | 3.5ppt | 2.3ppt | 0.4ppt | 0.3ppt |
| **Oxygen content** | 0.35mg/L | 0.02 mg/L | 0.23 mg/L | 14.11 mg/L | 17.35 mg/L |
| **Oxygen saturation** | 0.4% | 0.1% | 3.0% | 135.4% | 194.6% |
| **Nitrate** | 111 ppm | 30 ppm | 22 ppm | 8.5 ppm | 0.5 ppm |

We have contacted several people at the Minnesota Pollution Control Agency in an attempt to access well data for the site which the state has on record. We are still awaiting a reply.

Directly downwind from the site, there is a considerable, unpleasant odor from the site. Upwind, however, the smell is mild.

## Discussion

Conductivity was dramatically higher in the drainage ponds than in the stream, indicating high potassium content (and therefore more impurities), as we hypothesized based on the intense murkiness of the ponds. Conductivity was not greatly higher downstream from the ponds than upstream. The values for the stream both up- and downstream fell well within the range of 201.1-858$\mu$S that another Carleton group has found for bodies of water within neighboring Rice County in Spring 2010 (the same period in which we conducted our study). The values for the holding ponds lie well outside this range. This suggests that the improvements at the Sustane site are generally succeeding in preventing leeching from the holding ponds into the neighboring stream. However, the somewhat higher numbers downstream from the site do suggest the possibility of limited leakage from the site into the stream.

Carleton geology students have conducted research on nitrate content in bodies of water in Rice County. Nitrates in these waters ranged from 0.064-18.5 ppm. While nitrate values from the holding ponds are considerably higher than this range, values yielded by the stream both upstream and downstream from the Sustane site are in line with these figures. This again suggests that the site is largely successful in controlling pollution. However, the higher numbers downstream from the site do indicate that there may be contamination occurring, although this contamination is not out of line with what is found through much of Rice County as determined by other Carleton groups.

In examining both the nitrate and conductivity data collected by Carleton students in past years, it has been impossible to ascertain whether the variations we saw in the stream between our two measurement points (that is, within a 200m stretch of a single stream) are or are not typical. However, because no tributaries joined the stream during the intervening distance, because there were no other apparent sources to alter the stream water, and because both measurements demonstrated comparable changes in the same direction, we believe that it is reasonable to accept these measurements as provisional evidence that some leakage is occurring, pending further confirming tests.

## Conclusions

We found that all of our data, including salinity, oxygen content, and oxygen saturation, had values both upstream and downstream that were consistent with each other and notably different from those yielded from the holding ponds. This suggests that Sustane is generally successful in limiting contamination to neighboring waters, although the fact that numbers for both conductivity and nitrates are higher downstream from the site than they are upstream suggests that limited leaking may be occurring. However, due to our severely limited sample size, further testing is necessary to establish that leakage is in fact occurring.

We initially hoped to contact neighbors to the facility in order to interview them regarding pollution – especially odor – that may escape the site. This ultimately proved to be impossible at the present time due to a lack of availability of information concerning property ownership and residence near the site. However, research in this avenue remains a potentially important avenue for research on the impacts of the site on the surrounding region.

Unfortunately, we did not have the knowledge or resources to conduct soil tests, but in the future we would like to do such tests in all directions around the site. Such tests should be performed at variable distances from the site, to ascertain the radius of soil which is affected by the turkey manure. This would give us further information on how well Sustane is containing the manure and could lead to improvements to the site and to waste management in general.

## Acknowledgments

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# Conductivity and Phosphorus Levels in Rivers and Streams Near Beef And Swine Feedlots in Rice County, MN

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**Introduction to Geology**

**Spring 2010**

## Abstract

Responding to the startling data representing the proliferation of feedlots in Rice County, we studied conductivity and phosphorus levels in flowing water near sixteen feedlots across the county to determine whether feedlot runoff was contaminating the water and putting it at risk for eutrophication.

## Introduction

Southeastern Minnesota is a highly agricultural region of corn, soybeans, and feedlots. Barns and pastures for cattle, swine, and poultry scatter the landscape of Rice County, where producers have anywhere from one pig to tens of thousands of chickens or turkeys. Water quality can be particularly impacted in rivers or streams that receive the runoff from feedlots or manure lagoon overflow. When animals graze on large areas of pasture or rangeland, their manure is deposited across the landscape. When animals are confined to small areas, however, their manure is then significantly concentrated (Eghball, B. et. al. 1994). If not properly managed, this manure can contaminate nearby bodies of water. The Rice County Water Management Plan (2004) states that the county's goal is to "protect the public health, surface and ground waters...from contaminants and excessive nutrients derived from animal wastes."  Our question, then, is whether rivers and streams in Rice County, MN are impacted by the feedlots nearby, particularly in terms of conductivity (which indicates quantity of total dissolved solids) and phosphorus levels.

Livestock contribute significantly to phosphorus loads in surface water (Whalen 2001). Increased levels of phosphorus stimulate the growth of algae and other aquatic plants.  The result of increased phosphorus is nutrient enrichment, a condition known as eutrophication. This increase in nutrients causes the surface of the water to become overcrowded with plant life, which consumes the oxygen available to the entire body of water, denying oxygen to below-surface plant and animal life, which then perish.

Phosphorus levels in water are measured in terms of "natural background levels," which represent the total phosphorus due to chemical, physical, and biological conditions that result from natural changes to the earth's surface, such as weathering or decay. Natural background levels of phosphorus  are generally less than .03 mg/L, while 0.1 mg/L is the maximum phosphorus concentration before plant growth (and eutrophication) is dramatically accelerated. Therefore, it is important to test for phosphorus runoff in order to decrease the likelihood of eutrophication and other negative feedback on the environment.

Conductivity  is the ability or power to conduct heat, electricity, or sound. It can be used to measure total dissolved solids (TDS) in flowing water, which in this case can indicate levels of fecal matter present in the rivers and streams near feedlots. Conductivity is a proxy for measuring total dissolved solids because pure water does not conduct water very well, and the amount of total dissolved solids and conductivity are directly proportional. TDS is defined as “the combined content of all inorganic and organic substances contained in a liquid that are present in a molecular, ionized or microgranular suspended form" (Sanborn 2010). Because total dissolved solids refers to anything other than H2O in water and the conductivity of H2O is zero, conductivity can be used to discover total dissolved solids. Increased fecal matter is not a concern near feedlots if the manure is properly stored and aged, but manure lagoon overflows or improper storage occurs every year in regions with heightened feedlot activity. These overflows are problematic because they affect the TDS content, and therefore the overall health of the surrounding environment.

In this study, we evaluated the conductivity and phosphorus levels in rivers and streams that run on or near properties with small, medium, or large cattle and swine feedlots, for a total of 24 samples throughout Rice County. We discovered that it was very difficult to collect a sufficient amount of samples to stratify the tested feedlots by size, so we decided to focus solely on the *type* of feedlot being examined, in this case beef cattle versus swine. Our intent in gathering these samples was to see whether or not the surface water on the tested feedlots was in danger of eutrophication by comparing levels of conductivity and phosphorus in streams near beef and swine feedlots.

## Methods

### *Study Area Selection*

Our sample site data comes from a Rice County Agricultural Planning database that collects information about existing or future feedlots through a survey of farmers in the county. We began customizing the data to our purposes by mapping out all of the beef and swine feedlots in Rice County that had more than 5 Animal Units and included labeled rivers and streams. We categorized the feedlots into small, medium, and large by number of Animal Units. An "animal unit" is a unit of measure used to compare differences in the production of animal manure. It is a standard that employs the amount of manure produced on a regular basis by a slaughter steer or heifer for an animal feedlot or a manure storage area. There are different calculation for different animals. Depending on the animal, the animal unit measurement is calculated by multiplying the number of animals of each type by the respective multiplication factor and summing the resulting values for the total number of animal units. One mature cow is equal to one animal unit, whil one swine is 0.4 animal units.

For beef feedlots, we designated small feedlots as having between 5-20 Animal Units, medium as 21-150 Animal Units, and large as 151 or more Animal Units. For swine we designated small feedlots as having between 5-99 Animal Units, medium 100-999, and large as 1000 or more Animal Units.

Our goal in dividing groups by size was to compare how feedlot size affects the level of phosphorous and the conductivity of the water in nearby streams and rivers. In deciding which lots to include in our study, we divided the lots by whether or not they had a stream or river on the property, ultimately creating two groups. We selected four feedlots from each category of small, medium and large for beef and swine, giving us 12 feedlots for beef and 12 for swine. In order to ensure random testing, these sites were spread across Rice County geographically, limiting any environmental confounds. We planned to compare not only the effect that feedlot *size* has on conductivity and phosphorous levels, but also the affect that the *type*- beef or swine- of feedlot has on such values.

### *Conductivity Measurement*

To test the water conductivity, we used a YSI meter to measure total dissolved solids. Therefore, the samples first needed to be collected at each individual water source near a feedlot and the conductivity needed to be recorded. At each individual feedlot site, the closest body of water was found, and the YSI meter was used to test the conductivity by placing the end of the meter into the water and reading the output given. The output was given in microSiemens/m, which was then converted into total dissolved solids.

### *Phosphorus Measurement*

We collected a vial of water at each testing site. Ultimately, we collected 16 samples. The samples were then brought back to the Carleton Geochemistry lab and phosphorus tests were performed on the samples. We used the Hach DR 890 colorimeter to test for phosphorus content in the water samples. First, a reagent blank correction was run in order to ensure the accuracy of later tests. In order to accomplish this the test was run using deionized water, which gave a result of 0.00 mg/L of $PO_4$. Then, the Read button was pushed on the colorimeter and we scrolled down to blank and pressed ENTER. The value found from running the test on deionized water (0.00 mg/L) was then entered as the BLANK value and ENTER was pressed.

Next, the colorimeter test was run on each individual sample. The test was done using the Hach method for reactive phosphorus with PhosVer3 powder pillows. First a 10mL sample of the collected water was poured into a sample vial. Then the phosphate reagent powder pillow was added to the sample. Next, the sample was shaken for 15 seconds and a timer was set on the colorimeter to allow two minutes for the reaction to take place. After two minutes, in the presence of phosphorus, the water sample would turn blue. The sample vial was placed into the colorimeter, the top was placed over the water sample and the test was run, giving the phosphate amount in mg/L.

The following information indicates problematic phosphorus levels (*Water, Water Everywhere*. HACH Company. Second Edition. 1983.):

- 0.01 - 0.03 mg/L - the level in uncontaminated lakes
- 0.025 - 0.1 mg/L - level at which plant growth is stimulated
- 0.1 mg/L - maximum acceptable to avoid accelerated eutrophication
- > 0.1 mg/L - accelerated growth and consequent problems

**Results:**

After measuring levels of phosphates in surface water near feedlots (typically slow moving streams or natural springs), we found results between .04 mg/L to .22, with one extreme outlier at .64 mg/L (see figures 5,6). We found conductivity measurements in microSiemens between 306.2 to 601, with one extreme outlier at 100.8 (see figures 7,8). We converted the microSiemens of conductivity to TDS and got numbers between 196 PPM to 385 PPM, with one extreme outlier at 64.5 PPM.

## Discussion:

The objective of this project was to see whether or not water near or on registered feedlots was contaminated by feedlot runoff. We initially wanted to do a fecal coliform test to collect data on levels of manure present in the water near the sites, but we found that test to be difficult, expensive, and time consuming. The impending threat of eutrophication in water near sights of heightened human activity also interested us, and we found that phosphorus testing would be the best form of measurement since excessive phosphorus is the primary cause of eutrophication. We also decided to test for total dissolved solids, through conductivity, in order to determine if there was a relationship between an increased level of phosphorus and other water quality issues.

What we can gather from this information and these measurements is that the water we found exceeds standards set to avoid accelerated eutrophication in 8 of the 16 samples we collected. We also observed that of 8 beef lots, 5 (including outlier) exceeded levels of .1 mg/L of phosphorus while only 3 of the 8 swine lots presented this threat (see figures 5,6). It is thus apparent that beef lots are more likely to endanger nearby surface water than swine lots.

Our results showed that while there were varying levels of conductivity in the different bodies of water, we were not able to find a trend which related the amount of phosphorus and conductivity, or size of feedlot and conductivity. Figures 7 and 8 show the differing conductivity levels for swine and beef feedlots respectively and the data shows that while the values are relatively similar, it appears that there is a slight increase in conductivity in water near swine feedlots (see Figure 7). This increase could indicate that runoff produced from feedlots containing swine cause higher conductivity in streams. Although we initially intended to measure the conductivity (as a proxy for total dissolved solids) and phosphorus of running water near feedlots and then compare the two, our data was inconclusive pertaining to conductivity. When the R squared correlation values, which measure the strength of the relationship between two variables, were found for each individual type of feedlot we found values that ranged from -1 to 1. Since a R squared value of -1 or 1 indicates an extremely strong relationship between the two variables, and we saw from our data that that was incorrect, it was obvious that we did not have enough data points to ensure a correct value. Therefore, we decided that we should focus mainly on phosphorus levels in the water rather than the comparison between conductivity and phosphorus. However, when the classification of feedlots by animal was removed,therefore insuring a larger sample size, an R squared value was found of -.77, which indicates that there could possibly be some sort of relationship between phosphorus content and conductivity in feedlots overall. While this value seems promising, when the Buscho farm outlier is removed, the R squared value is -.24, which is a significantly weaker correlation. With the removal of the outlier in mind, it is apparent that our data still leads to no conclusion about the relationship between phosphorus content and conductivity.

## Conclusion

Our data showed that many of the streams near feedlots in Rice County, both beef and swine, are either in danger of or are close to being in danger of eutrophication, due to increased phosphorus levels in the water. Although we have found some interesting data and have been able to put together some striking evidence that the water we measured was in danger of eutrophication, there are many factors that need to be taken into consideration. Throughout the data collection process, we encountered difficulties in obtaining the actual water samples. In some cases, the water was not visible nor accessible without trespassing on the property of the feedlot owners. Also, there were other factors that may have affected data: In some cases the only accessible water source was flowing, while in others water was stagnant. In our results, the Buscho farm is an outlier because that data was collected from a non-moving water source. Therefore, results from that particular test site would not be comparable to samples that were taken from moving water. Additionally, we did not measure exact proximity of the water we took measurements from to the feedlots we focused on. This proximity could play a huge role in determining just how contaminated water is at what proximity. Also, not all of the tested water flowed at an equal rate. Some water was taken from streams that flowed faster than the slow moving natural springs. The flow rate could certainly play a decisive role in our measurement accuracy. Finally, due to the seasonal application of chemical inputs onto agricultural fields and feedlot manure production, phosphorus levels and conductivity could vary greatly. We only tested 17 water samples, which accounts for a small percentage of feedlots in Rice County.

In order to perform a more accurate study, a much larger sample size would be necessary, as well as a more controlled system of water testing.

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# Nitrate Fertilizer in the Water of Rice County:

## Geospatial Conclusions

By

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5/25/2010

## Abstract

The intensive use of nitrate fertilizers in commercial agriculture impacts the nitrate levels of the surrounding bodies of water and the composition of the groundwater. Rice County is an area of high agricultural productivity, the principal crops being corn and soy beans. These crops require heavy fertilization under current agricultural practices. Nitrates from fertilizers often make their way into the county watershed, which has impacts on potable water (drawn from ground water) and on the greater Mississippi River watershed, of which Rice County is a part. Elevated nitrate content in water has many impacts, ranging from health complications for humans, to local and downstream ecological effects. Our study sought to find if there was a connection between agriculture and the amount of Nitrates found in the water. We obtained over 60 samples each from the months of April and July for the year 2009. These samples were drawn from bodies of water around the county. We tested these samples for nitrogen content. We analyzed the nitrate values we found using statistical and geo-spatial methods. The results showed a definite pattern—the nitrate contents of water samples from areas where the land use is primarily fertilizer intensive agriculture (generally on the East side of the county) were higher than areas where the land was used in non-fertilizer intense agriculture (grass and hay) or conserved land (generally found on the West side of the county). We also noticed that there was variation between the different months samples were taken from: samples taken in April had, on average, higher nitrate values than samples taken from July. We offer several explanations for this, but further study is needed to offer a conclusive explanation as to why there is variation between different months.

## Introduction

Our group chose to study nitrate levels in open bodies of water in Rice County, MN. Water samples were collected from bodies of water in Rice County in the spring and summer of 2009. According to the Minnesota Department of Health, drinking water can have nitrate concentrations of up to approximately 10 parts per million (ppm). Nitrate levels in water can exceed the recommended level due to runoff from nitrogen fertilizers (used in agriculture) and the presence of fecal matter caused by both livestock and humans. These types of contaminations have important consequences at the local level and beyond. For humans, water with nitrate levels above 10ppm cannot be safely consumed (Minnesota Department of Health) and can cause health problems. Infants are especially at risk for nitrate poisoning and can develop "blue baby syndrome" or methemoglobinemia in which there is a dangerous reduction in the oxygen-carrying capacity of blood. There is also a known connection between elevated levels of nitrate in water and stomach cancer in adults (Almasri and Kaluarachchi). Water contamination can also affect local ecosystems by throwing off their microbial balance. Increased nitrogen concentrations, which are linked to the amount of land under cultivation, have affected the entire Mississippi watershed (Turner and Rabalais). The Mississippi watershed, of which Rice County is a part, is an area of high agricultural productivity. Nitrates from agriculture and livestock can leach into ground water and contaminate the watershed when they are in greater concentrations than can be broken down by naturally occurring microbes (Almasri and Kaluarachchi). The nitrogen then travels through the soil, ground aquifers, and other bodies of water until it reaches the Mississippi (Turner and Rablais). This water is carried to the mouth of the Mississippi and into the Gulf of Mexico, where conclusive research has shown that elevated nitrate levels caused by nitrogen pollution upstream are creating suffocating algae blooms and disrupting the coastal ecosystems (Galloway et. al). This disruption of the Gulf ecosystem has ecological effects for the area, as well as economic effects for the fisherman who rely on the health of the Gulf ecosystem for their livelihood (NY Times, 1/20/1998). Because of the local and far reaching consequences of nitrate contamination in water, measuring the amount of nitrates being released and why they are being released in varying concentrations in space is an important area of study.

Our hypothesis is based on previous work indicating that there is a strong connection between nitrogen levels in water and the abundance and proximity of agricultural production. We expect that of the samples collected and analyzed, higher nitrogen concentrations will be observed in samples drawn from areas of the county that have high agricultural production. Specifically, we expect to see higher nitrogen concentrations from samples drawn from the east side of the county because it has more agricultural land in cultivation and generally is more agriculturally productive. We also expect that nitrogen content will vary by month and that months that are closer to an application of fertilizer will have higher nitrate values.

## Previous Work

Nitrogen is essential for life, and thus has been studied extensively. Out of this vast body of research, we chose to examine and draw on past work that specifically links nitrogen with agriculture. Galloway and Cowling carefully discuss the history of nitrogen and agriculture. They point out that though nitrogen is essential for vegetative growth, and quite prominent in Earth's atmosphere, it was not readily available until 1913. Thereafter which, a process was invented to convert $N_2$ to usable $NH_3$. This discovery, called the Haber-Bosch process had a more than substantial effect on agriculture and specifically crop yields (Galloway and Cowling). Galloway and Cowling estimate that food production increased 90 fold from 1890 to 1990.

Almasri and Kaluarachchi found that nitrogen commonly enters groundwater from point and non point sources within the agro-ecosystem. Non-point sources include fertilizer and manure application and growing leguminous crops. Other non-point sources are associated with barnyard animals, for example dairies and feedlots. Point sources include septic tanks and dairy lagoons. They also point out the difficulty in quantifying and positively identifying sources in nitrate leaching.

Mitsch et. al, in describing methods of nitrogen reduction into the Mississippi, identifies overloading of synthetic nitrogen fertilizers on row crops such as corn or soy beans, as a main source of nitrogen pollution. This information is incredibly relevant to our report as corn and soybeans are the principal crops grown in Rice County. Also, these authors note that though under-applying nitrogen leads to dramatically reduced crop yields, applying excess has no adverse consequences. Therefore, farmers are more likely to add too much nitrogen, which is then more likely to run off. The time frame of application is also a factor in nitrogen leaching. Fertilizers applied in the spring are likely to be utilized by plants more readily as the plants are in the early stages of growth. Fertilizers applied in the fall are more likely to leach into groundwater as the crops are nearing the harvest and require fewer nutrients. Because they are not used, they may be carried by spring snow melt and precipitation. Their observations are especially relevant to our report as we will compare water samples taken from several different months.

However, from a review of the literature, it seems that the most efficient timing of nitrogen fertilizer application is somewhat disputed, or at least is variable depending on temperature and soil type. Several articles reported that the best time to apply nitrogen is 6-10 weeks after planting (Vitosh, Johnson, and Mengel; Davis and Westfall). David and Westfall say a fall application is not optimal for most soils, and Vitosh, Johnson, and Mengel expand saying:

> "Fall applications of N are feasible only in areas where low winter soil temperatures retard nitrification of ammonium. This limits fall application to the northern portion of the United States. The concern with fall application is that losses of N will occur between application and crop uptake in the next growing season. This may lower crop yield and recovery of applied N, compared with spring applications. Recommendations for fall applications are to use an ammonium form of N, preferably anhydrous ammonia, and delay application until the soil temperature is below 50 degrees F." (Mengel et. al.)

This and other evidence suggests that Minnesotan farmers apply nitrogen in the fall. This is important for our research as we think about why there may be variability of average nitrogen levels by month, as well as by geographic placement. Vitosh, Johnson, and Mengel also note that nitrogen fertilizer applications are entirely dependent on the specific needs of the crop. In addition, Turner and Rabalais explore land use over time and conclude that increased nitrogen in water is strongly associated with the percentage of land in pasture.

We also realized that we were probably not the first ones to think about the sources and variation in nitrate levels in water in Minnesota. Best Management Practices (BMPs) for nitrogen in Minnesota were first developed in the late 1980s. (Lamb et. Al) These BMPs are also split by region, as different climates and soil types in Minnesota require different management practices. Because the soil type in the south central part of the state (where Rice County is) was formed by glacial till, (Lamb et. Al.) nitrogen losses are increased. Glacial till has poor internal drainage and this part of the state gets a lot of precipitation, resulting in nitrogen losses through drainage tiles or denitrification. (Lamb et.al)

## Geologic Setting

The rocks in Rice County are predominantly sandstones, limestones, and shales. These sedimentary rocks are the result of transgression and regression in an ancient shallow sea that once covered the Midwest. The main formations of these sedimentary rocks found in Rice County are Platteville limestone, St. Peter sandstone, Decorah shale, and the Prairie du Chien group.

## Methods

## Water Sampling Methods

In order to study the Nitrate content in the water of Rice county it is important to get the number of samples right. While collecting the water samples it was essential to consider basic data from the source site such as coordinates (longitude and latitude) and land use surrounding sample site.

Once the samples were obtained, we went through a systematic process to obtain quantitative data on the nitrate content of the water. We used the WQ-CL sensor along with its computer software (NexSens). The sensors common water quality parameters include temperature, dissolved oxygen, pH, ORP, NO3, NH4, and Cl. In order to get accurate readings throughout the collection process, the sensor has to be handled with care and a reference solution is added to the sensor. After the reference solution has been filled, the sensor should be shook to ensure that there are no trapped air bubbles in the solution. The sensor needs to be rinsed with rinsed with distilled water and blot dried after every reading. An important part of setting up the sensor to take accurate readings is to calibrate it. The calibration process is explained in the manual (NexSens). Significant care has to be taken in the values that the sensor is calibrated to. We expected a nitrate values between 0-20 ppm, so therefore we calibrated to 5 and 50 ppm. The level the sensor is calibrated too can have a significant impact on the accuracy of the readings. Once the sensor is immersed in a sample, stirring is recommended as it decreases the amount of time needed to reach equilibrium. However, care needs to be taken to ensure that each sample is being stirred at the same speed. In addition, each sample was recorded with GPS coordinates indicating where it was taken from.

### GIS Methods

To investigate the part of our hypothesis that refers to the geographic distribution of nitrates, we used ArcGIS software to create 3 maps (see Appendices 1, 2, and 3). The first map (Appendix 1) shows land use in Rice County. The types of land use included are actively cultivated crops (corn and soybeans), passively cultivated crops (hay and grass), urban/developed areas, and uncultivated/undeveloped land (namely wetlands, forests, and grasslands). The second and third appendices are also maps of Rice County with the nitrate levels we analyzed from the samples layered on top of them. Each has a colored point indicating where a sample was taken from. The color of the points are graded, with darker colors representing higher nitrate levels and lighter colors representing lower nitrate levels. We would have liked to create maps that layered the graded nitrate levels on top of the land use patterns, but decided that the nitrate data was not clearly visible when layered on top.

### Statistical Methods

We used the statistical program S+ to create histograms of the water sample data for July and April to understand their basic distributions and get summary statistics, such as their median values and to obtain a visual representation of their ranges. We then used a box plot distribution to compare the spread of both sets of samples.

# Results

## GIS Results

After analyzing our GIS maps, we found visual evidence for our hypothesis. Looking at the maps (again, see Appendices1, 2 and 3), the greatest concentrations of crops that require intensive fertilization (corn and soybeans) are located in the Southeast part of the county (see Appendix 1). The maps showing the geographic distribution of our April and July nitrate samples (Appendices 2 and 3, respectively) in general show darker points (i.e. higher nitrate concentrations) in the Southeast part of the county. Though we did not test to see if the distribution is statistically significant or just the result of random sampling variation, visually the results are convincing. In addition, to conclusively determine whether nitrate values are higher in the more agriculturally productive part of the county, a larger sample size and further statistical analysis would be needed.

## Nitrate Test Results

For the July 2009 samples (see Appendix 5), the distribution was skewed right, with 75% of the values falling between 0.75ppm and 5.3ppm. The median was 1.335ppm, with a minimum value of .31ppm and a maximum value of 12.56ppm. For the April 2009 samples (see Appendix 4), the distribution was also slightly skewed right, with 75% of the data falling between 1.8ppm and 6.2ppm. The median was 3.0ppm with a minimum value of .064 and a maximum value of 18.5. Using the following statistical method, we determined that the nitrate levels in Rice County open water was higher in April than in July.

The box plot below (Figure 1.) shows that April had higher values of nitrates in the water than did July. The boxes represent the inter-quartile range. April's box is 'higher' than July's, indicating that it had generally higher values. The red lines in the interior of the boxes indicate median values. The fact that they are not centered in their boxes indicates that the distributions are skewed towards lower values, though July's distribution is more skewed than April. The bracket lines on each side of the boxes show the maximum and minimum values, i.e. the range. April has a much larger range than July. Finally, the lines outside of the bracketed distributions indicate outliers (i.e. values that are more than 1.5 X the value of the Inter-quartile range). The data for April contained many more outliers. Though we did not specifically investigate each data point, the mere presence of so many outliers clustered indicated to us that these were not rogue values, but rather a further indication that in general, water in Rice County in April had higher concentrations of nitrogen. We feel that this distribution is strong enough evidence to conclude that April had higher nitrate values than July.

### Nitrate values for April vs. July

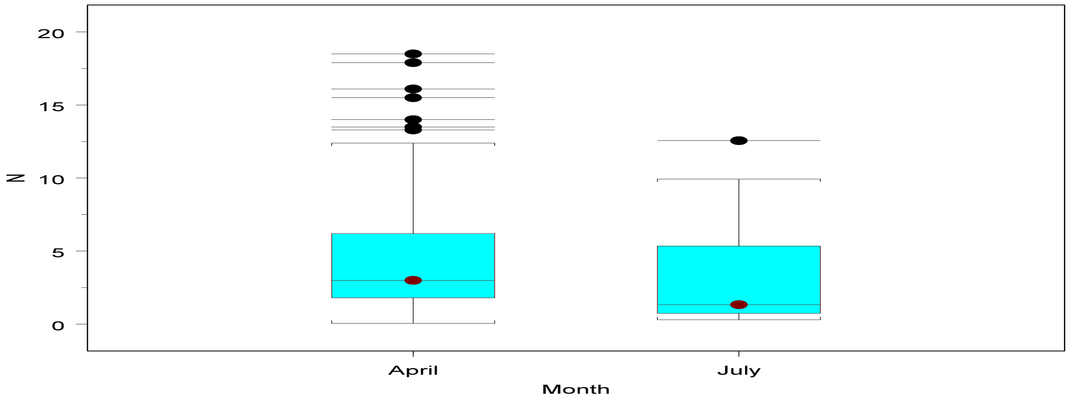

**Figure 1. Box plot comparing the sample distribution of nitrates in April and nitrates in July. N (y-axis) is measured in parts per million (ppm.)**

## Discussion

Based on the results of our statistical and ArcGIS spatial analyses, we think that there is preliminary evidence to suggest that nitrate values are connected to agriculture and also to the timing of fertilizer application. From a synthesis of the information from the April and July maps and the map of land use in Rice County, it is clear that the more fertilizer intensive crops (corn and soy) are grown in the areas where we generally see higher values of nitrates. Also, from our statistical analysis of the nitrate levels, it is clear that in general the values of nitrate were higher for April than for July.

Our findings about the relationship between nitrate levels and proximity to fertilizer is as we expected: excess nitrate leeches into water. Previous literature seems to have reached a general conclusion about the presence of this phenomenon. What we found surprising in our results was the stark divide between the Southeast and Northwest sides of the county. It would be interesting to find out more about why this division in cultivation patterns is so drastic. Further research could also try to be more specific about how direct proximity to agriculture affects nitrate levels in water. In addition, we would like to stress that to conclusively prove that nitrates are related to agriculture, a test for statistical significance would need to be done (which would require many more samples to be taken).

Our results about the relationship between fertilizer application timing and nitrate levels were a bit unexpected. Initially we expected that our data would show nitrate levels were higher in July than in April. Our expectations were based on the assumption that farmers usually plant around May and therefore fertilize the soil then as well. We had hence anticipated higher nitrate values for July. However, our data showed patterns that were fairly contradictory to what we had anticipated. The data showed that the month of April consistently showed higher nitrate values than the month of July. This made us re-think our assumptions about agricultural patterns and fertilizer timings in MN.

After further research and a review of the literature, we outlined two basic reasons as to why the data contradicted our initial presumptions about the timing of high values of nitrate concentrations in open water. The first is that conditions in Minnesota allow farmers to fertilize their soil in the fall. The cold ensures that the fertilizers are still effective after the winter. This added with the fact that March and April are usually the months around which in Minnesota the snow begins to thaw, which could result in surface run off of the fertilizer could explain why the nitrate levels in April were higher than expected. Secondly, our inference was that because some farmers may fertilize in the fall as well as after planting in the spring, the rains which occur between April and July would carry the freshly fertilized soil to the nearest water body. Even if the farmers did fertilize in May, we don't have sufficient data on drainage lag times to make an accurate prediction about lag time effect on nitrate levels in July. And again, to conclusively prove that nitrate levels are higher in April than in July, further statistical inference is necessary.

## Conclusion

Nitrates are an effective fertilizer and are widely used in commercial agriculture. Nitrates have been found to be carcinogens as well as damaging to the environment. While nitrate use is efficient for farmers, it important to be aware of the ramifications of using nitrates to stimulate crop growth, and the effects that they have on the surrounding areas, especially when they make their way into the water table. Our hypothesis for this enquiry was that nitrates in water are linked to its use in the surrounding agricultural area. We also postulated that there was a connection between the timing of fertilizer application and nitrates in the water.

Our inquiry found evidence to support our hypotheses, though we acknowledge that there is room for further study. While not all nitrates leave the agricultural area where they are applied, their presence in the water in Rice County is not only a threat to the wildlife and residents of the area, but as the area is part of the greater Mississippi watershed, it can have ramifications for the entire Mississippi river ecosystem, including the fragile coastal wetland areas of Louisiana and Mississippi. For many reasons, it is important for farmers to find a solution to the problem of elevated nitrate levels in the water to ensure the health of humans and the environment.

## Acknowledgements

Many people helped us with our research and with this report. We would first like to thank Prof. Bereket Haileab of the Carleton College Geology Department, for all his support and for making us laugh. We would like to thank our TAs, Liz Lundstrom and Nate Evenson for answering our questions. We would like to thank Jake Reznik, for teaching us to use the nitrate probe and generally making himself available. Additionally, we are very grateful to Wei-Hsin Fu of the ENTs department for giving us a wonderful crash course in GIS. We are indebted to Nathan Yaffe and Laura Dismore for taking time to help us make our lovely maps. This project would not have been possible without Nick Holschuh's previous work. Lastly, we would like to thank our Intro Geo class for wonderful comradery as we began our lifelong foray into the world of rocks.

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# An Analysis of Chloride Content in the Open Waters of Rice County, Minnesota

Rose Kantor, Brian Kempers, Hye Mi Ahn, and Mary Van Dyke
Geol. 110, Professor Bereket Haileab, Carleton College
2 June 2010

Abstract: As an important ion in natural waters, chloride ($Cl^-$) plays a role in the health of freshwater ecosystems. The main contributor to $Cl^-$ is run-off road salt, used as a de-icer during winter months. This study aimed to evaluate $Cl^-$ levels in Rice County, Minnesota during the summer of 2009 and to find the factors that correlate with geographical variation in $Cl^-$. Despite known road salt use in this county, we determined that $Cl^-$ had only a minor contribution to conductivity in June 2009, and we attributed this to the flushing of open waters in spring and summer. Our analysis showed no relationship between sample sites' proximity to roads or to elevation. We found that certain watersheds had on average higher $Cl^-$ levels than others, but with no obvious trend. Further work should investigate changes in $Cl^-$ over all four seasons.

## *Introduction*

Chloride ($Cl^-$) is an anion found in soil and water and is an indicator of salinity in the environment. Anthropogenic sources of $Cl^-$ include sewage treatment, industrial output, water softener, fertilizers ($KCl$), and rock salt ($NaCl$) used to de-ice roads during the winter months (Kelly, 2010). Chloride is important because it can be used to track other, more dangerous pollutants, and because it alone can have harmful effects on aquatic ecosystems and on the safety of drinking water (Kelly, 2010). Based on studies of $Cl^-$ levels in the lakes of the Twin Cities Metropolitan Area in Minnesota, maximum $Cl^-$ levels occur in January, during road salt application, while minimum chloride levels occur in November, after the natural waters have been flushed by rainfall (Novotny, 2008). As the use of road salt has increased (Figure 1), so have levels of $Cl^-$ in natural waters across the US. Road salt run-off is so strong in urban areas during winter that $Cl^-$ becomes the main contributor to specific conductivity (Novotny, 2008). As a result, road salt application often leads to the formation of year-round haloclines in lakes. Less is known about $Cl^-$ levels in rural and agricultural areas where road salt use is lower and fertilizer use is higher.

Rice County is a rural, agricultural area located in southern Minnesota (Figure 2). In addition to its widespread animal feed lots, it supports a number of corn and soy bean farms, particularly in its eastern half. As such, run-off from agricultural fertilizers, many of which contain $Cl^-$, has been a hypothesized cause of higher $Cl^-$ levels in nearby waters. However, because the county's predominant fertilizer is ammonium nitrate, we would expect there to be higher nitrate, not $Cl^-$, levels in local streams and ponds. Previous work on the natural waters of Rice County (Holschuh, 2009, unpublished) has focused on primarily nitrate. From samples taken in June 2009, Nick Holschuh was able to show that there exists a strong correlation between nitrate and specific conductivity (Figure 3). Thus, nitrate was likely the primary contributor to specific conductivity in that season. Additionally, findings from that study indicate that the hydrogeochemistry of the county reflects an east-west divide in land use.

In this study, we examined $Cl^-$ levels in Rice county, Minnesota using samples taken from June 2009. Our objectives were to develop a relationship between $Cl^-$ and specific conductivity, to determine if observed concentrations of $Cl^-$ can be attributed to road salt applications, and to examine regional trends in $Cl^-$ concentrations. Our analysis revealed that in our samples, $Cl^-$ correlates moderately with conductivity and that $Cl^-$ levels could best be attributed to the division of watersheds in the county.

### *Methods*

Samples were taken from 67 different locations across Rice County, Minnesota from 16 June to 23 June 2009 (Figure 4). Samples were then stored, sealed and unrefrigerated, and $Cl^-$ levels were measured on 9 May 2010 using a calibrated WQ-Cl sensor USB probe. To obtain the most accurate measurement, three readings were taken at 10-second intervals after the probe had been submersed in sample for one minute.

These measurements were then averaged together and recorded alongside the GPS coordinates of the samples.

Nick Holschuh performed conductivity measurements in the field during June 2009. For each location, he attempted to immerse a YSI probe two feet below the surface, though for water sources less than two feet deep, samples were taken as deep as possible. These alternative measurements occurred only about 10% of the time.

GIS file layers were then created to map the measured $Cl^-$ concentrations and conductivities for each location. We first plotted our samples on a map of Rice County using the GPS coordinates attached to the samples (Figure 4). From there, we overlaid this map with maps depicting the bodies of water, roads, elevation, and watersheds of Rice County, which we obtained from the Carleton College GIS laboratory. The data were viewed using ArcMap software, and regression analysis was performed to determine any geographic variation in $Cl^-$ concentration.

### *Results*

Most samples had low to moderate concentrations of $Cl^-$, though some were as low as 2.6 mg/L and some were as high as 194 mg/L. In fact, two locations at the top of that range had nearly four times the concentration of $Cl^-$ as the rest of the samples. While samples taken to the southeast of these locations showed intermediate $Cl^-$ concentrations, such a trend was not seen in the other, surrounding samples. Moreover, there did not seem to be any geographic trend connecting similar concentrations of $Cl^-$. For example, low concentration samples were found not only at the heads of streams and rivers but also along the banks of the Cannon and in the large lakes to the west.

Because previous studies had showed that $Cl^-$ levels were related to road salt and that during peak road salt applications, $Cl^-$ was largest contributor to conductivity (Novotny, 2008), we decided to examine how $Cl^-$ was related to both conductivity and proximity to roads (Figures 5, 6, and 7). As we observed, $Cl^-$ increased as conductivity increased, showing a moderate correlation between the two variables ($R^2 = 0.28$). This indicates that $Cl^-$ is a partial contributor to conductivity. However, if we remove the two outliers around 200 mg/L, this correlation drops considerably ($R^2 = 0.054$, data not shown). The correlation between $Cl^-$ and the distance to nearest road was similarly small ($R^2 = 0.032$), regardless of whether outliers were included. Furthermore, the samples containing high concentrations of $Cl^-$ were not collected near the major highways, as one might expect. In fact, both high concentration samples were located in the countryside, where there are fewer roads and a smaller chance of road salt application. We even found that low concentration samples were taken just as often from city centers as they were from rural settings.

We next hypothesized that drainage might either concentrate $Cl^-$ levels in low-lying areas, or it might concentrate $Cl^-$ levels in local watersheds. To test the former, we looked for a relationship between $Cl^-$ and elevation but found no significant trend (Figure 8; $R^2 = 0.029$). However, if we project $Cl^-$ content onto the unsampled areas (Figure 9), the latter hypothesis appears more promising. In fact, when this done, we can see two pockets of high $Cl^-$. Not only do these pockets straddle the Cannon River, but they also correspond to recognized watersheds in the county. As we found, the highest average $Cl^-$ concentrations were located in these two watersheds with nearly all other watersheds sharing similar $Cl^-$ concentrations (Figure 10).

### *Discussion*

Building on the work of Nick Holschuh, we analyzed $Cl^-$ concentrations from sixty-seven water sources in Rice County, Minnesota. From our dataset, we were able to examine the relationship of $Cl^-$ to conductivity, proximity to roads, elevation, and watershed groupings. Aside from the two high concentration and two medium concentration samples mentioned above, the county appears to be quite homogenous with regards to $Cl^-$ content. Despite the findings of previous studies, we concluded that $Cl^-$ concentration was related to the particular watershed from which the sample was taken. In the study conducted by Novotny et al. (2008), it was found that $Cl^-$ was the main contributor to conductivity during the winter months. However, during the summer months in Rice County, nitrate appears to be the main contributor to conductivity, for $Cl^-$ content is fairly low in most areas and shows a weak relationship to conductivity. For example, our $Cl^-$ levels ranged from 2.6 to 194 mg/L, while Novotny et al. (2008) found that $Cl^-$ levels in Minneapolis/St. Paul lakes had a median of 154 mg/L, though some were as high as 1000 mg/L. In terms of seasonal timing, our results seem to make sense, for the main run-off during the summer months is likely to be nitrate fertilizer rather than road salt.

Error in our chemical analysis could also have affected our results. The $Cl^-$ probe required maintenance and lost around 40% of its calibration after thirty measurements. We attempted to control for this by re-calibrating the probe midway through our sample measurements, but this should have been done more frequently. Furthermore, because our samples needed to remain uncontaminated for future analysis, we measured $Cl^-$ directly without adding the ionic strength adjustment buffer. This absence of an ionic strength adjuster could have caused the probe to misread the $Cl^-$ content because of the natural variation of dissolved ions in our samples.

Further work on $Cl^-$ in Rice County should be expanded over a longer time period of time and should include fresh samples from the winter months when road salt is used. It would also be interesting to examine how the proximity of major highways and roads to the water source affects the $Cl^-$ concentration (our focus was on smaller roads). More sampling in urban areas should also be done, as this is likely where the most road salt is used. Lastly, while sampling farm field drainage could show higher $Cl^-$ concentration levels due to the use of KCl fertilizer, we were unable to observe this phenomenon in our study.

### *Conclusion*

Chloride content does not appear to be the main contributor to specific conductivity in summer, nor does it appear to be spatially related to areas of high population density or areas near roads. This is likely because our samples were collected in summer, when road salt had been flushed from the surface waters by rainfall.

*Figures Appendix*

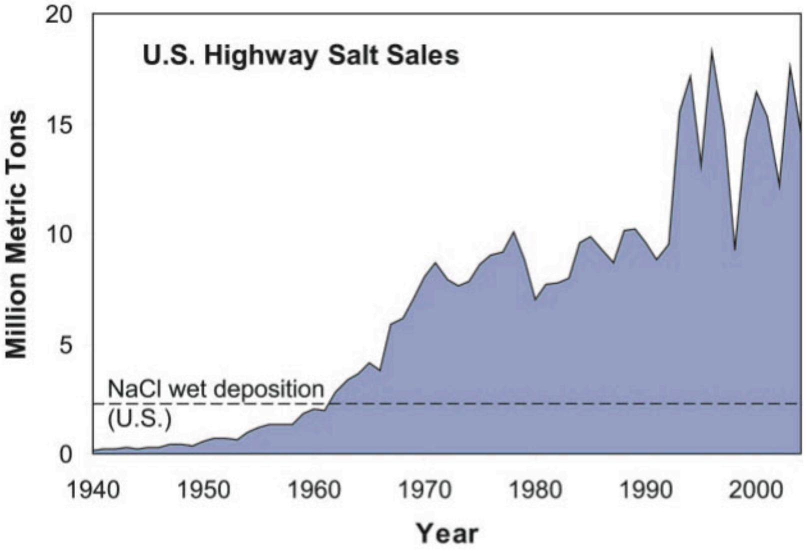

Figure 1. Road salt increase over a sixty-year span. From 1940 to 2000, the amount of road salt used for de-icing has increased, approaching nearly eighteen million metric tons (Jackson, 2005).

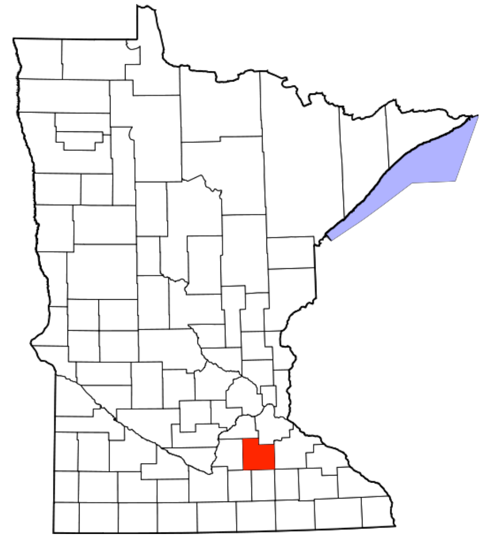

Figure 2. Rice County (in red) is located in southern Minnesota. A majority of its farms are located in the eastern half of the county (Wikipedia Commons).

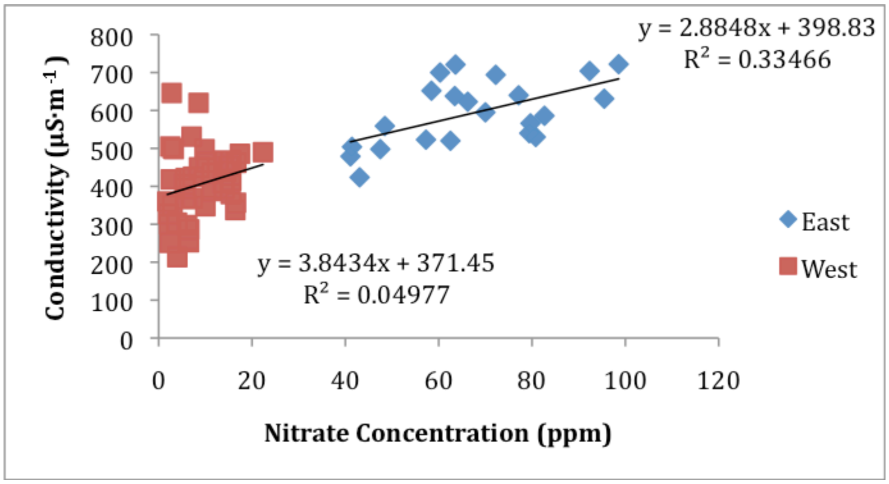

Figure 3. Correlation between nitrate and conductivity. Particularly in the eastern portion of Rice County, there is recognizable correlation between the nitrate concentration and the conductivity of the water.

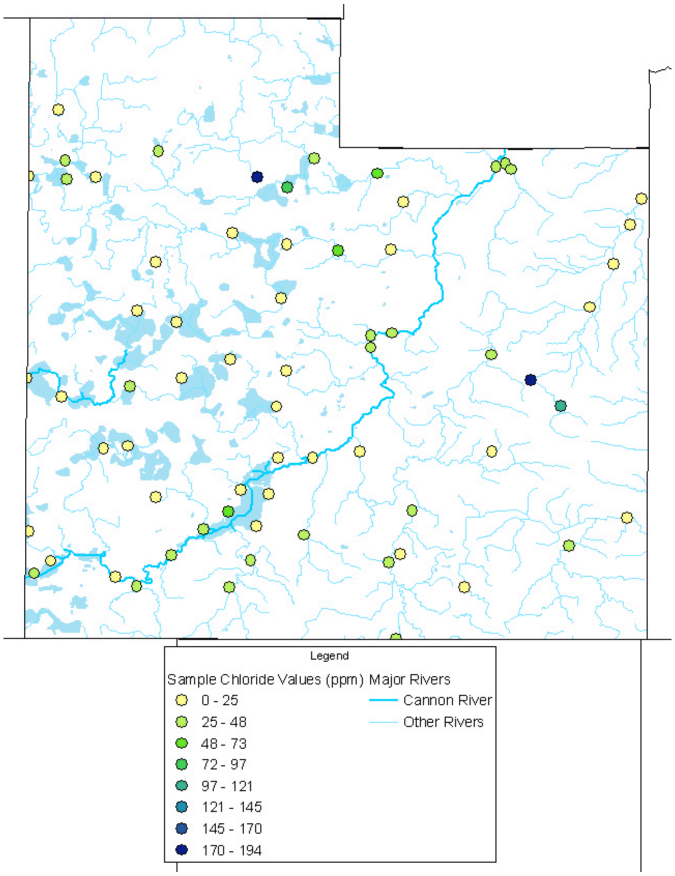

Figure 4. Locations of samples. Samples were collected at the locations shown above from 16 June to 23 June 2009.

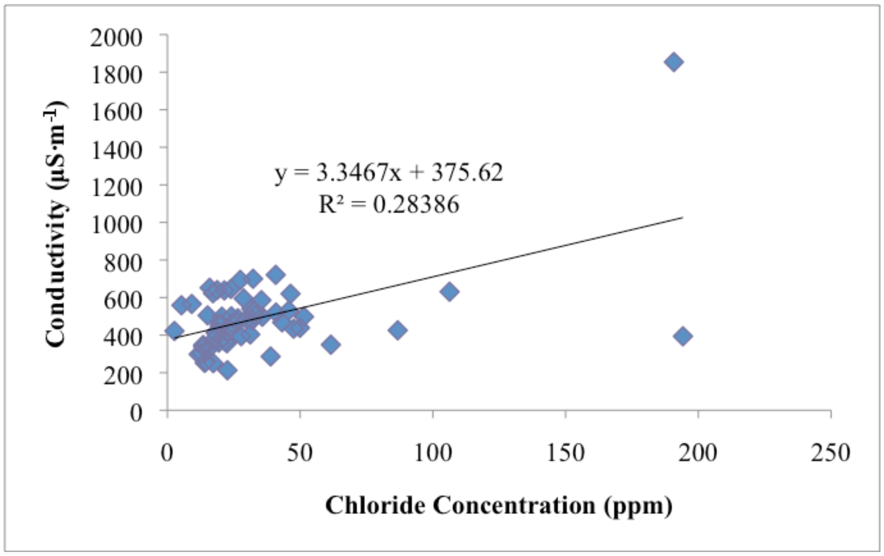

Figure 5. Correlation between Cl$^-$ concentration and conductivity. For each sample collected, the chloride concentration was plotted against conductivity. With an R$^2$ value of 0.284, the correlation appears weak to moderate.

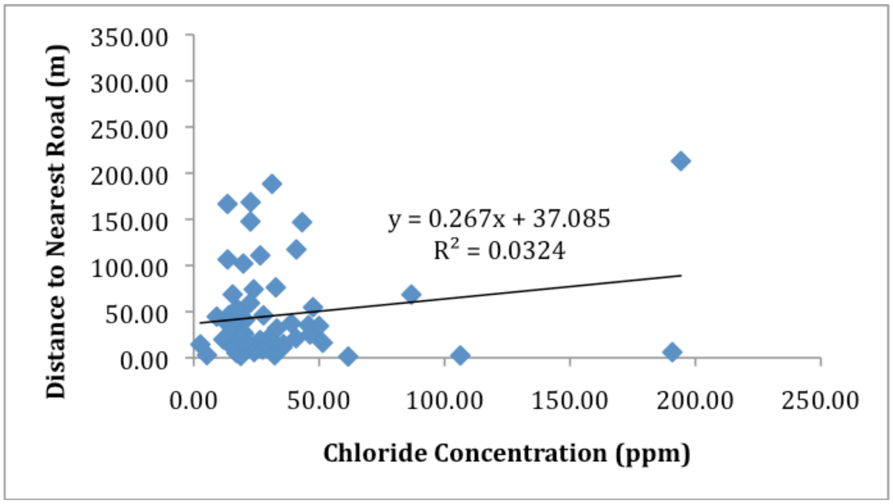

Figure 6. Correlation between Cl$^-$ content and the proximity to roads. For each sample collected, the Cl$^-$ concentration was plotted against the distance to the nearest road.

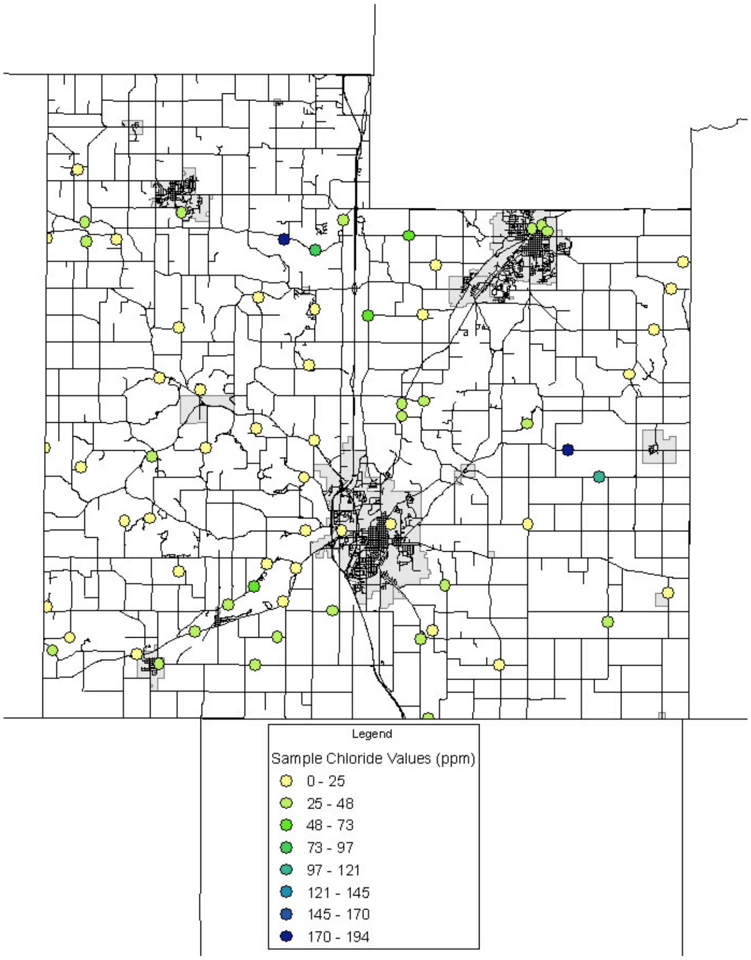

Figure 7. Relating Cl$^{-}$ content to roads and highways. The sample Cl$^{-}$ concentrations were plotted on a road map of Rice County. There does not appear to be any clear relationship between Cl$^{-}$ concentration and proximity to roads.

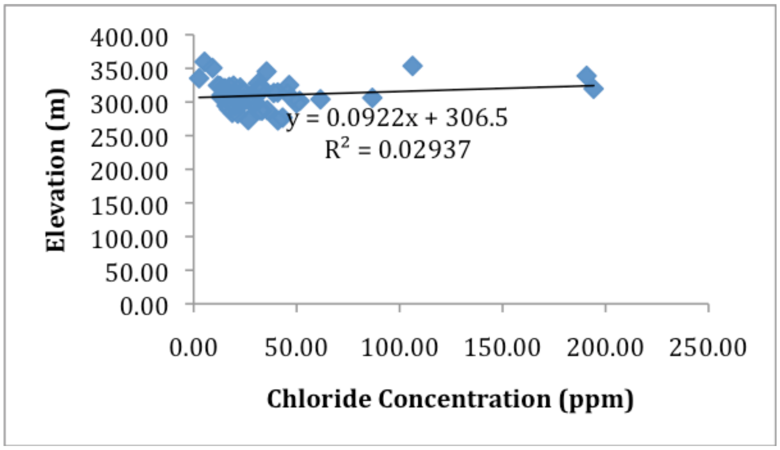

Figure 8. Correlation between Cl$^{-}$ concentration and elevation. For each sample collected, Cl$^{-}$ concentration was plotted against elevation. With an $R^2$ value of 0.029, the correlation appears almost nonexistent.

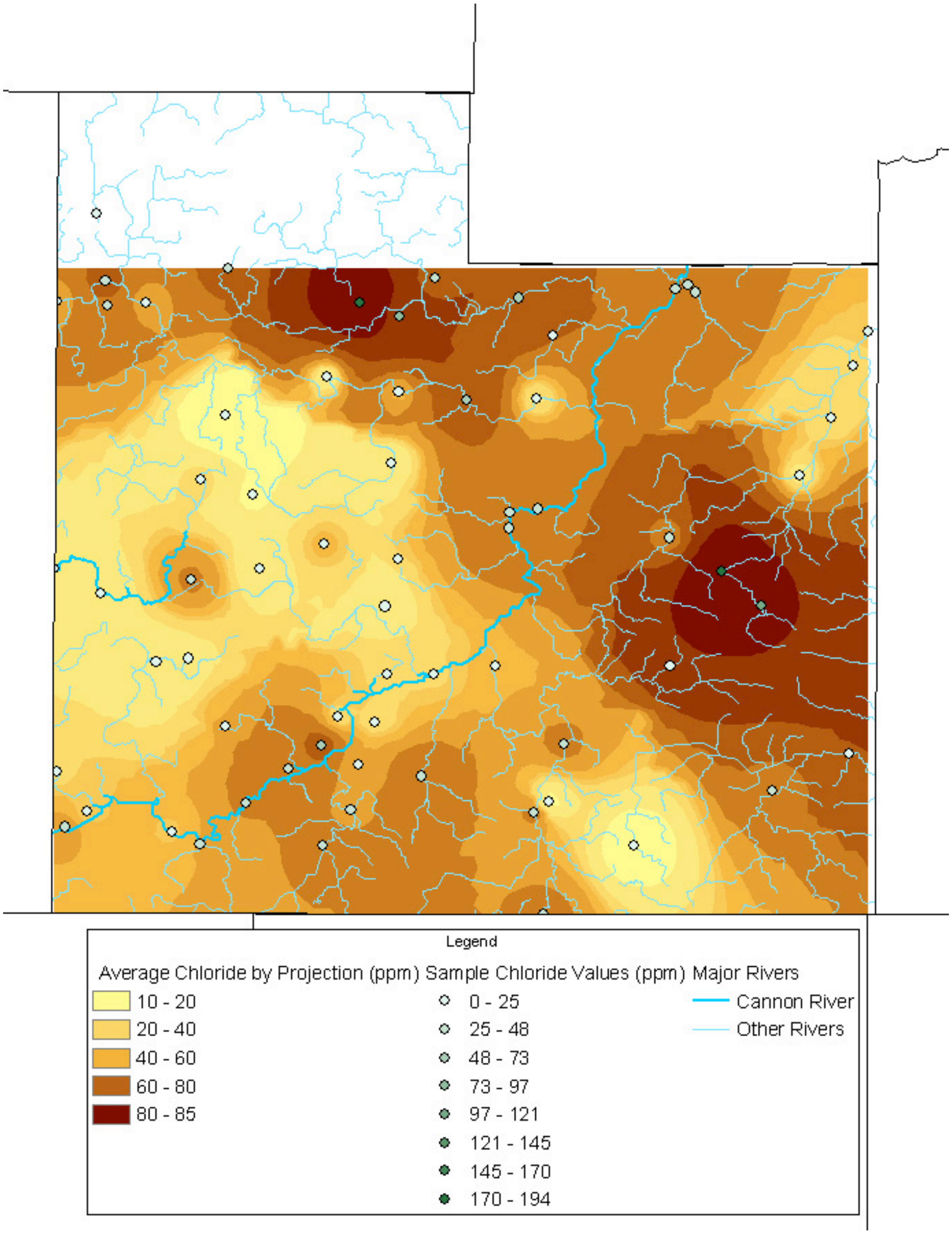

Figure 9. Chloride content in Rice County, June 2009. Based on the collected water samples, the $Cl^-$ concentration was estimated throughout the county. The two areas of high $Cl^-$ content straddle the Canon River, which runs diagonally across the map.

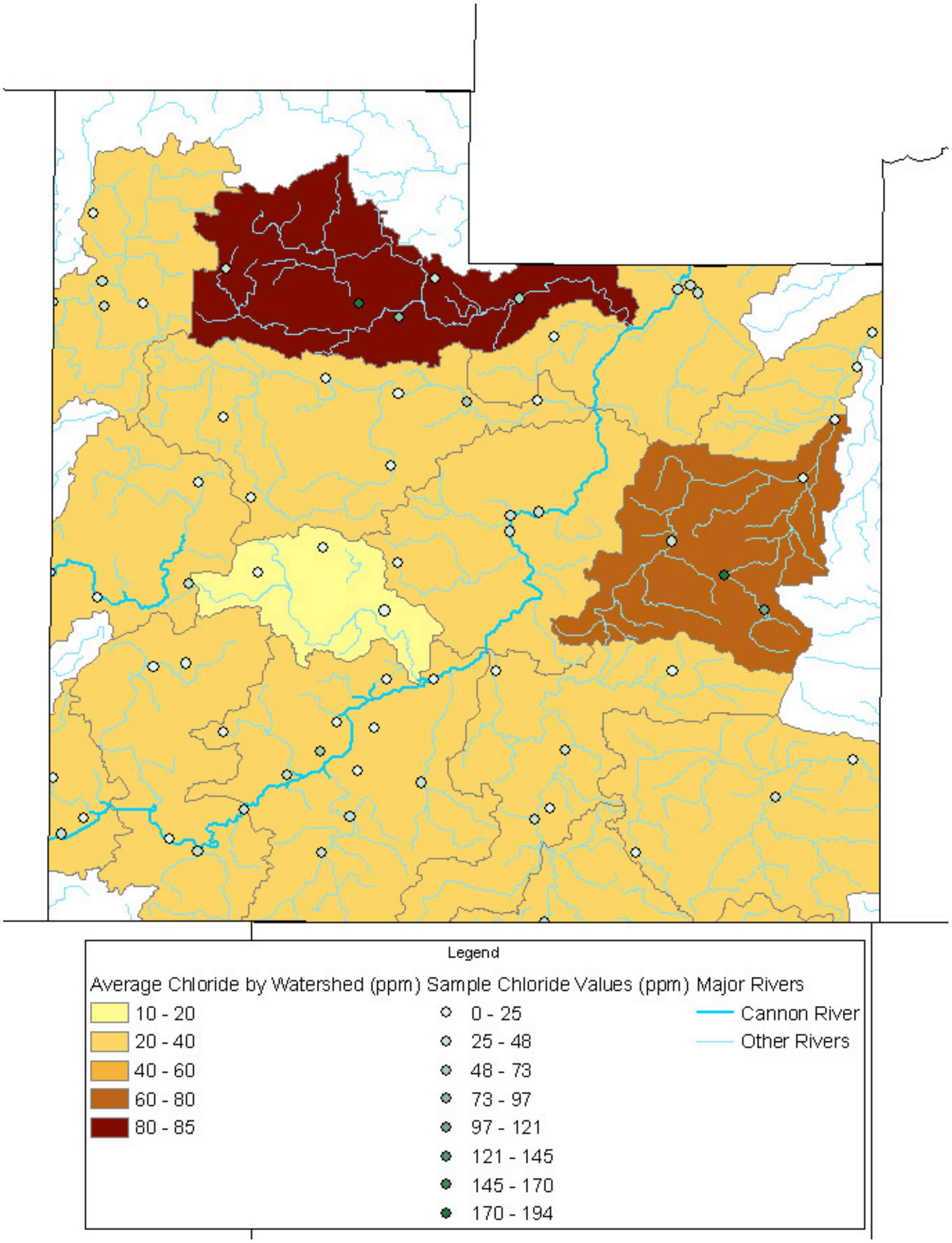

Figure 10. $Cl^-$ content in local watersheds. A map was created of Rice County based on the average $Cl^-$ concentration in each of its watersheds. The four highest $Cl^-$ concentration samples are localized in two watersheds.

## *Acknowledgements*

Nick Holschuh, Nate Evenson, Liz Lundstrom, Bereket Haileab, Tim Vick, Carleton College Geology Department, Wei Hsin Fu, and Carleton College GIS lab.

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Wikipedia commons. File:Map of Minnesota highlighting Rice County.svg. Visited 5/29/10. Modified 2/12/06. http://commons.wikimedia.org/wiki/File:Map_of_Minnesota_highlighting_Rice_County.svg

# Calcium Levels in Open Water Sites of Rice County, MN

Introduction to Geology, Spring 2010

Emily Altschul, David Freedman, David Hecht, Justin Perkins

## Abstract:

Calcium is a factor in water hardness, which affects the quality of drinking water, and is a limiting factor in the growth of many aquatic organisms. Calcium concentrations in open water sources could be related to upstream plagioclase feldspar-rich rocks and calcium-bearing sediment exposures (e.g. limestone), as well as calcium-rich runoff. Calcium concentrations in 61 open water locations around Rice County were studied. The correlation between exposures and open water calcium levels was not, however, evident; there was no discernible pattern to our results.

## Introduction:

Little research has addressed the causes of changing calcium levels in open water environments. In fact, a comprehensive study of calcium levels in Rice County has never before been performed. The research that has been published focuses largely on effects of fluctuations in calcium levels–not what leads to these differences. Calcium fluctuations are important because they dramatically affect the biosphere. According to Leybourne, et. al. (2008), calcium has been shown to be a limiting factor in aquatic environments because some organisms require high calcium levels. More relevant to our research objective, atmospheric deposition and mineral weathering rates have been shown to affect calcium levels, and estimates of weathering rates of calcium in soil have been shown to predict future lake calcium levels.

We investigated which parts of Rice County contain the highest levels of calcium bearing sediments, and are thus most likely to cause nearby water sources to have high calcium content using the data pre-stored in the GIS software file, GEOL110. According to a study by Battis, et. al. (2010), the groundwater of the northwestern part of Rice County is characterized by generally high calcium values, especially compared with the lower values in the south-central and northeastern parts of the county. This study also puts forth a potential for error in calcium testing: the atomic absorption chemical inference between calcium and phosphate. This means that phosphates can bind to calcium ions, which would make these calcium ions not appear in calcium readings. The areas of the county with more agriculture would presumably have more phosphates, and thus lower calcium levels and/or a larger possibility for error.

The major objective of this study is to better understand the differences in calcium levels of the open water environments in Rice County, Minnesota. This will allow us to know which water sources are harder and more likely to contain calcium-dependent organisms. This will also indicate which types of rock surface water passes through, and which types rain water is eroding.

We hypothesize that in the northwest part of Rice County, calcium levels will be higher because of the increased presence of exposed calcium-bearing sediments, while they will be lower in the south-central and northeastern parts of the county. This will occur because calcium will be eroded from these sediments into the water by precipitation.

## Methods:

### *Laboratory Methods:*

First, the $Ca^{++}$ ISE Sensor was cleaned with water and then drained. It was next flushed with Ca Reference Fill Solution (1M KCl), with which it was then filled to the appropriate level before being conditioned for approximately two and a half hours in a 10ppm calcium standard solution, then rinsed with deionized water. The sensor was then plugged into the computer and calibrated between two calcium standard solutions, one at 10ppm, the other at 100pm, each with 2mL of Ca ISA 4M KCl to ensure similar ionic strength. Once the sensor was calibrated, calcium levels from 61 open water sites in Rice County, which were collected in April 2009 by Nick Holschuh, were tested. Approximately 40mL of each sample was poured into a 50 mL beaker. The sample's calcium readings, both its ppm and mV values, were read by the sensor, which was stirred steadily through the testing process. Once the values leveled at or around a single value, that value was recorded. The sensor was dried, cleaned in deionized water, and dried again between each sample. The probe was recalibrated after every ten readings. This was all done according to the procedures outlined in the Nexsens WQ-CA manual.

### *ArcGIS Analytical Methods:*

*Arc*GIS software was used once the calcium level readings were collected and completed for the samples from April 2009. Calcium content was submitted to the program by longitude and latitude, so that it could be incorporated into the pre-existing map of Rice County. Using the data previously collected and stored in the shared file, the levels of water calcium content measured in the lab were compared to the following characteristics of Rice County in an attempt to find a pattern: local stratigraphy, crops, feedlots, and soil pH.

## Results:

The results for the calcium content of each sample (taken in April 2009) were recorded with units parts per million (ppm) and milliVolts (mV). Samples listed with "-99999" had no result because the sample was unavailable. The minimum Ca-content in parts per million was 43.91ppm, the maximum was 171.59ppm (although this reading should be considered with some speculation because the probe was calibrated between 10ppm and 100ppm), and the median value was 71.45ppm. The average Ca-content was 68.05ppm (and -118.14mV). The results are attached in the Appendix. After superimposing data for local stratigraphy (rock type), crops (land use), feedlots, and soil pH in Rice County, no correlation was found between calcium content in open water and any of these geographic properties.

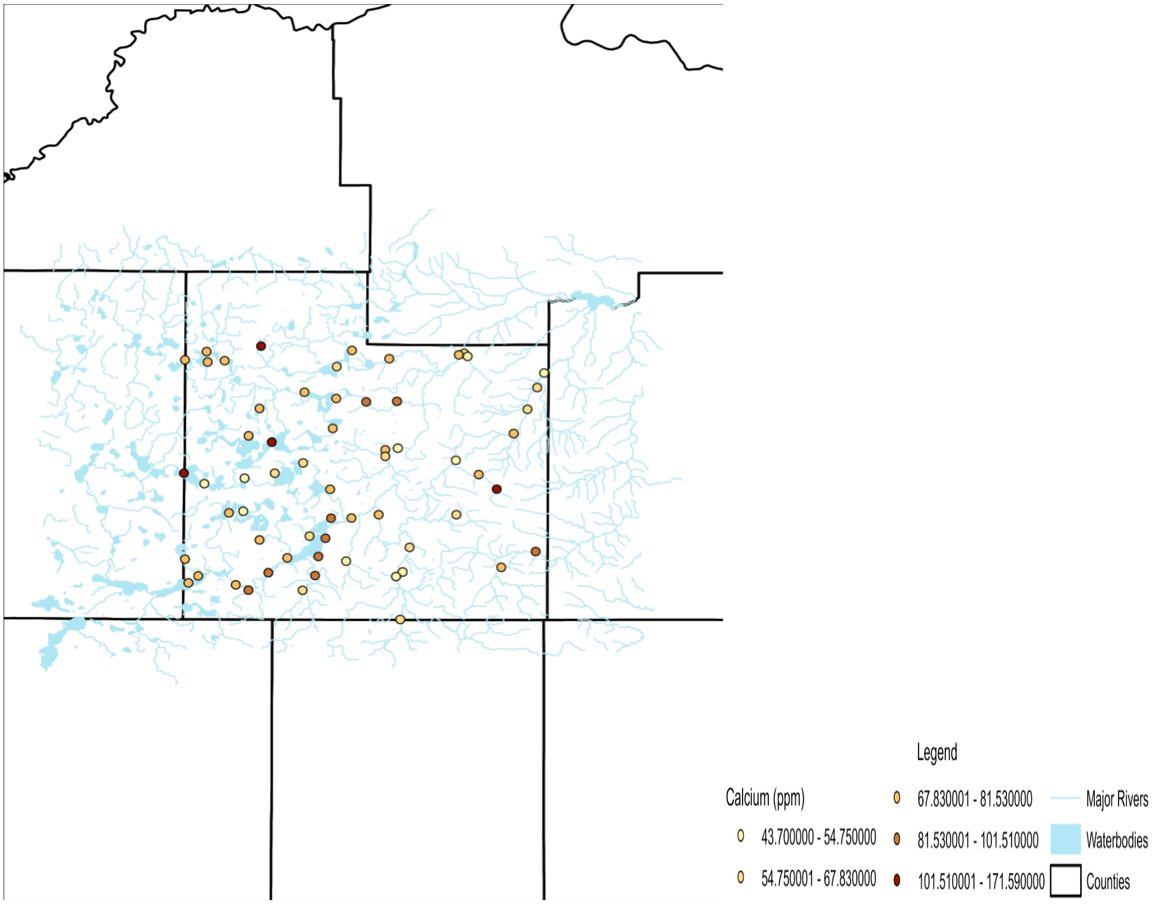

Figure 1. Calcium concentration distribution and open water sites in Rice County

## Discussion:

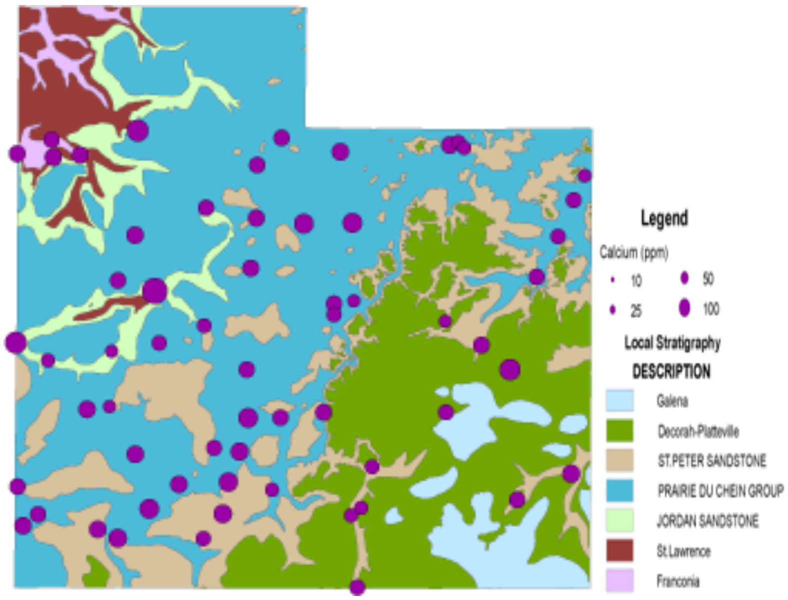

Figure 2. Calcium levels in open water and rock types in Rice County

As seen on the map, measured calcium levels in open water sites in the county are distributed with no discernible pattern. We would expect higher calcium concentrations in waters flowing through areas with exposed Prairie Du Chein formations and Decorah Platteville limestone because these rocks are calcium-rich, but based on the data, this is not the case. A possible reason for the lack of correlation between calcium concentration and proximity to calcium-rich rock formations is that most of the streams in Rice County are fed from springs. These springs are most likely draining the calcium carbonate from the bedrock, causing stream samples in such areas to have lower calcium concentrations than would be expected based upon their surrounding stratigraphy.

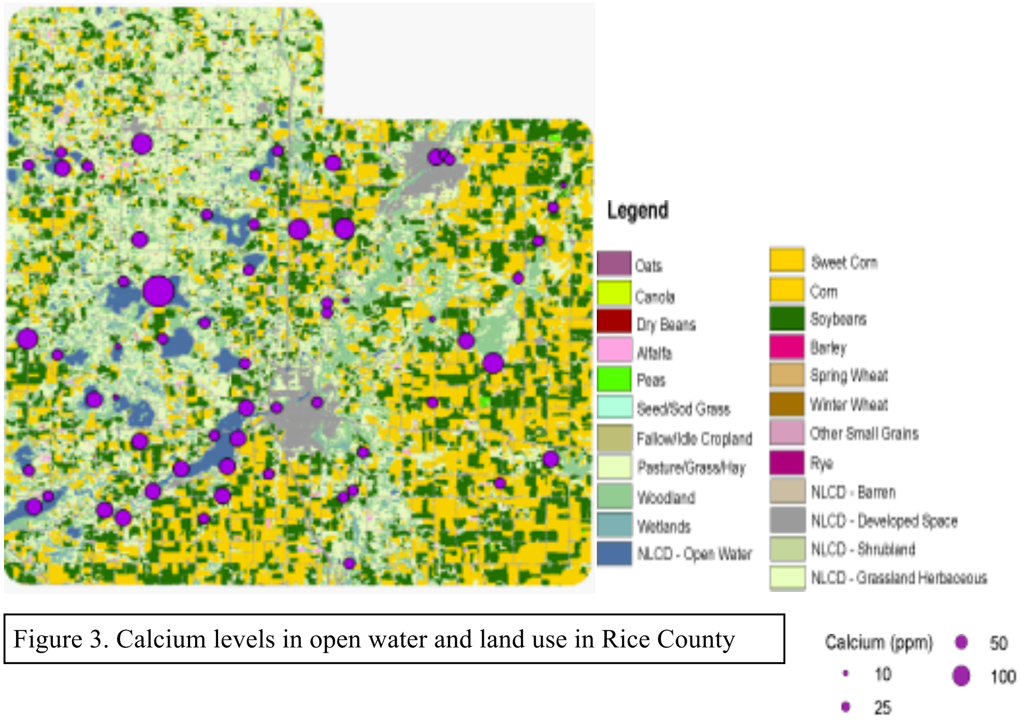

Figure 3. Calcium levels in open water and land use in Rice County

Above is a map of calcium levels in open water sources in Rice County superimposed over a map of land usage in the county. The yellow areas represent corn, and the green represents soybeans. The greatest concentration of land used for agricultural purposes is located in the southeastern region of the county. Higher phosphate concentrations would be expected in these agricultural regions due to chemicals added to the soil. This is notable because phosphate binds with calcium, and therefore interferes with accurate measurement of calcium content. Thus, we cannot say with certainty whether or not calcium levels are affected by the surrounding rock type because of the problems posed by the presence of phosphate that is unevenly distributed throughout Rice County.

## Conclusion and Future Research:

The lack of a discernible pattern and problems calibrating the probe led us to reflect on the accuracy of our data. A point of concern in the result data pertains to the equipment used to take the measurements. The instruction manual for the probe states that the reference solution should never fall below the designated line in the probe, but when we found the $Ca^{++}$ probe, the fluid inside had crystallized. Although we think the probe was calibrated properly when the first set of samples (April 2009) was recorded, it would not calibrate with the same standards upon further testing only two weeks later. Further problems arise if we take into account the possibility that phosphate levels are higher in the southeastern region, and would therefore skew the data toward lower calcium levels in places where the levels could be higher than observed. Thus, we believe more research and testing is necessary to determine calcium distribution data in open water sites in Rice County. The research done in the future should be executed with a different set of equipment as well as the addition of lanthanum chloride solution to each solution to reduce error due to phosphate absorption (as suggested by Battis, et. al.).

## Acknowledgments:

This project would not have been possible without the help of the Carleton Geology Department, Bereket Haileab, Nick Holschuh, Elizabeth Lundstrom, Nathan Evenson, Wei-Hsin Fu, and Ann Zawistoski.

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## Appendix:

## Table 1: Measurement of Calcium Levels in Open Water in Rice County

| Sample_ID | Long | Lat | Ca_ppm_April2009 | Ca_mV_April2009 |
|---|---|---|---|---|
| 1 | -93.151648 | 44.462859 | 57.44 | -129 |
| 2 | -93.15888 | 44.461195 | 81.53 | -124.3 |
| 3 | -93.146886 | 44.45969 | 51.26 | -130.5 |
| 4 | -93.50119 | 44.491894 | -99999 | -99999 |
| 5 | -93.25142 | 44.457138 | 81.53 | -124.3 |
| 6 | -93.239713 | 44.367887 | 43.91 | -132.4 |
| 7 | -93.256353 | 44.366243 | 71.08 | -126.1 |
| 8 | -93.256476 | 44.359722 | 60.01 | -128.4 |
| 9 | -93.232939 | 44.244017 | 54.18 | -129.8 |
| 10 | -93.264984 | 44.30122 | 73.18 | -125.7 |
| 11 | -93.223805 | 44.268743 | 56.61 | -128.9 |
| 12 | -93.241548 | 44.239588 | 54.17 | -134.5 |
| 13 | -93.235906 | 44.196551 | 66.04 | -131.4 |
| 14 | -93.301253 | 44.465265 | 69.48 | -130.5 |
| 15 | -93.345075 | 44.454665 | -99999 | -99999 |
| 16 | -93.321751 | 44.449022 | 67.83 | -131.1 |
| 17 | -93.364609 | 44.423303 | 72.15 | -132 |
| 18 | -93.182672 | 44.225664 | -99999 | -99999 |
| 19 | -93.322201 | 44.417137 | 72.87 | -123.2 |
| 20 | -93.326681 | 44.387297 | 72.3 | -123.9 |
| 21 | -93.322054 | 44.346436 | -99999 | -99999 |
| 22 | -93.101659 | 44.249001 | 72.19 | -132.1 |
| 23 | -93.329779 | 44.326529 | 70.88 | -131.1 |
| 24 | -93.464435 | 44.302426 | 80.96 | -129.4 |
| 25 | -93.301284 | 44.297855 | 71.45 | -131.2 |
| 26 | -93.328435 | 44.297662 | 99.11 | -126.1 |
| 27 | -93.056113 | 44.264706 | 85.41 | -128.9 |
| 28 | -93.357055 | 44.27958 | 66.12 | -132.2 |
| 29 | -93.335688 | 44.277581 | 86.16 | -128.9 |
| 30 | -93.367115 | 44.267469 | -99999 | -99999 |
| 31 | -93.345068 | 44.259281 | 93.11 | -127.7 |
| 32 | -93.386552 | 44.257795 | 79.3 | -129.8 |
| 33 | -93.411464 | 44.242988 | 99.4 | -126.9 |
| 34 | -93.437977 | 44.225414 | 90.93 | -128 |
| 35 | -93.454778 | 44.230577 | 77.61 | -128.9 |
| 36 | -93.505033 | 44.239435 | 70.33 | -130.2 |
| 37 | -93.517827 | 44.232419 | 79.48 | -128.5 |
| 38 | -93.308217 | 44.254707 | 51.42 | -134.2 |

| Sample_ID | Long | Lat | Ca_ppm_April2009 | Ca_mV_April2009 |
|---|---|---|---|---|
| 39 | -93.423557 | 44.275524 | 79.48 | -128.6 |
| 40 | -93.24109 | 44.414588 | 101.51 | -125.4 |
| 41 | -93.281997 | 44.41396 | 100.91 | -125.5 |
| 42 | -93.44546 | 44.304123 | 46.19 | -135.7 |
| 43 | -93.522645 | 44.255982 | 72.03 | -129.9 |
| 44 | -93.524731 | 44.341925 | 124.33 | -122.7 |
| 45 | -93.524469 | 44.45498 | 73.55 | -129.6 |
| 46 | -93.497464 | 44.331506 | 54.75 | -134.3 |
| 47 | -93.443802 | 44.337213 | 44.17 | -137.1 |
| 48 | -93.438832 | 44.379573 | 70.33 | -131.1 |
| 49 | -93.407713 | 44.373364 | 171.59 | -119.5 |
| 50 | -93.403755 | 44.342343 | 61.5 | -132.7 |
| 51 | -93.365973 | 44.352754 | 57.77 | -133.6 |
| 52 | -93.424574 | 44.406813 | 79.01 | -129.5 |
| 53 | -93.471441 | 44.454479 | 74.21 | -130.3 |
| 54 | -93.495618 | 44.463413 | 70.54 | -130.9 |
| 55 | -93.494096 | 44.453011 | 81.18 | -129.1 |
| 56 | -93.365877 | 44.225402 | 59.93 | -133 |
| 57 | -93.422895 | 44.469275 | 120.57 | -124.1 |
| 58 | -93.162414 | 44.355837 | 43.7 | -137 |
| 59 | -93.044963 | 44.443155 | 47.91 | -135.9 |
| 60 | -93.107788 | 44.327111 | 115.5 | -124.6 |
| 61 | -93.131869 | 44.34167 | 76.93 | -131.4 |
| 62 | -93.34944 | 44.240261 | 89.88 | -129.6 |
| 63 | -93.085448 | 44.382556 | 69.35 | -132.8 |
| 64 | -93.067297 | 44.406738 | 61.57 | -134.3 |
| 65 | -93.054195 | 44.428512 | 65.85 | -133.4 |
| 66 | -93.161729 | 44.301426 | 65.45 | -133.5 |
| 67 | -93.231443 | 44.441174 | -99999 | -99999 |

# Permeability and Porosity in Quaternary Deposits in Rice County

By Alex Brewer, Kate Dorwart, Tom Holmes, and Libby Isenstein

## Abstract

In this study, we assessed the levels of porosity and permeability in Quaternary deposits in Rice County, Minnesota, and explored the further implications of our findings. We tested a sampling of sediment from a quarry located within county boundaries, and calculated the porosity and permeability of this material. Our sample proved to be fairly porous and moderately permeable, which runs counter to pre-existing information on the nature of Rice County Quaternary deposits, which indicates that our sample may come from an anomalous pocket of more permeable sediment. By examining these geologic attributes, we are able to learn more about the local wells that provide drinking water for Rice County residents.

## Introduction

Porosity and permeability are measurements that assess the composition of a given type of sediment. According to the *Glossary of Geology*, porosity is the "percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected" (Jackson 503). The porosity of a medium is its capacity to store fluids within its internal pore space. Porosity is the ratio of the volume of openings (voids) within a sample to the overall volume of the material (Grotzinger 408). Various factors affect a substance's porosity. For example, material with tightly packed, poorly sorted, smaller particles will have a lower porosity than a material with loosely-packed, well-sorted, larger grains (Grotzinger 408). Porosity can be as low as 1% in tightly packed rocks such as granite, or unfractured shale, but in looser soils it can be as high as 55% (Grotzinger 409).

Permeability is the “property or capacity of a porous rock, sediment, or soil for transmitting a fluid. It is a measure of the relative ease of fluid flow under unequal pressure and is a function only of the medium” (Jackson 478). Put more simply, permeability essentially measures the ease with which fluids flow through a porous substance. The unit for standard permeability is a Darcy, named after Henri Darcy, the engineer who innovated permeability studies with his work with the pilot tube. In 1855 and 1856, Darcy conducted several column experiments, the results of which supported the creation of his law regarding the flow of sands (Grotzinger 414).

Like porosity, permeability is determined by the packing, shape and sorting of granular materials. It is possible for a sample of sediment to be very porous, but have low permeability because the porous voids are not interconnected. Conversely, if a rock is permeable, it must also be porous.

Porosity and permeability have never been measured before in the Quaternary deposits in Rice County. However, these layers are of particular geologic interest because 10% of wells in Rice County are drilled no deeper than the Quaternary deposits, thus a significant amount of local drinking water originates from this layer. The average depth of Quaternary deposits in Rice County ranges from 800 to 1,200 feet above sea level. It is important to examine how local water sources interact with these soil deposits because these sources provide drinking water for the residents of Rice County. The best drinking wells are drilled into aquifers—beds that are both porous and permeable, thereby allowing for superior storage and transmission of water (Grotzinger 408). Studying Quaternary geology in Rice County could directly affect the health and well-being of residents, and could help formulate ideas about prime well locations and depths.

**FIGURE 1:** Satellite view of Dundas Wash Plant quarry, *Google Maps*

Our sample was collected from the Dundas Wash Plant quarry, located off of Road 263 in Dundas, Minnesota. The quarry is pictured above.

In order to research the permeability and porosity of Quaternary deposits we collected sand and gravel from the Dundas Wash Plant pit, a quarry currently operated by Southern Minnesota Construction. The quarry is located off of Road 262 in Dundas, Minnesota. We brought our sample back to the lab and ran a series of tests to determine the permeability and the porosity of the sample. We also sieved our sample in order to better understand the different grain size variation within the Quaternary soil. We performed a number of trials to construct a more accurate and detailed picture of the local geography and assess the broader implications of our findings for Rice County residents.

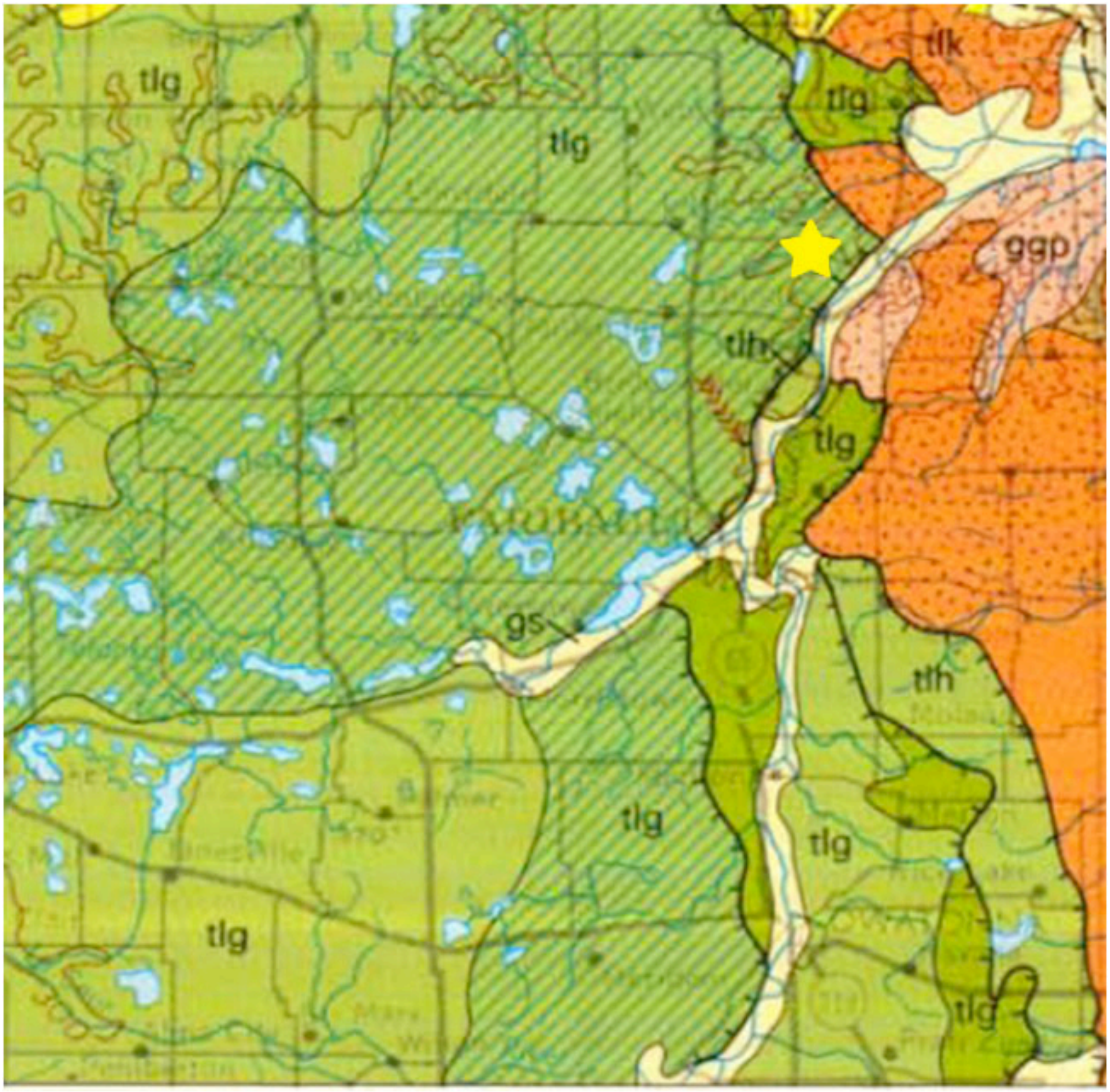

**FIGURE 2:** This map shows the make-up of the Quaternary layer in the Rice County area. The yellow star indicates the approximate location of the quarry from which we drew our sample. All Quaternary sediments in this region (indicated in both green and orange) are composed of loamy till.

## Local Geologic History

A Quaternary deposit is the layer of sediment left behind from the most recent glacial period. Quaternary deposits constitute the uppermost layer of the local geography in southern Minnesota. This period of glacial activity occurred during the Cenozoic Era, which lasted from 1.8 million years ago to the present. Large glaciers are composed of smaller lobes, which drift or move large distances over extensive periods of time. The glacial till in Rice County was deposited by the Des Moines lobe, which originated in the Dakotas along the Red River Valley and made its way through southern Minnesota to Iowa (Hall). Gradual climate changes accounted for the slow melting of the glaciers, which caused it to move and leave behind a heterogeneous composition of rocks and soil. See Figure 2 for a map of Quaternary deposits in Minnesota.

The local soil in Rice County is composed largely of clay deposits which are generally very impermeable, and include Gray tills, Superior-provenance till, Northwest-provenance till, and basal sediments (Hobbs 1995). In addition to clay, local soil also consists of sand and gravel located largely in river valleys (Hobbs 1995). The areas dominated by glaciofluvial deposits “include most of the Cannon River, North Fork Zumbro River and Prairie Creek valleys, and lower parts of the Straight River valley” (Hobbs 1995).

The thickness of Quaternary deposits in Rice County varies from approximately 700 feet to 1150 feet above sea level (Hobbs 1995). In most locations, Northwest-provenance tills are found directly above the layer of St. Peter Sandstone bedrock formed during the Ordovician period, although there are pockets of basal sediments that can separate the Northwest-provenance tills and the sandstone. Above the Northwest-provenance lies the Superior-provenance till, followed by Gray till (Hobbs 1995).

In 1995, the Minnesota Geological Survey studied the composition of five different cross sections within Rice County. Figures 3 and 4 illustrate the findings of this study, represented by stratigraphic diagrams. We located the source of our sample on this map and, found that cross sections B-B’ and C-C’ were closest to the quarry. Figure 4 shows the stratigraphy of these two cross sections.  In these crossings, the majority of

Quaternary deposits are marked as being “less permeable” (designated on the legend as dtu, pkt, pst, and pbs). There are smaller elongate pockets of more permeable tills dispersed across the sections. These are the areas that would make the best wells, as they easily transmit water flow, but have impermeable layers above and below keeping unwanted particles out.

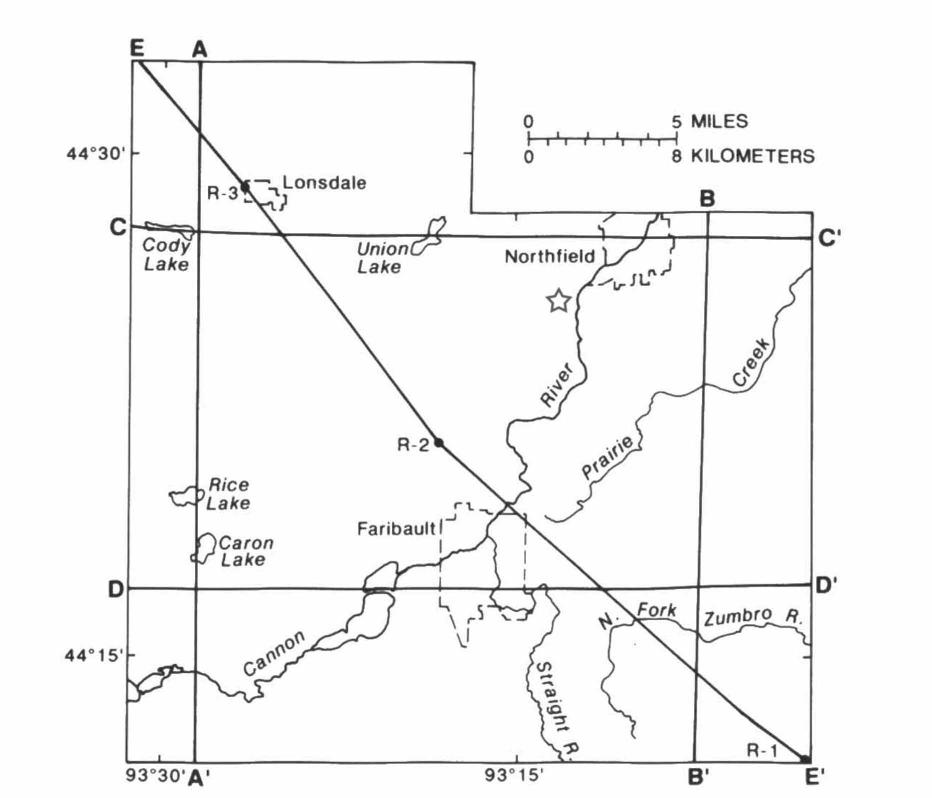

**FIGURE 3:** Map of Rice County with locations of stratigraphic cross sections.The B-B’ and C-C’ cross sections are the closest to the location of the Dundas Wash Plant quarry, designated by the star symbol. See diagrams of the stratigraphic cross sections in Figure 3

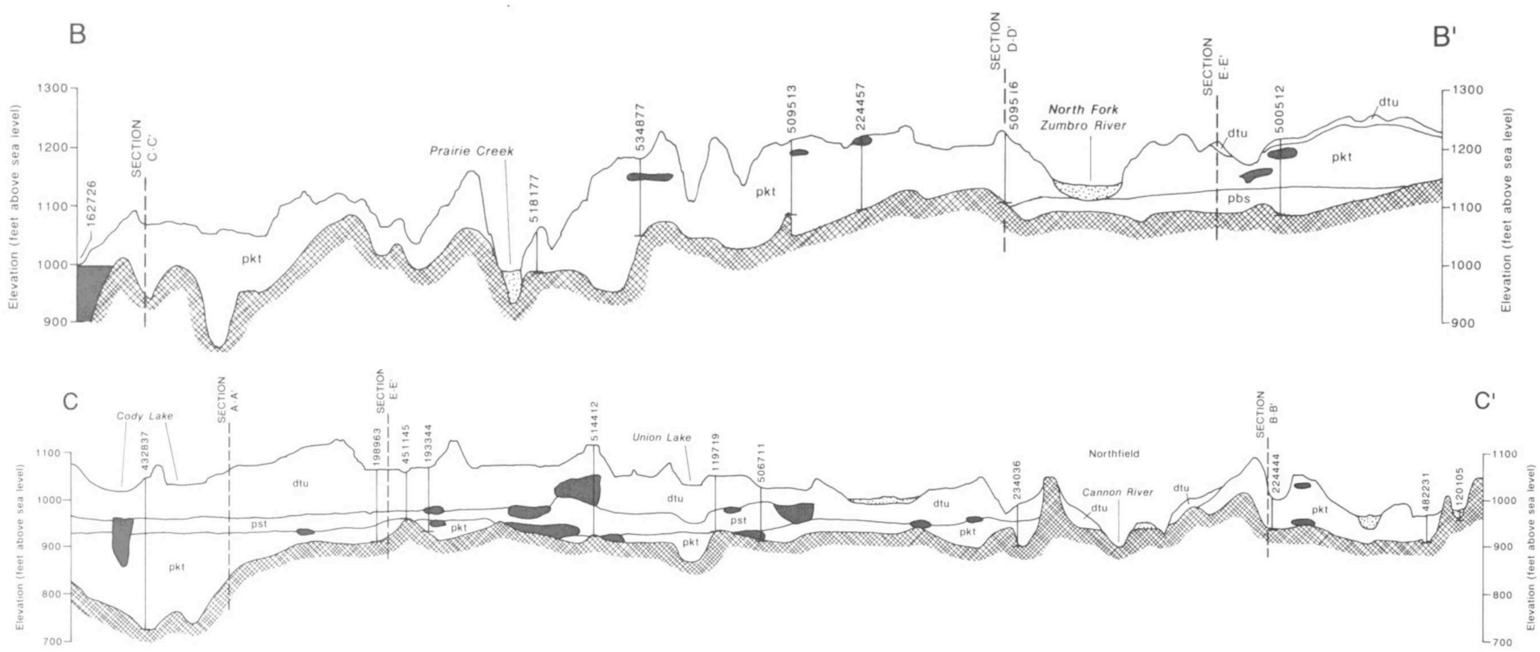

**FIGURE 4** Stratigraphic sections of Rice County. *Minnesota Geologic Survey.*

This diagram represents two cross sections of Rice County geography that approximate the stratigraphy of the site from which our sample was drawn. It shows that the local Quaternary layer is composed mostly of impermeable rock with dispersed pockets of more permeable sediment.

Less permeable tills (commonly referred to as "clays")
dtu: Gray tills
pkt: Northwest-provenance tills
pst: Superior-provenance tills
pbs: Basal sediments

More permeable units (commonly referred to as "gravel")
░ and ■ : Glaciofluvial deposits

## Methods

Before testing our sediment for porosity and permeability, we sorted the sample into five grain fractions with a set of differently sized sieves, sized at 10 holes/in², 18 holes/in², 35 holes/in², and 60 holes/in². A basic pan basin caught the finest material. A total of 1 kg of material was sieved and sorted. This is important to determine because the grain size of a sample will affect its permeability. Figure 5 for an image of our sample prior to being sieved.

**FIGURE 5:** The sample collected from the quarry was poorly sorted and unconsolidated.

To determine the porosity of the sediment, we used a plastic tube with a diameter of 3.5 cm secured in a vertical stand. We fastened a rubber cap with a hose to the bottom of the tube, and closed the hose with two separate clamps to ensure that no water or soil would leak from the tube. We placed 100 mL of sediment inside the tube that once inside the apparatus was approximately 7 cm thick. The tube was suspended over a bucket to catch any accidental leakage. We measured 400 mL of water into a graduated cylinder, and poured this water into the tube at an extremely slow pace until the sample was fully saturated (or until the water level and the upper surface level of the sediment were the same). We measured the amount of water absorbed by subtracting the remaining water in the beaker from the original volume of 400 mL. We then washed the tube and repeated the process three more times, for a total of four trials.

In order to determine the permeability of the sediment, we poured 100 mL of sediment into a tube of the same size, quickly followed by 100 mL water. We placed a bucket underneath the hose and left it unclamped so water was free to flow through the sediment and into the bucket. By inserting two layers of screen at the mouth of the tube, we prevented fine grains from escaping with the water. During each trial, water flowed through the sediment into the bucket. After twenty minutes, we measured the water in the bucket to see what percentage of the original water traveled through the sediment in the designated period.

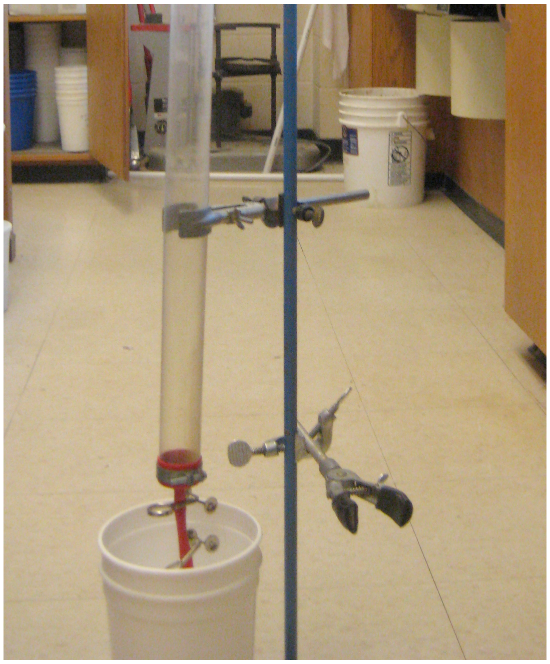

**FIGURE 6:** Apparatus

A plastic tube with diameter of 3.5 cm suspended vertically over a small bucket. The mouth of the tube was covered with a rubber hose that remained clamped during porosity testing, but was open during permeability testing to allow water to flow through to the bucket.

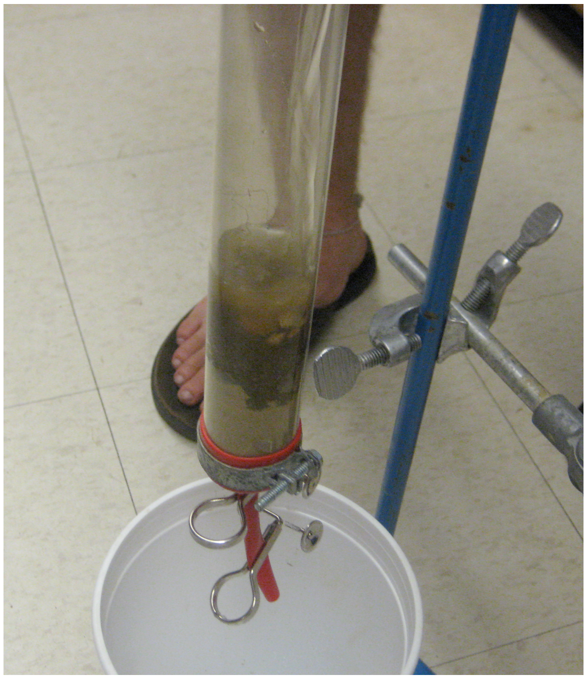

**FIGURE 7:** Measuring porosity

To determine the porosity of the sediment, we slowly added water to the 100 mL of sediment in the tube, and measured the amount of fluid needed to saturate the sample.

## Results

We used a set of sieves to sort a 1 kg sample of the sediment into five groups based on size of grain. The sieve sizes are indicated in the Table 1. Approximately 33% of the mass of the sample consisted of the largest grains, which were trapped in the topmost sieve (category 1). 31% of the overall mass was trapped in category 3, 17% in category 2, 11% in category 4, and only 8% in category 5.

**Table 1: Sieving 1 kg of sediment**

| Sieve size (holes/square inch) | Amount of sediment left in sieve (grams) | % of total |
|---|---|---|
| 10 (category 1) | 335.1 | 33.5 |
| 18 (category 2) | 169.2 | 16.92 |
| 35 (category 3) | 309.3 | 30.93 |
| 60 (category 4) | 109.1 | 10.91 |
| Bottom dish (category 5) | 77.5 | 7.75 |

These results predict that the sample will be moderately permeable. Samples with significant amounts of large grain will be permeable, as the liquids will be able to flow between the spaces between the grains. Finely grained sediment tends to be less permeable, as there is less space for the liquids to flow through. Our sample proved to be poorly sorted, with significant amounts of both large and finely grained sediments.

Testing found the sediment to have an average porosity of 26.75%. See Table 2 for porosity results. Porosity is calculated with the following equation (Grotzinger 408):

$$\phi = \frac{V_V}{V_T}$$

Where $\varphi$ is the porosity, $V_V$ is the volume of voids, or water absorbed by the sediment, and $V_T$ is the total volume of the sample, in our case, 100 mL.

**Table 2: Porosity of 100 mL of sediment**

| Trial | Water absorbed by sediment (mL) | Porosity (ϕ) |
|---|---|---|
| 1 | 25 | 26% |
| 2 | 28 | 25% |
| 3 | 24 | 27% |
| 4 | 28 | 28% |
| **Average** | **26.25** | **26.25%** |

Finally, the sediment also proved to be fairly permeable, with an average of 70.37 mL flowing through the 100 mL of sediment during a duration of 20 minutes. The individual trial results for this test can be found in the following chart. Permeability is calculated with the following equation (Grotzinger 415):

Where *v* is velocity of flow through the porous medium, *k* is the permeability of the medium, μ is the dynamic viscosity of the fluid, *ΔP* is the applied pressure difference, and *Δx* is the thickness of the bed of the medium.

**Table 3: Permeability of 100 mL sediment**

| Trial | Water flow through sample in 20 mins (mL) | % Water that flowed through sediment |
|---|---|---|
| 1 | 70 | 70% |
| 2 | 71 | 71% |
| 3 | 68 | 68% |
| 4 | 72.5 | 72.5% |
| **Average** | **70.37** | **70.37%** |

These results indicate moderate permeability, which is consistent with the results of our sieving which showed the sample to be poorly sorted with substantial presence of large-grained material. Large-grained material tends to be more permeable than fine-grained sediment (Grotzinger 415).

## Discussion

Based on our tests and observations, we propose that our sample is drawn from one of the previously mentioned anomalous pockets as illustrated in Figure 4. According to the Minnesota Geological Survey, the majority of Quaternary sediment is similar to clay in its physical appearance, while there are also smaller more permeable pockets that are composed of gravel and sand. Our sample more closely matches the irregular pockets in its physical properties. Our sample was moderately permeable which is atypical of the majority of the characteristically impermeable Quaternary soil in Rice County (Hobbs 1995).

One means of contextualizing our results is to compare our findings with the characteristics of another rock commonly found in Rice County, the St. Peter Sandstone, the layer below the Quaternary sediment. One study reports that the sandstone has an average porosity of 39%, which is approximately 13% higher than that of our Quaternary sample (Jones et al). On average, 20 mL of water took 26 seconds to pass through 100 mL of saturated sediment (Jones et al). Though the methodology used in this study differed from our own, therefore making a direct comparison impossible, these results indicate that the St. Peter Sandstone is more permeable than our sample, and significantly more permeable than the majority of Quaternary material.

Approximately 10% of wells in Rice County are drilled only to the Quaternary deposit between 16 and 351 feet deep (Bethune, Personal Communication). These shallow wells are distributed mostly in the Western part of the county (Figure 8). The average depth of a Quaternary well is 138 feet deep, compared to the overall average of 234 feet (Bethune, Personal Communication). The remaining 90% of the county’s wells extend deeper to the St. Peter Sandstone layer. Although it is easier and more affordable to drill shallow wells, they are not necessarily as safe or reliable as wells drilled to the St. Peter Sandstone layer. By nature of their depth, shallow wells have less protective filtering, and are subject to a higher risk of contamination. Additionally, the elongate Quaternary pockets of permeable material are more likely to dry up than a larger layer of Sandstone bedding.

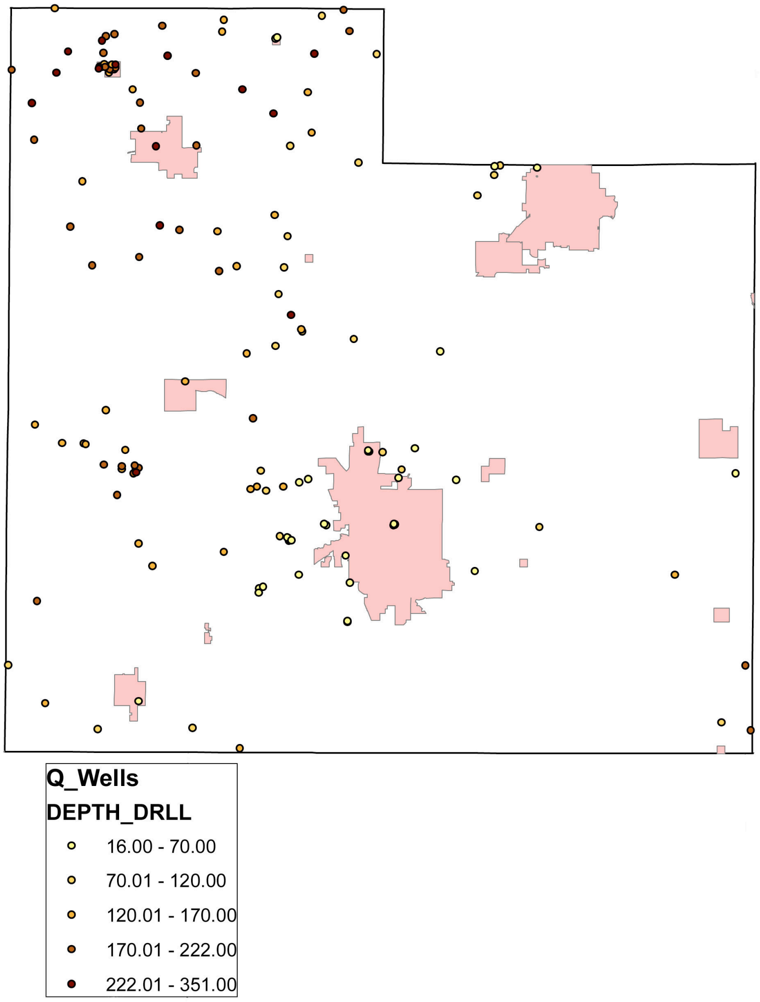

**FIGURE 8:** Wells in Quaternary deposits in Rice County, MN.
This figure shows the distribution of wells drilled in Quaternary deposits in Rice County. City limits are represented by pink patches. Wells drilled in Quaternary deposits (depth measured in feet) are located mostly in the Western region of the county.

There were several limitations that may have impacted the validity of our results. First, as we only had one sample to work with, we cannot claim it to be indicative of any significant trends in Rice County. Furthermore, because our sample was found unconsolidated in a quarry, and not in situ, our results do not reflect the soil in its most natural state.

Additionally, the technology used in our study is less advanced than that available to professional researchers. One method employed by scientists with access to more extensive resources involves magnetic scanning to measure porosity and permeability (Anferova 306). Our results were not as exact as they would have been with more advanced technology.

One possible confounding variable was the residual sediment left on the inner walls of the tubes from previous trials. Another potential problem was that some of the finest sediment passed through the protective screen at the mouth of the tube. Not only could this have allowed extra water to flow through the thinner layer, but the presence of the escaped sediment could have inflated the volume of the final water measurement. This issue could have lead to a falsely high measure of permeability.

Further research opportunities in this field would involve collecting a wider variety of samples, preferably in situ. A more varied sampling, including both consolidated and unconsolidated sediment, would provide researchers with a point of reference with which they could compare their findings and contextualize their data. Furthermore, it would be useful to run the permeability trials with previously saturated soil.

## Conclusion

This was a cursory examination of the permeability and porosity of Quaternary deposits in Rice County. Quaternary deposits in Rice County are, as a whole, impermeable, especially compared to more aquiferous layers such as the St. Peter Sandstone beneath. There are, however, anomalous porous pockets which are more permeable, and these are the regions that could be utilized as a water source for shallow wells. This study did not seek to make any grandiose statements about the porosity or permeability of the regional soil based upon our limited experimentation but rather to characterize the soil so that future research can be done on this type of deposit and the way in which it interacts with groundwater.

## Acknowledgements

We would like to thank the Carleton College Geology Department and Bereket Haileab for providing us with guidance during this project. Special thanks also to Tim Vick for his direction and patience, and James Bethune, for his time and instruction. Finally thanks to Tabatha Jones, Brian Lambert, and Sarah Stadler for allowing us to use their data in our discussion, and to our TAs Nate Evenson and Liz Lundstrom.

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# Porosity and Permeability of St. Peter Sandstone

Intro to Geology

Tabatha Jones, Brian Lambert, Sarah Stadler

Spring 2010

## Abstract

The porosity and permeability of rocks are important determinants in the use of bedrock as an aquifer. The St. Peter sandstone of southeastern Minnesota has a high porosity and permeability, allowing it to be a source for water. This project examines the porosity and permeability of both consolidated and unconsolidated St. Peter sandstone and the possible implications of it as an aquifer.

## Introduction

The porosity and permeability are important characteristics of the St. Peter aquifer, although little research has been done on the St. Peter formations in southeastern Minnesota. An aquifer is an underlying bedrock or layer that is filled with water and is often used for wells (Swanson, 2010). The porosity and permeability of the St. Peter sandstone are important, as they are closely related to the health of the aquifer and the quality of the groundwater (Bahr and Weaver, 1991). The porosity of the aquifer rock determines the amount of water that can be contained within the aquifer, and the permeability determines the rate of flow through a given medium. These are important because the more uniform and course the sand grains, the more connected pore space there is available for the retention of water (Swanson, 2010). These characteristics of the rock also determine the structure and the occurrence of water-bearing zones (Swanson, 2010). Furthermore, the quality of the groundwater is impacted by the size of the sand grains and thus its ability to filter-out impurities (Bahr and Weaver, 1991). Retention—the ability of stone to hold water that has been absorbed—and yield—the amount of water released by stone after absorption—also impact aquifer health. Rocks with high permeability tend to have a high yield as well. These features together establish the flow rate of water through rock, and the residence time of the groundwater, which in turn determines the mineral content, concentration of contaminants, and the salinity of the water.

The porosity and permeability of the sandstone have been the impetus for many studies, as they determine a number of different qualities of the sandstone. The permeability and the nature of the packing zones in sandstone are affected by the network of pores and pore throats (open space), explaining why sandstones, particularly those that are quartz rich—and thus tend to be well rounded and well sorted—tend to be aquifers (Carr, 1999). St. Peter is considered a sedimentary bedrock aquifer (Swanson, 2010). Overall, the body of literature on sandstone examines the porosity and permeability of the studied rock, yet in doing so, a wide variety of different techniques are applied.

In our study of the St. Peter sandstone, we examined the porosity and permeability of this geologic formation that is prevalent in the Midwestern United States. We hoped to determine, through our measurements, the usefulness of the St. Peter as an aquifer. We expected that the St. Peter sandstone, given the uniformity of the sand grains that compose it, would hold and allow the flow of a large amount of water relative to its total volume.

## Methods:

We studied three distinct qualities of the St. Peter sandstone, its permeability, its retention, and its porosity. This occurred in a few stages, first to establish the porosity of the sandstone in its unconsolidated and consolidated forms, second to discover the yield (how much water will drain from the saturated sand) and retention (how much water the sand is able to retain), and third to determine the permeability of its unconsolidated form.

Our first step was to measure the porosity of the unconsolidated sandstone (see Figures 1 and 2, pg.9). We began by constructing an apparatus tube, consisting of a clear plastic tube, a filter of fine cheesecloth placed over a fine metal screen at the bottom of the tube that was then sealed with a tightly clamped hose attachment. The tube was then filled with 100 mL of dry, unconsolidated sandstone and was vertically clamped to a stand (see Figure 5, p.11). The sand level was then marked on each tube. In our study we measured the porosity by dripping water into the unconsolidated sandstone and measuring the amount of water required to saturate the sand (see Figure 6, pg.11). The tubes were filled with water until the sand was completely saturated (i.e. the water level was equal to the top of the sand). This process was repeated for each of the ten prepared tubes so the average porosity of the sample could be established. The porosity could then be calculated by using the following formula:

$$\%\ Porosity = \frac{Volume\ of\ Water\ (mL)}{Volume\ of\ Rock\ (mL)}$$

The second step was to measure the retention and yield of saturated, unconsolidated St. Peter sandstone. In order to obtain this measurement, the tubes were placed vertically on a stand and filled with unconsolidated sandstone that was then saturated. The retention and yield were then measured by opening the clamp at the bottom of the tube and allowing it to drain for three minutes into a collection beaker. The amount collected was measured and then subtracted from the total amount of water necessary to saturate the sand. This was repeated 10 times and was used to determine the retention of water in the unconsolidated sandstone.

Our next step was to measure the porosity of the consolidated St. Peter sandstone. The first step of this process was to mass 10 samples of consolidated rock. After each sample was massed it was then placed into a beaker filled with 100mL of water, where it was left for three minutes to become saturated. After three minutes, the water displacement—caused by the sample in the beaker—was recorded. Each sample was then massed again on the scale to determine the amount of water absorbed (see Figure 3, pg.10). We used the amount of water absorbed to find the pore space in our samples (see

Figure 4, pg.10). Once these steps were completed the porosity of the consolidated sandstone could be determined through the following equation:

$$\%\ Porosity = \frac{Volume\ of\ the\ Water\ Absorbed\ (mL)}{Corrected\ Volume\ of\ the\ Sample\ (mL)}$$

The final step was to measure the permeability of the unconsolidated St. Peter sandstone. This was achieved by setting up an apparatus similar to the one used to measure the porosity of the unconsolidated sandstone. However, in this instance the sand was already saturated and the clamp was in place when 20 additional mL of water were added to the tube. The clamp was then released to allow the water to flow into a collection beaker and amount of time required for the water to return to the saturation level was timed. This process was repeated ten times.

**Observations and Results:**

The average pore space of unconsolidated sandstone was 39%. The consolidated sandstone's pore space was 20% (Tables 1, 4 and 5, pg.12, 15, and 16). As for permeability, it took an average of 26 seconds for 20 mL of water to pass through 100 mL of sand (Table 2, pg.13). The average retention was 39.5 mL and the average yield was 3.1 mL after three minutes (Table 3, pg.14).

**Discussion:**

The St. Peter sandstone in outcrops and bedrock is generally found in its consolidated form; however, there may be some variability within the formation itself. For instance, sandstone that is closer to the surface is likely to be less packed than the sandstone that is buried deeper underground (Minnesota Geological Survey). The high permeability of St. Peter Sandstone causes it to yield a rather large amount of water compared to its volume (Maderak, 1965). Compared with quaternary deposits, in which

100mL of stone yielded 70 mL of water in 20 minutes, an equal amount of the St. Peter sandstone yielded 20 mL in an average of 36 seconds (Brewer, 2010). This may be relevant for instances of fracture flow in St. Peter sandstone, in which water flows more rapidly through the unconsolidated sand that settles in fractures than it would flow through intact stone (Runkel, 2003).

Our research presented several interesting insights into the nature of the St. Peter sandstone. One interesting observation was the large pore space of unconsolidated sandstone, which was on average approximately 40%. This is almost double that of the consolidated rock. The highly permeable nature indicates that water can flow fairly freely within the rock and unconsolidated sand, and is therefore likely to have a relatively short residence time in which water remains in the formation and does not flow. The low residence time may be beneficial, for it allows a fast recharge rate to replenish the aquifer, and it might prevent the accumulation of too many solutes in the water and thereby keep the water fresh. Unfortunately, there may be some downsides to a high flow-rate—primarily the possible contamination from surface sources—that might not have the chance to be adequately filtered.

One concern we have is whether our tubes are an accurate representation of the bedrock and its included structures, such as fractures. The tubes are vertical and highly contained, unlike bedrock in nature. Also, our data were recorded as accurately as our supplies and tools would allow us, but more precise measuring devices would have allowed for more precise measurements. Another area of uncertainty involved the apparatus. It leaked slightly (less than 1 mL), and might have contributed to error in our measurements.

**Future Research:**

Future research might examine the differences between St. Peter and different sandstones in the region, such as the Jordan sandstone. It might also compare St. Peter sandstone with other types of sedimentary layers found in the area. There also may be some variation in St. Peter itself between the different locations of outcrops and bedrock.

Another opportunity for future research involves a study of the frequency and occurrences of fractures in the St. Peter sandstone. This would help determine how easily and frequently surface water enters into the St. Peter aquifer. Sampling the permeability of consolidated sandstone using plug tests presents another research avenue.

**Conclusion:**

On average, consolidated St. Peter sandstone had 20% pore space, which was doubled for unconsolidated rock. Overall the methods used for the measurement of unconsolidated sandstone is not an accurate substitute for the sandstone in its consolidated form, which is most commonly found in bedrock; however, it can be used to study the fracture flows that do occur naturally (Minnesota Geological Survey). Although we did not run tests on other rock types, St. Peter sandstone appears to be highly permeable and is in fact an aquifer. In this capacity it provides water to wells and other sources, as it allows for groundwater deep beneath the surface to flow without being strictly contained (Maderak, 1965). This permeability can be helpful for recharging a depleted aquifer, but might also have a negative impact on groundwater by possibly allowing contaminate from the surface into the aquifer.

**Acknowledgements:**

We would like to thank the Carleton Geology Department. In particular we thank Tim Vick for all of his help in developing our methods, our TAs Adam Denny and James Bethune for their technical advice, and Bereket Haileab for inspiration and guidance.

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**Figure 2 Consolidated St. Peter sandstone.**

Figure 3 Unconsolidated St. Peter sandstone.

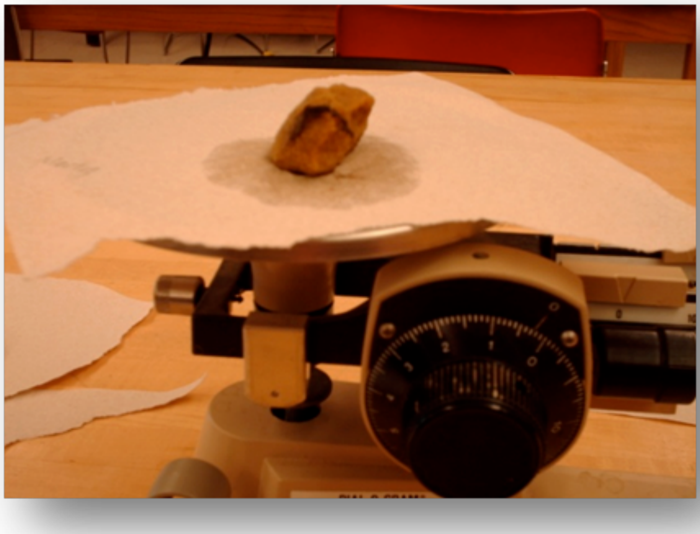

Figure 4 Massing and calculating porosity of consolidated St. Peter sandstone.

**Figure 5 Measuring change in volume of consolidated St. Peter sandstone.**

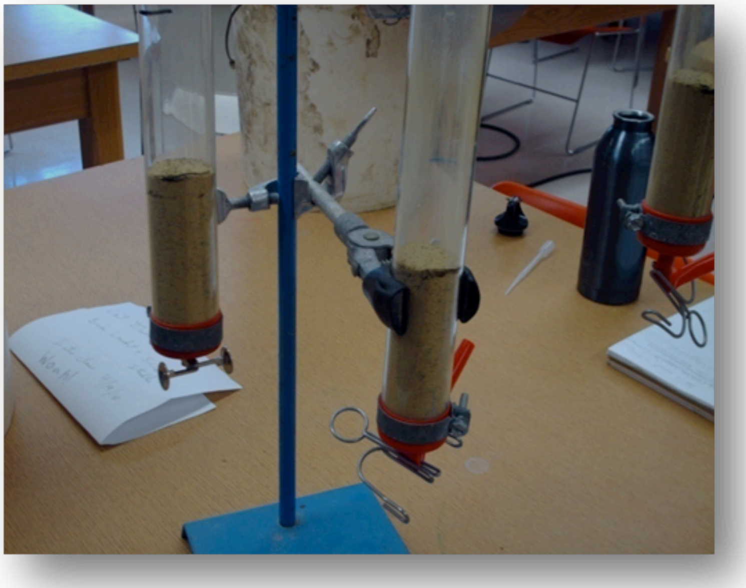

**Figure 6 Apparatus with dry, unconsolidated St. Peter sandstone.**

**Figure 7 Unconsolidated St. Peter Sandstone being saturated.**

Table 1: Porosity of Unconsolidated St. Peter Sandstone

| Trail Number | Amount of Sand (mL) | Amount of Water Held (mL) |
|---|---|---|
| 1 | 100 mL | 37 mL |
| 2 | 100 mL | 33 mL |
| 3 | 100 mL | 42 mL |
| 4 | 100 mL | 36 mL |
| 5 | 100 mL | 38 mL |
| 6 | 100 mL | 41 mL |
| 7 | 100 mL | 36 mL |
| 8 | 100 mL | 42 mL |

| | | |
|---|---|---|
| 9 | 100 mL | 41 mL |
| 10 | 100 mL | 44 mL |
| Average | 100 mL | 39 mL |

Table 2: Permeability of Unconsolidated St. Peter Sandstone

| Trial Number | Amount of Sand Added (mL) | Amount of Water Added (mL) | Time (seconds) |
|---|---|---|---|
| 1 | 100 | 20 | 33 |
| 2 | 100 | 20 | 46 |
| 3 | 100 | 20 | 25 |
| 4 | 100 | 20 | 32 |
| 5 | 100 | 20 | 30 |
| 6 | 100 | 20 | 23 |
| 7 | 100 | 20 | 30 |
| 8 | 100 | 20 | 28 |
| 9 | 100 | 20 | 32 |
| 10 | 100 | 20 | 27 |
| Average | 100 | 20 | 30.6 |
| Average – Outlier | 100 | 20 | 26 |

Table 3: Retention and Yield of St. Peter Sandstone

| Trial Number | Time (min) | Yield (mL) | Retention (mL) |
|---|---|---|---|
| 1 | 3 | 4 | 33 |
| 2 | 3 | 3 | 30 |
| 3 | 3 | 2 | 40 |
| 4 | 3 | 3 | 33 |
| 5 | 3 | 3 | 35 |
| 6 | 3 | 2.5 | 38.5 |
| 7 | 3 | 5 | 31 |
| 8 | 3 | 3 | 39 |
| 9 | 3 | 3 | 38 |
| 10 | 3 | 2.5 | 41.5 |
| Average | 3 | 3.1 | 35.9 |

Table 4: Density of Consolidated St. Peter Sandstone

| Trial Number | Mass (g) | Rock Volume (mL) | Density (g/mL) |
|---|---|---|---|
| 1 | 42 | 20 | 1.85 |
| 2 | 26 | 13 | 2 |
| 3 | 68 | 30 | 2.267 |
| 4 | 35 | 20 | 1.75 |
| 5 | 18 | 05 | 3.6 |
| 6 | 46 | 23 | 2 |
| 7 | 37 | 21 | 1.76 |
| 8 | 55 | 24 | 2.291 |
| 9 | 47 | 25 | 1.88 |
| 10 | 41 | 24 | 1.708 |
| Average | 41 | 20.5 | 2.1106 |
| Average - Outlier | 40.5 | 20 | 1.945 |

Table 5: Pore Space in Saturated Consolidated St. Peter Sandstone

| Trial Number | Mass of Saturated Sample (g) | Mass of Water Absorbed (g) | Ratio or Pore Space to Total Volume |
|---|---|---|---|
| 1 | 42 | 5 | 0.25 |
| 2 | 27 | 1 | 0.078 |
| 3 | 75 | 7 | 0.23 |
| 4 | 40 | 5 | 0.16 |
| 5 | 19 | 1 | 0.4 |
| 6 | 53 | 7 | 0.13 |
| 7 | 42 | 5 | 0.14 |
| 8 | 62 | 7 | 0.208 |
| 9 | 54 | 7 | 0.28 |
| 10 | 47 | 6 | 0.125 |
| Average | 46.1 | 4.6 | 0.2 |

# A Survey of Fracture Orientation in the Platteville Limestone of Goodhue County, Minnesota

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Introductory Projects
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## Abstract

Fracture patterns of the Platteville limestone were studied in Goodhue County, Minnesota in order to determine orientation of underling karst topography. The majority of the strikes measured ran east/west, leading to the conclusion that the orientation of possible sinkholes and seeps will most likely run along the same orientation. Knowledge of seep and sinkhole orientation has important implications for well-drilling and safety precautions.

## Introduction

Much of Rice and Goodhue counties extract their water via wells from aquifers deep underground. The majority of these aquifers are seated in sandstone. Some, however, are in carbonate components, such as dolomite or limestone; these aquifers are difficult to target precisely since the water is stored in caches rather than in broad reserves. There are many conditions and variables that affect the water's descent. One such variable would be non-porous stone and impermeable layers of shale, which would hamper the water's mobility. Another variable is the permeability of the Platteville Limestone, a carbonate layer standing between the sandstone and the surface, which would enable the water's mobility. Although the limestone itself is not porous, its fractures make it permeable. Our project sought to observe how the fracture orientation of the Platteville limestone affects water flow and the formation of karst topography.

Karst topography is the dissolution of carbonate rock, such as limestone by slightly acidic rainwater. Over the course of time, the acidic water eats away at the rock layer creating small fractures. The water then runs through the rock, eventually carving out larger, more defined fractures and other larger karst landscapes such as sinkholes and seeps. A sinkhole is an area where weakened carbonic rock has caved in to make a hole. A seep is an area where groundwater previously contained within the bedrock can surface. Water coming from seeps leaks out of the rock above ground over a broad area, whereas water from springs flow out in narrow, defined spots.

Fractures, sinkholes, and seeps allow groundwater to penetrate the bedrock extremely quickly, especially if the rock is not porous. The length, depth, frequency, and complexity of connections between fractures in the Platteville Limestone directly affect the water supply of sandstone aquifers beneath it.

We measured 62 fractures at two outcrops created by the same road cut of County Highway 14 in Goodhue County. We drew our conclusions from these measurements along with other observations of the rock face and the farm land above the Eastern outcrop.

## Methods

We began our survey by finding our location through GPS. We then measured the dimensions of each outcrop by having someone walk along the outcrop holding a meter tape until the tape ran out. The process was then repeated until the entire width was measured. Someone then climbed to the top of the outcrop and dropped the meter tape down in order to find the height.

For both sides of the road cut, the height, width, depth, strike and dip of joints and fractures were recorded beginning at the North end and systematically progressing to the Southern end. To measure the dimensions of the joints and fractures, a meter stick, tape measurer, or caliper were used. A Brunton hand compass was used to measure the strike and dip according to the right hand rule.

Once we found a general trend amongst the strike and dip measurements, we concluded our field research and continued analysis in the lab by compiling the orientation measurements in a rose diagram. We then compared our joint dimensions with the sinkhole probability map of E. Calvin Alexander et al.

## Results

Our outcrop is 316.1 ft above sea level with coordinates N 44˚21.8892 and W 092˚56.048.

The Eastern outcrop dimensions were 150 meters wide and 15 meters tall, and the Western outcrop dimensions were 148 meters wide and 17 meters tall.

We found that the majority of fractures we measured had a strike of E/W and a near vertical, Northward dip, as can be seen in **Table 1** and **Table 2**. The mean of their orientation can be deduced from **Figure 1**.

Of the fractures we measured, 49 are between 10 centimeters and 100 centimeters tall, 10 are taller than 100 centimeters, and 3 are less than 10 centimeters tall.

Of the fractures we measured, 20 of the fractures are less than 5 centimeters wide, 25 have a width between 6 centimeters and 20 centimeters, and 17 are wider than 20 centimeters.

Of the fractures, 17 have a depth less than 10 centimeters, 32 have a depth between 11 centimeters and 60 centimeters, and 13 are deeper than 60 centimeters.

**Table 1** Fracture measurements of the out crop on the east side of the road cut**.**

| **Eastern Face** | | | | | |
|---|---|---|---|---|---|
| Fracture # | Height (cm) | Width (cm) | Depth (cm) | Strike | Dip |
| 1 | 52 cm (at least) | 7 cm | 20 cm | 265° W/E | 85° N |
| 2 | 60 cm | 28 cm | 80 cm | 85° W/E | 72° N |
| 3 | 80 cm | 7 cm | 41 cm | 255° W/E | 83° N |
| 4 | 20 cm | 1 cm | 30 cm | 225 S/W | 74° N/W |
| 4 | 78 cm | 1.5 cm | 14 cm | 280° W/E | 89° N |
| 5 | 25 cm | .5 cm | 3 cm | 265° W/E | 82° N |
| 6 | 12 cm | .4 cm | .5 cm | 267° W/E | 82° S |
| 7 | 80 cm | 3 cm | 50 cm | 273° W/E | 78° S |
| 8 | 42 cm | 25 cm | 15 cm | 278° W/E | 81° N |
| 9 | 170 cm | 10 cm | 70 cm | 283° W/E | 88° S |
| 10 | 26 cm | 4 cm | 6 cm | 230° S/W | 80° N |
| 11 | 54 cm | 5 cm | 22 cm | 252° W/E | 83° N |
| 12 | 92 cm | 40 cm | 62 cm | 257° W/E | 82° N |
| 13 | 66 cm | 16 cm | 27 cm | 293° W/E | 87° S |
| 14 | 71 cm | 20 cm | 22 cm | 283° W/E | 79° N |
| 15 | 91 cm | 31 cm | 38 cm | 290° E/W | 85° N |
| 16 | 7 cm | 6 cm | 4 cm | 233° NE/SW | 80° NW |
| 17 | 34 cm | 2 cm | 57 cm | 198° S/W | 84° W |
| 18 | 17 cm | 14 cm | 32 cm | 283° E/W | 71° N |
| 19 | 17 cm | 9 cm | 4 cm | 234° NE/SW | 88° NW |
| 20 | 43 cm | 3 cm | 16 cm | 273° W/E | 56° N |
| 21 | 54 cm | 22 cm | 22 cm | 280° E/W | 85° N |
| 22 | 232 cm | 24 cm | 61 cm | 290° E/W | 84° N |
| 23 | 94 cm | 9 cm | 16 cm | 275° W/E | 99° N |
| 24 | 25 cm | 12 cm | 23 cm | 268° E/W | 77° N |
| 25 | 82 cm | 11 cm | 38 cm | 283° E/W | 87° N |
| 26 | 117 cm | 8 cm | 14 cm | 277° W/E | 83° N |
| 27 | 9 cm | 2 cm | 2 cm | 273° E/W | 88° N |
| 28 | 110 cm | 26 cm | 18 cm | 261° E/W | 80° N |
| 29 | 43 cm | 12 cm | 36 cm | 310° NW/ S/E | 88° S/W |
| 30 | 37 cm | 50 cm | 48 cm | 267° W/E | 60° N |
| 31 | 56 cm | 18 cm | 6.8 cm | 293° W/E | 56° N |
| 32 | 60 cm | 22 cm | 4.5 cm | 180° W/E | 88° N |
| 33 | 15 m | 24 cm | 30 cm | 259° W/E | 76° N |
| 34 | 8 cm | 4 cm | 50 cm | 277° W/E | 71° N |

**Table 2** Fracture measurements of the out crop on the west side of the road cut.

| **Western Face** | | | | | |
|---|---|---|---|---|---|
| Fracture # | Height (cm) | Width (cm) | Depth (cm) | Strike | Dip |
| 1 | 53 cm | 4 cm | 140 cm | 80° E/W | 88° N |
| 2 | 100 cm | 30 cm | 8 cm | 229° W/E | 84° N |
| 3 | 94 cm | 4 cm | 1 cm | 70° E/W | 71° N |
| 4 | 14 cm | 1 cm | 100 cm | 287° W/E | 83° N |
| 5 | 77 cm | 26 cm | 13 cm | 90° E/W | 89° N |
| 6 | 64 cm | 5 cm | 80 cm | 277° W/E | 81° N |
| 7 | 300 cm | 46 cm | 6 cm | 290° W/E | 86° N |
| 8 | 16 cm | 7 cm | 50 cm | 281° W/E | 83° N |
| 9 | 20 cm | 10 cm | 27 cm | 222° W/E | 87° N |
| 10 | 100 cm | 7 cm | 23 cm | 299° W/E | 72° N |
| 11 | 42 cm | 21 cm | 4 cm | 287° W/E | 60° N |
| 12 | 37 cm | .5 cm | 9 cm | 234° W/E | 73° N |
| 13 | 27 cm | 14 cm | 11 cm | 240° W/E | 79° N |
| 14 | 100 cm | 56 cm | 76 cm | 105° E/W | 53° N |
| 15 | 32 cm | .9 cm | 32 cm | 65° E/W | 54° S |
| 16 | 30 cm | 1.9 cm | 6.5 cm | 58° E/W | 77° S |
| 17 | 32 cm | 13 cm | 72 cm | 80° E/W | 82° N |
| 18 | 21 cm | 36 cm | 91 cm | 75° E/W | 79° N |
| 19 | 57 cm | 25 cm | 76 cm | 20° E/W | 68° N |
| 20 | 55 cm | 19 cm | 41 cm | 110° E/W | 75° N |
| 21 | 40 cm | 7 cm | 25 cm | 95° E/W | 82° N |
| 22 | 12 cm | .2 cm | 1 cm | 103° E/W | 82° N |
| 23 | 42 cm | 15 cm | 21 cm | 84° E/W | 85° N |
| 24 | 32 cm | 2 cm | 6 cm | 117° E/W | 87° N |
| 25 | 120 cm | 17 cm | 44 cm | 100° E/W | 65° S |
| 26 | 63 cm | 5 cm | 8 cm | 100° E/W | 78° N |
| 27 | 110 cm | 12 cm | 100 cm | 73° E/W | 71° N |
| 28 | 250 cm | 35 cm | 100 cm | 115° E/W | 77° N |

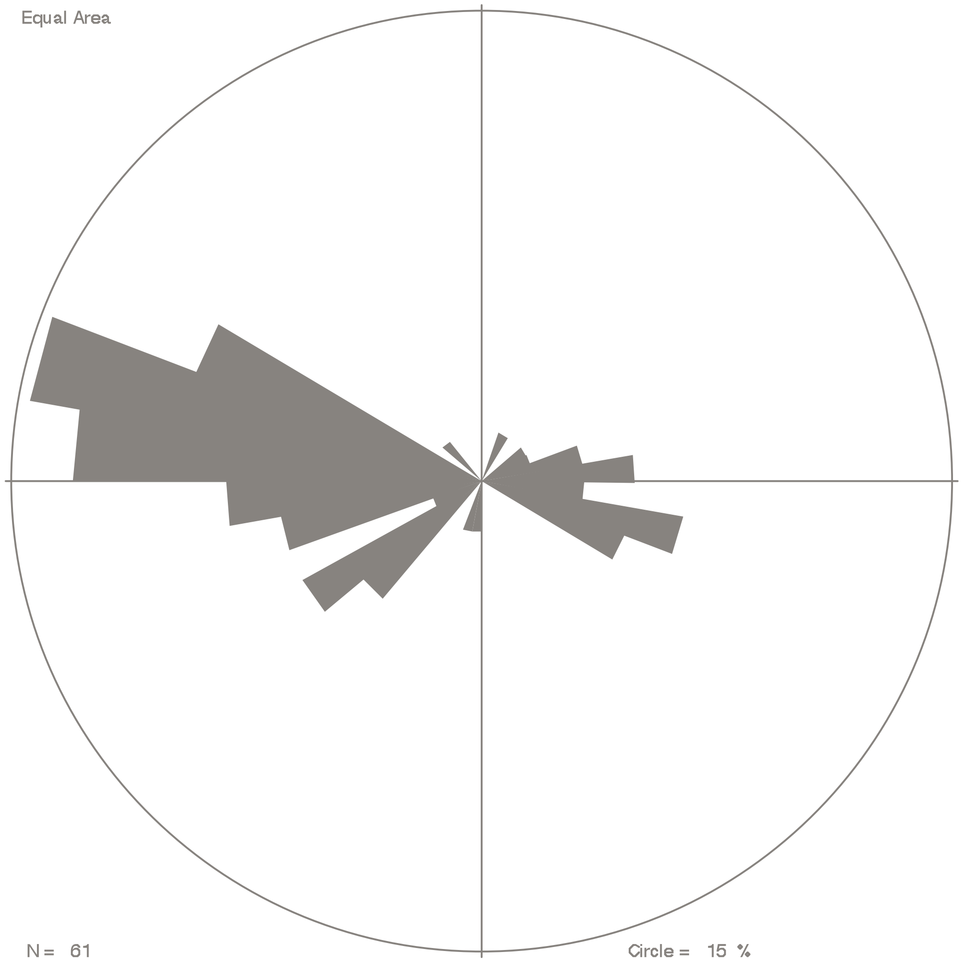

**Figure 1** Rose diagram showing the range of orientation of fractures.

## Discussion

Based on the Sinkhole Probability study conducted by E. Calvin Alexander et al. and our own observations, we believe that a sinkhole sits on the land above our research site and a seep likely resides within the very rock that we measured. We were never able to ascertain the exact location of the sinkhole due to time constraints and the fact that the land is private property, but the map produced by Alexander's study asserts that the sinkhole is a high probability. There were also several other sinkholes residing in plain sight not far from our rock face.

The study also predicts the placement of seeps deep within the rock of our research site. According to Alexander, "many springs and seeps occur where the Decorah Shale, Platteville Limestone, and Glenwood Shale intersect the land surface" (Alexander et al. 2003). Similar seeps and springs serve as the sources of the Little Cannon River, Belle Creek, and the North and Middle Forks of the Zumbro River (Alexander et al.).

Seeps are made possible because of the bedrock's permeability. According to Anthony Runkel, "permeability pertains to the relative ease with which a rock can transmit a liquid through these open spaces" (Runkel 1998). This stands in contrast to porosity, which "is simply the open spaces in a rock, such as cracks, voids, and tiny pore spaces" (Runkel). Based on Anthony Runkel's mapping of the bedrock lithology of Goodhue County, our site is very permeable. Permeability depends on the size, frequency, and complexity of the system of fractures and solution features, created by karst processes over time. Our site, which is mainly carbonate rock, has many fractures and joints. These karst features are well developed and occur frequently, a fact which suggests moderate to high conductivity (the rate at which water can move through the rock): anywhere from 1 to 40 feet per day.

Thus, the Platteville Limestone is highly permeable. Runkel even provides an expansive stratigraphic column image which shows the rock's hydrostratigraphic character. Here, the Platteville is fractured increasing its permeability. Its high permeability allows it the status of aquifer. The Platteville makes a good aquifer because, in addition to its karst-driven permeability, the limestone is bounded on low permeable confining units. The Decorah Shale sits above the Platteville, and the Glenwood Shale lies below the Platteville. Both components are clastically fine, with strong to moderate cementation and thus low permeability. Whereas the layer of Platteville, a carbonate with strong cementation but many fractures for water to get caught in, stands in between them. Water that manages to pervade the Decorah shale leaks through the Platteville but is then unable to penetrate the Glenwood below, thus filling up the Platteville's fractures, eventually creating a seep which reaches all the way up through the remaining bedrock to recharge the groundwater source.

Yet the rock is permeable, not porous, so the water flows into all the cracks and faults, and fills them up. All of the water in limestone is stored in these fractures, which are essentially random caches. Because of this, it is hard to find and predict where the water will be, decreasing limestone's feasibility as a desirable aquifer. Thus, most wells are drilled through the limestone into the sandstone below. According to mapping conducted by Emily J. Bauer (1998), there is a well near our research site, but the well driller's log has proven to be inaccessible to us at the time of this report.

There are also wells drilled into limestone aquifers. Runkel states in summary that "the coarse clastic (quartzose) [sandstone] and karstic carbonate rock components [limestone] likely contribute most of the yield to water wells developed in Paleozoic strata [e.g. our section of Goodhue county]." However, basing our assumptions off of a map of Rice county wells, which shows that most wells plunge deeper into the more promising sandstone aquifers than limestone, we shall assume that this well, unless it struck a limestone groundwater cache by chance, goes all the way into the St. Peter.

Thus, the well must go through the Platteville to reach the St. Peter's aquifer. While the well driller's log cannot be recovered at this point, it is clear from the map that the well does not draw from quaternary sediment deposits, but goes into the bedrock. The drilling path might intersect a fracture, thus increasing the well's water drawing rate. Yet, what seems more likely is the effect that the limestone's porosity will have on the sandstone aquifer. Runkel notes that "the density and connection of fracture vary laterally and vertically and can markedly affect the hydrologic behavior of each of the components. Fractures and connections among them are most abundant where bedrock is at or within 100 feet of the surface" (Runkel 1998). The two exposed Platteville faces that we studied were exceedingly close to the surface which suggests excellent water-baring potential. But Runkel predicts that the majority of Platteville in Goodhue County is a mere 10-15 feet thick, and lies under a blanket of early Ordovician rock and quaternary sediment that can stand up to hundreds of feet thick. So, clearly, the limestone is often covered by younger rock, rock that, for the most part, has low permeability and would hamper the water from running down to the Platteville, which in turn would keep the water from entering the sandstone aquifer.

## Conclusion

The vast amount of both joints and fractures, considering total displacement, length of features, and frequency, we conclude that this section of Platteville is extremely permeable. The rock's proximity to the surface enforces our belief, and the lack of younger bedrock serves to ensure that water reaches the fractures efficiently and copiously.

Ascertaining an overall direction of the fractures within the rock could potentially help determine the positioning of future wells if intersection with water-baring faults is desired, or if the well aims to draw directly from a carbonate aquifer.

More so, knowing the strikes of the joints and fractures can help us predict the location of other karst features, such as sinkholes and seeps. The majority of our fractures lie along an E/W trend. By using our research site as an origination point and plotting a line in an east-westerly direction consistent with our strikes, and following that line out, we could determine the location of other, hidden karst features, as well as the possible locations of sinkholes yet to be formed.

This ability is important, because sinkholes often mean trouble for the public community. Sinkholes are environmentally hazardous because they provide a direct route between the surface and the underlying aquifer. This allows water to bypass layers of rock that would have normally filtered the water. Agricultural chemicals and fertilizers, such as those that were most likely sprayed on the farm field above our outcrop, can easily dissolve in water and move through the fractures of the underlying

Platteville. If these chemicals were to flow to a sinkhole that connected to the Goodhue aquifer, the entire region's water supply would be contaminated.

Sinkholes can also cause physical destruction. Soil loss is the most common problem faced, which leads to lost real-estate and crops. Sinkholes have also swallowed up farm equipment and even, in some instances, buildings. By knowing the orientation of this karst topography, we take protective measures to avoid such hazards.

It should be noted that some difficulties arose when measuring the most expansive faults and joints due to their height and unsafe weather conditions. However, based on photographs taken, it appears that the massive joints followed the trend and dipped nearly vertical. It was also difficult to determine how tall a joint was due to high levels of scree that extended between 20 to 200 centimeters at the base of the outcrop. Similarly, due to the biomass at the top of the outcrop, it was impossible to determine how deep the joints and fractures extended. Another difficulty arose in ascertaining whether the fracture had been caused naturally or by the road blasting that created the road cut. Nonetheless, these factors would not affect orientation, which is where we draw the bulk of our conclusion.

## Acknowledgements

Our group would like to acknowledge the help of Bereket Haileab and our TA's, who helped us transform the idea of this project into a reality.

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# An Analysis of Fractures and Their Implications in the Prairie du Chien Group, Goodhue County, MN

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Introduction to Geology
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## Abstract

Outcrops of the Prairie du Chien located on HW 19 near Cannon Falls, MN were studied, paying particular attention to the geometry and density of through-going fractures. Two groups of fractures were discovered, those lying in the NE direction and those in the NW direction. The two groups are separated by an average of 84.6°. The fractures increase the permeability of the Prairie du Chien.

**Keywords:** fracture, Prairie du Chien, percolation, permeability

## Introduction

We compiled joint and fracture measurements for outcrops of the Prairie du Chien group in southeastern Minnesota. Joints are fractures in the rock that are continuous through multiple stratigraphic layers.  Surface water percolates through these fractures and recharges underground aquifers. One such aquifer in southeastern Minnesota is the Prarie du Chien-Jordan aquifer. This aquifer provides water for Rice and Goodhue counties. Unfortunately, the presence of various contaminants in the water percolating through the Prairie du Chien group (fertilizers, pesticides, etc.) threatens the purity of the regions ground water. Studying the fracture patterns in this rock formation can help us to understand the effects of pollutants on groundwater.

Our group traveled to two rock outcrops of Prairie du Chien rocks located about 10 miles east of the town of Cannon Falls, see Figure 1.  The outcrops were road cuts on either side of Highway 19.  Both outcrops exhibited significant fracturing and we took measurements from each of them.  The 40 fractures that we measured are all examples of through-going fractures, which means they cut through multiple beddings.

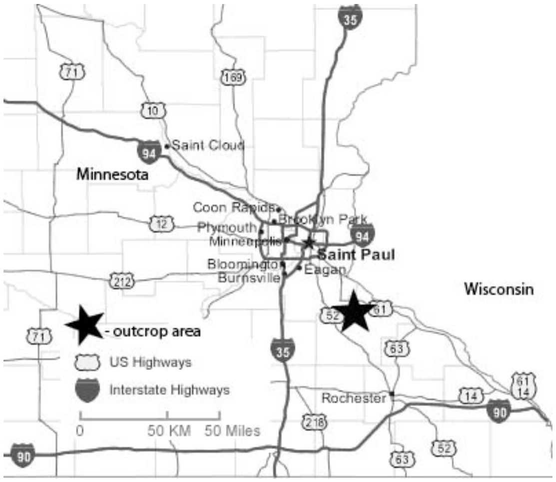

Figure 1. Map of Minnesota with outcrop labeled.

## Methods

We conducted fracture analysis at two road cuts on Highway 19 in Goodhue County, MN. Outcrop A is located at 44° 30’ 16.25” N 92° 44’ 09.97” W at an elevation of 299.3 meters. Outcrop B is located at 44° 30’ 15.40” N and 92° 45’ 20.57” W at an elevation of 292.6 meters. Outcrop A is approximately 1.6 km east of outcrop B, see figure 4. Using a Brenton compass, we took strike measurements of each fracture. We measured the aperture, or the width of the opening, with calipers. We measured the distance between fractures at outcrop A with a meter stick.

We collected data from four different rock faces, two facing south and two facing north. Once all of our data was collected, we had four groups of similar data. To simplify our analysis, we wanted to compare two groups. Because the four groups are oriented NW, SW, SE and NE, we added 180 degrees to our measurements of the SE and SW oriented measurements to normalize all of our data into NE and NW. Our data is displayed using rose diagrams in Figure 5, representing the quantity of fractures at given orientations. All rose diagrams were created with the program Fabric8.

Next, we performed simple calculations to generalize our findings. We found the arithmetic means of the apertures and the orientations of the fractures. We also calculated the average spacing between the fractures in outcrop A.

## Observations and Results

Exposed vertical surfaces of the Prairie du Chien are littered with vertical fractures that extend through several beddings. We observed two separate outcrops, labeled Outcrop A and Outcrop B. These fractures lie on two near-normal planes—those that lie NE, at a mean strike of 53°, and those that lie NW, at a mean strike of 335°. Fracture aperture is also consistent throughout the outcrops, with a mean of 29 mm. In outcrop A, we were able to measure the distance between each fracture. The average distance between each fracture is 2.7 meters. The strikes of these two planes found at both outcrops indicate that there is a criss-crossing network of fractures throughout the Prairie du Chien. The intersecting planes are nearly perpendicular, and the mean angle between the two is 84.6°.

Figure 2. Summary of fracture orientation and aperture.

| | Mean Orientation (degrees) | Mean Aperture (mm) |
|---|---|---|
| Total | -- | -- |
| NE | 53 | 32 |
| NW | 335 | 26 |
| Outcrop A | -- | -- |
| NE | 53 | 31 |
| NW | 332 | 23 |
| Outcrop B | -- | -- |
| NE | 52 | 36 |
| NW | 338 | 29 |

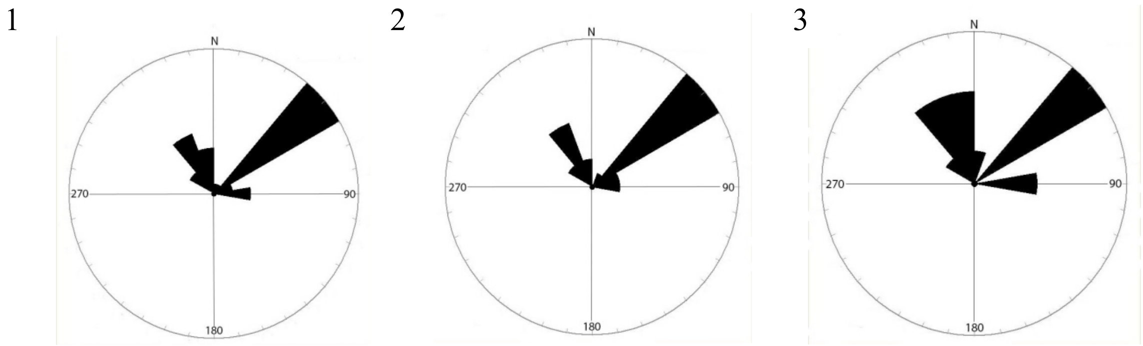

Figure 5. Rose diagrams show the concentration of fractures in specific orientations. 1 represents the total fractures. 2 represents outcrop A only and 3 represents outcrop B only.

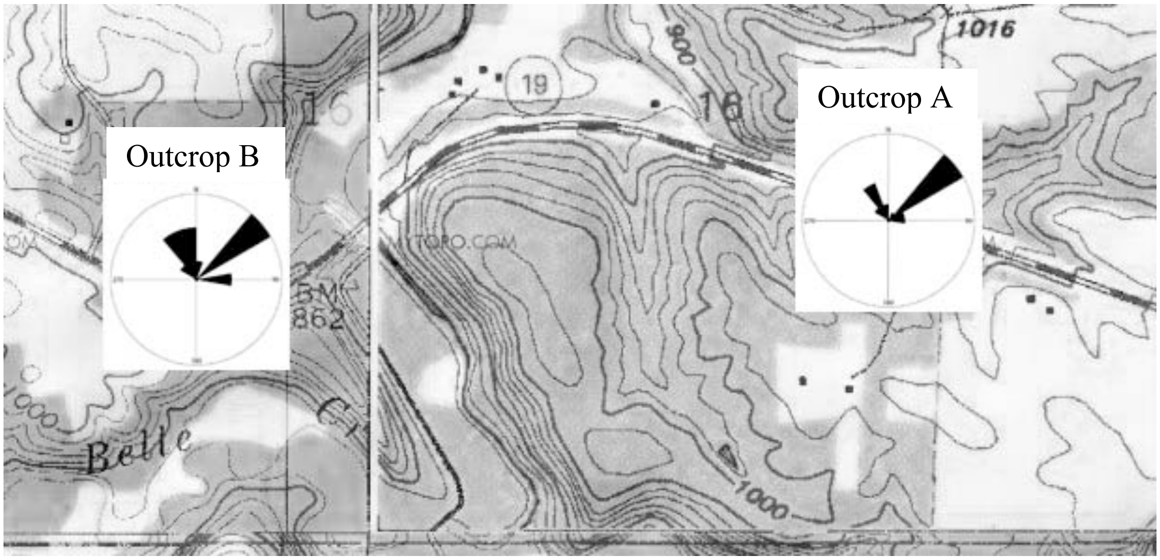

Figure 6. A topographic map overlaid with location-specific rose diagrams of strike measurements taken at outcrops A and B. Highway 19 is visible connecting the two outcrops. http://www.digital-topo-maps.com/.

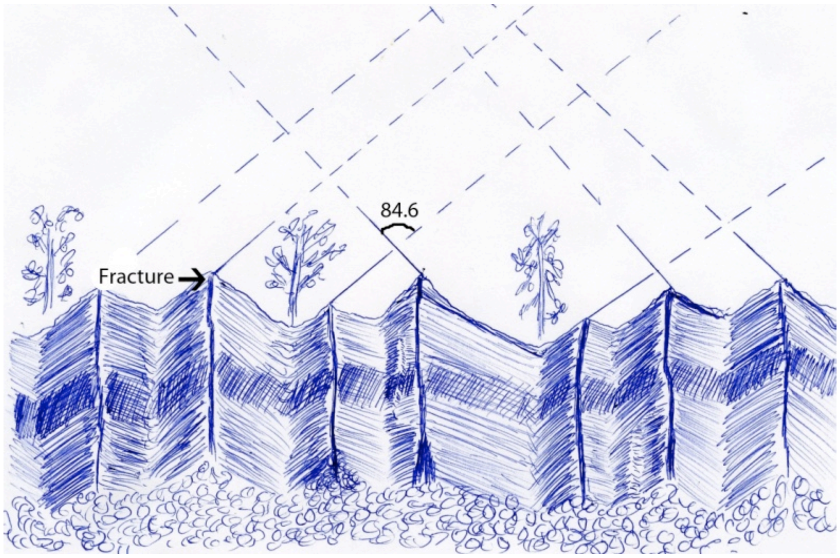

Figure 7. An illustration of the orthogonal fractional planes. Childs-Walker, 2010.

## Discussion

The Prairie du Chien group was formed during the early Ordovician period (480 Ma) by slowly transgressing oceans which deposited layers of sediments on top of the preexisting Jordan sandstone, forming the Shakopee formation and Oneota Dolomite that compose the Prairie du Chien. See Appendix A for a visual of the stratigraphic situation. The Prairie du Chien is primarily composed of dolomite—the result of carbonate deposition from undersea organisms—although some layers of shale and quartz can be found as well. (Blue, 2008). Locked into this formation is a major source of ground water for Rice county—the St. Peter-Prairie du Chien Jordan aquifer. The fractures in the Prairie du Chien group were formed by non-tectonic forces, such as expansion due glacial rebound and weathering. Surface water percolates into the aquifer via these fractures.

The St. Peter-Prairie du Chien formations underlie most of western Rice County. These rock groups hold a large supply of all the water used by Rice County residents and agriculturists. The St. Peter-Prairie du Chien-Jordan aquifer is located between the

Maquoketa confining unit and the St. Lawrence-Franconia confining unit. (Olcott, 1992). In the western half of Rice County the topmost confining layer is missing, recharge of the aquifer is comparatively more rapid.

The origin of these fractures was a fundamental goal of our inquiry. The presence of faulting in northwestern Minnesota that strikes parallel to our fractures initially led us to believe that fractures in the Prairie du Chien were formed by tectonic forces (Morey 2000). However, examination of the geologic time scale revealed that the formation of the Prairie du Chien occurred after the cessation of tectonic activity in Minnesota. The Prairie du Chien group was formed during the early Ordovician period about 480 Ma. The fractures in the unit were most likely formed during the Pleistocene era (between 2.5 million and 12,000 years ago) by the ongoing process of glacial rebound. The recession of glaciers at the end of the most recent ice age caused a decrease in stress on the rock formations in Minnesota (Smith, 1997). As the Prairie du Chien group returned to its pre-glacial state, vertical fracturing occurred. Recent uplift and decompression of the brittle dolostone caused fractures and joints to form in areas of weakness. Chemical weathering as a result of acidity in natural rainfall has widened the existing fractures in the carbonate rock (Smith, 1997). The relatively precise geometry of the fractures in the formation is a point of interest. As seen in Figure 7, the fracture planes have formed nearly perpendicularly to one another. While we cannot definitively determine why this should be so, we hypothesize that the structure of the dolostone causes it to be weaker along the perpendicular fracture planes we measured. This is an area in which we hope to conduct further research.

The Oneota Dolostone, which is the primary component of the Prairie du Chien, has a relatively low porosity (Wendte, 2004). However, the presence of fractures makes the rock formation highly permeable and allows surface water to percolate down into the underlying Jordan Aquifer. This has serious implications for public health in Minnesota. According to a study conducted by the University of Minnesota, at least 57 chemicals, many of which are known carcinogens, are used as fertilizers and pesticides in our region (Agriculture). The fractures in the Prairie du Chien allow contaminated ground water to enter the aquifer and could affect drinking water quality.

## Conclusions

The fractures in outcrops of the Prairie du Chien group are conjugate fractures that strike to the Northeast and Northwest. While we are unable to determine the precise cause of the fracturing, we are able to hypothesize that it was caused by glacial rebound. The fractures increase the permeability of the Prairie du Chien group, a fact that could have a negative impact on the purity of the ground water in southern Minnesota.

## Future Work

One serious issue with this work is the limited scope of our research. Data was collected from two outcrops less than 2 km away from each other, and we dealt with a total of only 40 samples. Future work could be more extensive research, covering a greater area and an overall increase in samples.

## Acknowledgements

We would like to thank Bereket Haileab for his unwavering optimism and support of our project. We would also like to thank all of the T.A.s, Nate Evenson in particular for his dependable assistance gathering, interpreting and displaying our data.

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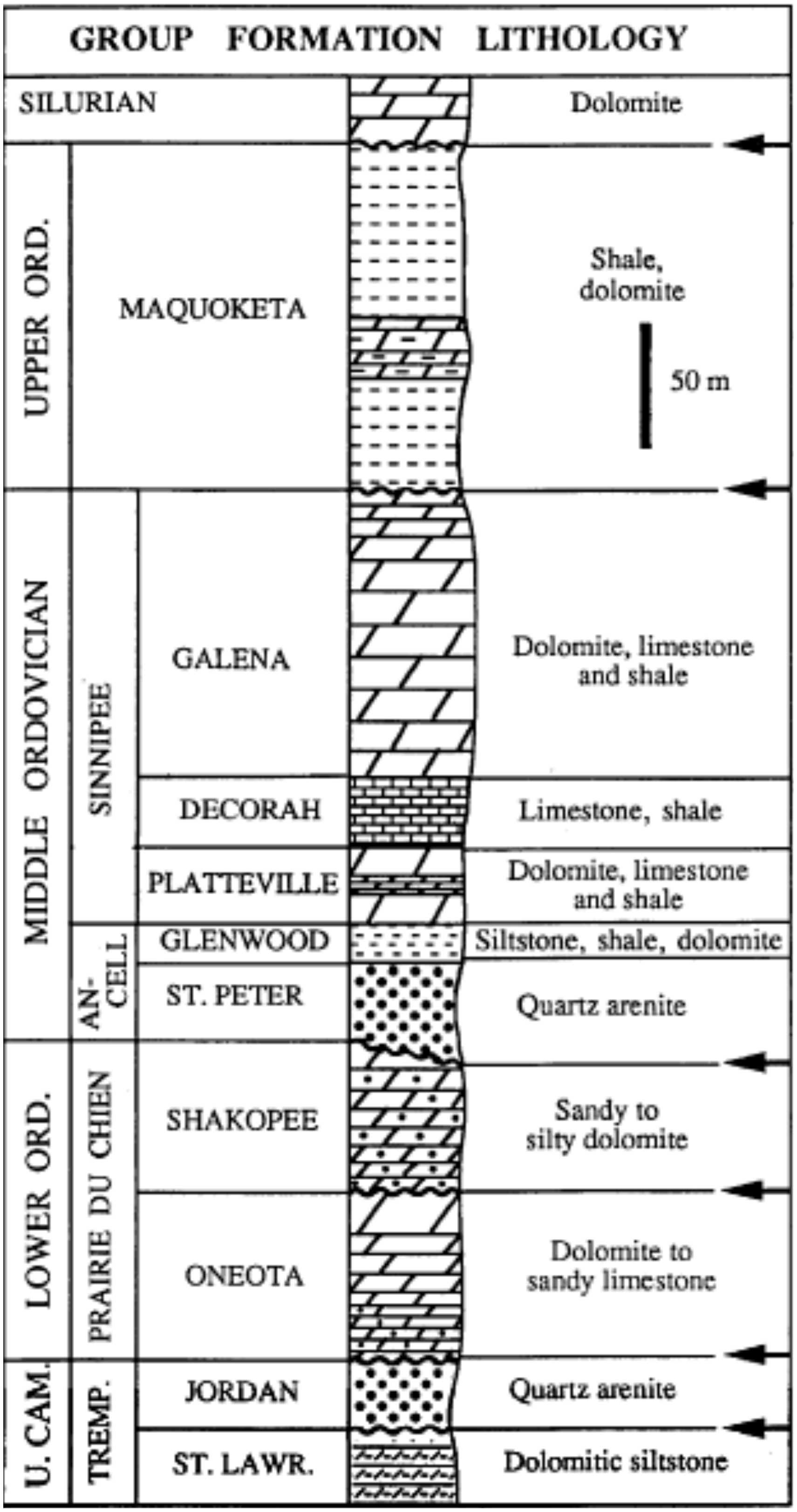
## Appendices

Appendix A. The Prairie du Chien Group is found in the bottom half of this stratigraphic map (Smith, et al).

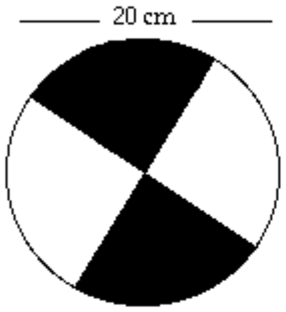


Appendix B. An image of outcrop A. These fractures lie in the NE direction.

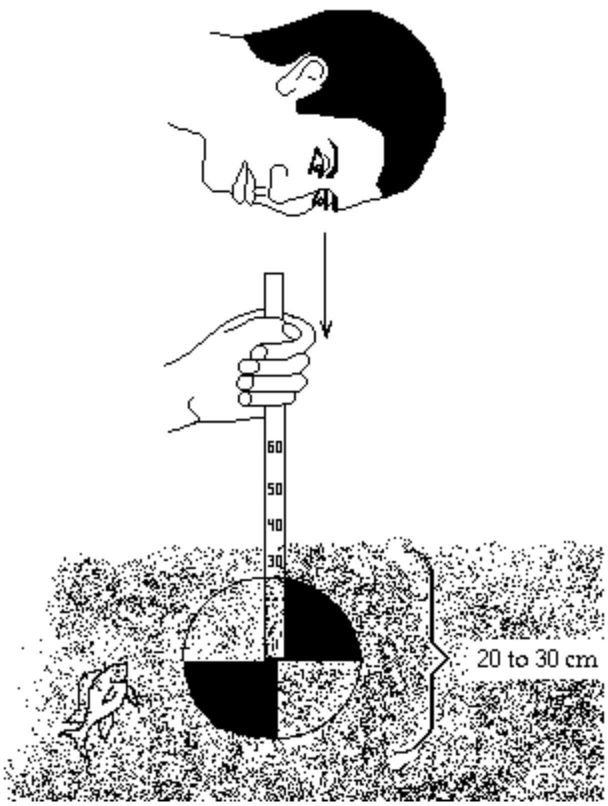
Appendix C. An image of outcrop A. These fractures lie in the NW direction.

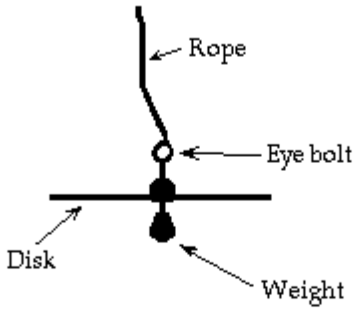
# Turbidity in Rice County

Jasmine Cutter
Madeline Muzzi
Noah Sapse



**Top view of a Secchi disk**





**Side view**

Professor
Bereket Haileab
Spring 2010

## Abstract

The purpose of this research was to determine the correlation between land use and the level of turbidity of the surrounding bodies of water in Rice Lake county Minnesota. Turbidity is an indicator of water quality and can affect plant and animal life alike. To test the waters we collected 40 samples from Rice Lake county waters, classified the surrounding land, and recorded the turbidity level. Problems arose when classifying the land type because many bodies of water interacted with several different types of environment. Our data was not as definite as we would have liked. We found no direct correlation between land use and turbidity level.

## Introduction

### The Hydrology of Rice County

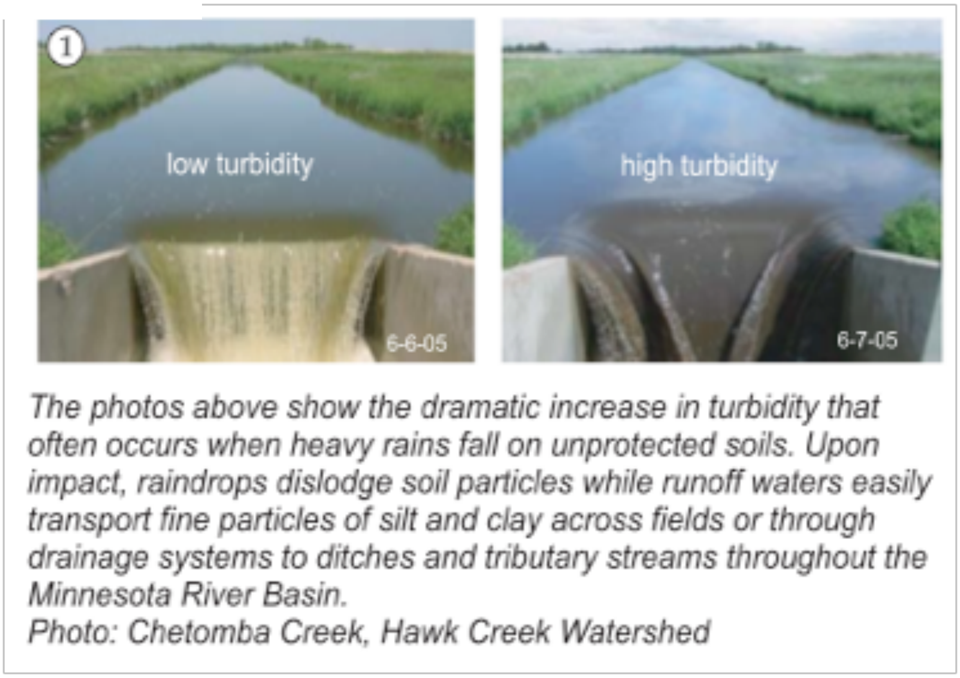
Rice County is rich in open water resources; it contains a multitude of lakes, streams, rivers and wetlands. These waterways were carved by the Wisconsin glaciation and their meltwaters filled many of the lakes. Rice County has 65 lakes, many streams and wetlands and two major rivers -- the North fork of the Zumbro River is in the southeast and the Cannon River, which flows southwest to northeast throughout the whole county and empties into the Mississippi River near Redwing.

**What is Turbidity?**

Turbidity is the opaqueness of a liquid. It can range from high (very cloudy) to low (very clear). Turbidity can result from suspended silt, sand, or mud; bacteria, algae, humic acids (from plant decay) or chemical precipitates. High turbidity can be problematic because sediment in water "causes habitat degradation for fish and other aquatic life, channel stream filling, [and] nutrient deposition." Cloudiness impairs the abilities of fish to feed, navigate and mate. "The U.S. Environmental Protection Agency (1998) identifies sediment as the single most widespread cause of impairment of the nation's rivers and streams, lakes, reservoirs, ponds, and estuari

The sediment laden Minnesota River (left) flows into the Mississippi River (right).

Figure 1: Documentation of Turbid MN Rivers (from Minnesota River Basin TMDL Project for



*The photos above show the dramatic increase in turbidity that often occurs when heavy rains fall on unprotected soils. Upon impact, raindrops dislodge soil particles while runoff waters easily transport fine particles of silt and clay across fields or through drainage systems to ditches and tributary streams throughout the Minnesota River Basin.*
*Photo: Chetomba Creek, Hawk Creek Watershed*

Figure 2: Documentation of Turbid MN Rivers (from Minnesota River Basin TMDL Project for Turbidity)

es. (Source: Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data USGS, 2000) In 2010, 18% of US waterways were labeled impaired due to high turbidity. Suspended sediments and other turbidity factors can be caused by point pollutants (industrial effluents), or diffuses (runoff from urban areas or crops). Sediments can runoff fields or enter through tiles, or be blown off fields, furthermore, inefficient drainages systems can contribute to bank erosion. Dissolved salts and nutrients such as phosphorus and nitrogen can come from natural sources, or result from land management practices or discharges from wastewater treatment plants. High levels of some nutrients can lead to eutrophication and hypoxia. Thus, turbidity can often be an indicator of water quality.

## Land Use and Water

The state of the surrounding lands affects both the turbidity and the quality of the waterbodies. All water that falls to the earth eventually makes its way to a larger body of water, carrying with it nutrients from the soil, as well as human and organic contaminants. Thus, the land use has an important impact on watersheds.

Land that is used for vegetable farming could actually reduce the turbidity of nearby water bodies. Turbid waters are more likely to be found near areas with exposed soil than near heavily vegetated areas because plant roots help to anchor sediment in place. Conversely, animal farms and feedlots are likely to have exposed soil and muddy areas, and would therefore be more like to elevate the turbidity levels of surrounding waters. Both types of farm are likely to reduce nearby water quality because runoff from farms is more likely to contain pesticides or bacteria from fertilizer and or animal waste.

Bodies of water near roads are likely to have increased levels of turbidity. Especially during construction, areas near roads have less vegetation and more exposed soil than farmed lands. This is likely to lead to higher turbidity. In addition, runoff water from roads often contains road salt or gasoline, both of which can contaminate water. Because salt, gasoline, and other volatile organic compounds contain carcinogens their presence in water should be avoided.

## Causes of Turbidity

Turbidity can be caused by a myriad of factors. Human factors include waste discharge from developed areas or feedlots.  Also, runoff from watersheds with poorly managed soils leads to erosion. Many waterbodies experience a seasonal algal bloom; however, these are often intensified by the introduction of excess nitrogen in runoff from agricultural lands or phosphorus from feedlots. In iron rich areas the oxidization of iron can cause a reddish tint in water and increases turbidity because small particles of hematite become suspended. In some rivers where both iron and sulphur are present, bacteria will sometimes synthesize pyrite which can marginally increase turbidity as well. A major source of non-particle caused turbidity in many rivers is the presence of air bubbles due to turbulent current (EPA Guidance Manual:Turbidity Provisions, 1999).

## Significance of Turbidity in Terms of Human Health

Turbidity is an indicator of poor water quality; often this poor quality manifests itself in the form of presence of organisms. Turbidity can be caused by the pathogens themselves; additionally, turbidity particles can also act as homes for bacteria. Filtration of water has been shown to greatly reduce the quantity of pathogens (Fox, 1995). The removal of turbidity has a high correlation to removal of parasites as shown by Lechavalier and Norton in 1991.

High turbidity will also fill tanks and pipes with mud and silt, and can damage valves and taps. Where chlorination of water is practiced, even quite low turbidity will prevent chlorine from killing the germs in the water efficiently (fact sheet 2.33).

### Fecal Coliform (*E. Coli*) Bacteria

High turbidity levels, attributed to soil runoff, are "often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria.

These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated

headaches" (EPA website)

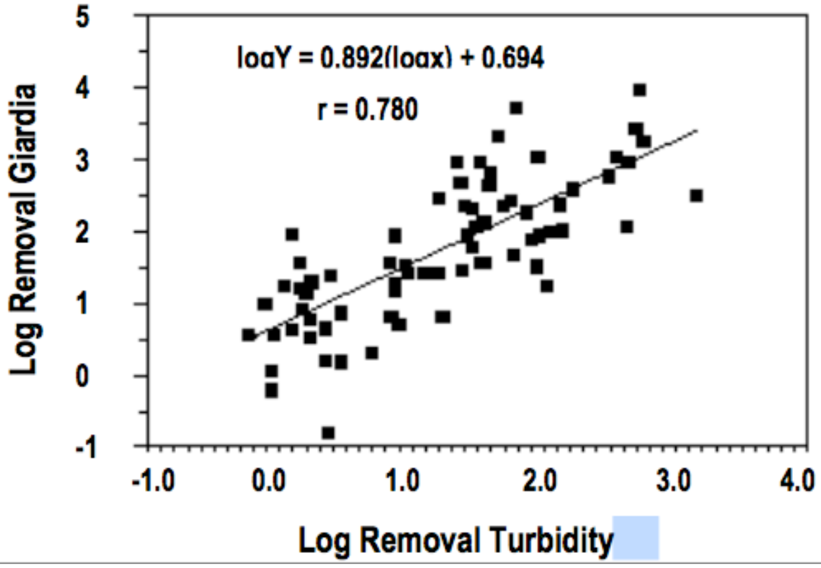


*Figure 3 Removal of Giardia As Compared To Removal of Turbidity*

**Importance of Phosphorus**

Elevated phosphorus levels lead to an overabundance of algal growth which can result increased turbidity and a decrease in light penetration. The algae blocks light, and then, when the plants die en mass, their decomposition requires large amounts of dissolved oxygen -- thus depleting the resources for other aquatic life. Really high levels of algal growth (algal blooms) can release toxins into the water; “instances of this have occured within the Minnesota River

Basin and resulted in the death of animals (including pets) that ingested these toxins" (2000-2005 Minnesota River brochure). Thus, since elevated phosphorus levels have been proven to be a problem in other, nearby areas, there is a possibility that elevated phosphorus levels could be affecting the turbidity in Rice County.

### Importance of Nitrogen

Nitrogen can have an effect on turbidity that is similar to phosphorus; it also stimulates plant growth. Excess nitrogen (or nitrate) levels are associated with hypoxic zones in the Gulf of Mexico. Many major rivers, such as the Minnesota and the Mississippi carry excess nitrate to the Gulf of Mexico, which not only leads to hypoxia (low oxygen) environment, but can also lead to methemoglobinemia (blue-baby syndrome).

## Purpose

As stated, the introduction of foreign detritus into water bodies via wind and water can affect not only the clarity of the water but also its chemistry. For example, salts and other inorganic molecules can be introduced to water bodies near roads when rainwater washes thawing compounds off paved surfaces and carries them into waterways. Proximity to agricultural lands is another way that chemicals can be introduced to open water. Highly fertilized fields can leach nitrogen and other compounds into streams, lakes and ponds. Thus, we wanted to discover if there is an easily visible correlation between turbidity and the location of the water sample. Does proximity to roads lead to a higher turbidity than proximity to agricultural lands? Can we discover anything about the composition of the suspended solids? Is the turbidity most likely caused by biological factors (bacteria, algae), chemical (nitrogen, salt) or geological (silt, mud)?

We were wondering if road salts would correlate with turbidity in a negative or positive manner: While the possible increase in road salts would certainly be an increase in dissolved solids it also could impair biological activity, a large proponent of the sediments that add to turbidity. Increased conductivity could also affect biological activity in a way that would increase turbidity. Likewise, the runoff from agricultural drainage, rich in nitrogenous fertilizers, would likely lead to eutrophication and elevated turbidity after algal blooms. How would these two factors affect the possible geologic composition of the suspended particles? Roads, which are non-porous would lead to an increase in runoff amount and speed, but would this disturbance of the soil around the waterbody, lead to greater (geological) turbidity than farmland? Farmland may trap runoff depending on the quality of soil management, but at could also produce greater turbidity because there is more loose soil in fields. We are hoping that a study of the conductivity, and the turbidity, and an analysis of centrifuged solids in bodies of water in Rice County will show a correlation between the type of dissolved solids and the location of the water sample.

## Methods and Materials

### Location

Many of our samples were taken from areas very near to Northfield. We tried to get a variety of different types of open water sources (rivers, streams, lakes, ponds, tiles, drainage creeks) that abutted a variety of different land-use areas (agricultural fields, roads, residential, rural).

### Procedure

In order to ensure consistent results we used the same procedure at each location that we tested. Upon arriving at each site, we observed the surroundings and recorded them in our field book. We were careful to note if there were any farmlands, feedlots, or manmade features such as roads or buildings. We also recorded the GPS location of our test sites. After noting the surroundings we took water samples. Each sample was marked with the coordinates of its site.

To test the water clarity of each site we used a turbidity tube. Turbidity can most effectively be measured by photoelectric detectors or nephelometers, but clarity can also be measured using a secchi turbidity tube. The secchi tube is a clear cylinder with a black and white disk at the bottom and a valve for releasing water. Water is poured into the tube, and the liquid is observed; if the black and white disk is not visible, then water is released through the valve until the observer sees the disk. Then, the depth at which the disk is visible is recorded based on the cm ruler on the side of the tube. In order to get our samples, we waded into the water and filled the tube, being careful not to collect any of the sediment stirred up by our footsteps. Once the tube was filled, it was brought back to shore. After this, one group member would look into the top of the tube and state what she saw, while another member let out water from the bottom of the tube. This would continue until the student looking into the tube reported that they could see the disk at the bottom. The measurement was then read off the side of the tube and recorded in the field book. This process was repeated two times and the average of the three measurements was recorded as the final result. For a visual explanation refer to the diagrams provided below:

## Results

### Observations

Our group sampled from 11 different locations within Rice County. Four of the turbidity samples came from sources bordered by agricultural land. Three came from areas that were approximately equidistant from farmlands and roads (usually tile drainage areas or ditches). Five samples were from bodies of water that were very close to roads. One sample was from the Cannon River away from any immediate roads or agriculture fields. One of the Lyman Lakes samples was taken from the area near Evans and thus is more of a residential sample than agricultural or paved, though it definitely represents a developed area. In addition to these eleven samples, we got seven more samples from our TAs and 23 samples from two groups that tested water quality in fall 2004.

Table 1: Data sorted by type and turbidity

| **sample_ID** | **Land_Use** | **Turbidity** |
|---|---|---|
| Phelps** | Rural | 9 |
| Duban** | Rural | 10.5 |
| Sanborn** | Rural | 12 |
| McMahon** | Agricultural | 25.5 |

| | | |
|---|---|---|
| Rice | Rural | 29 |
| St. Catherine** | Agricultural | 36 |
| Bass Lake | Ag | 42 |
| Fish** | Rural | 43 |
| Dennison Rd | Ag | 57 |
| Kate’s Tile | Ag | 120 |
| Creek | Ag | 120 |
| Hunt* | Agricultural | 120 |
| Caron* | undeveloped | 49.2 |
| Shields * | undeveloped | 76.6 |
| Cedar 1* | undeveloped | 86.8 |
| | | |
| Ditch | Ag/Road | 91.8 |
| Creek | Ag/Road | 97.4 |
| Creek | Ag/Road | *120* |
| Rice | undeveloped | 125 |
| Cedar 2* | undeveloped | 125 |
| | | |
| Cynthia** | Road | 14 |
| Boatlaunch Bass Lake | Road | 50 |
| Retention Pond | Road | 70 |
| Spring Creek | Road | 82 |
| Lyman Lake | Residential | 83 |
| Cannon River | Road/Urban | 100 |
| Wolf Creek | Road | 120 |
| | | |
| Cannon River | Rural/town | 120 |
| French 2* | residential | 6.5 |
| Mazaska 2* | limited industrial | 42 |
| French 2a* | residential | 42.1 |
| U. Prior** | residential | 47 |
| French 1* | residential | 48.5 |
| Roberds 1* | residential | 68 |
| Spring** | residential | 72 |
| Roberds 2* | residential | 91 |
| Mazaska 1* | limited industrial | 112 |
| L. Prior** | residential | 120 |

* Data from “Water Quality in Western Rice County” Fall 2004
** Data from “A Study of Water Quality of Lakes in Rice and Scott Counties” Fall 2004

This chart shows that our data ranged from 42mm to 120+mm. The most turbid samples were from Bass Lake, which had a visibility of only 42mm and 50mm. The clearest samples were from the Cannon River (rural), Wolf Creek (road), Kate's Tile (ag) and another tile (ag). All of these had a reading outside the range of our secchi tube -- greater than 120mm.

The relationship between land-use type and turbidity can be more clearly seen in the following chart:

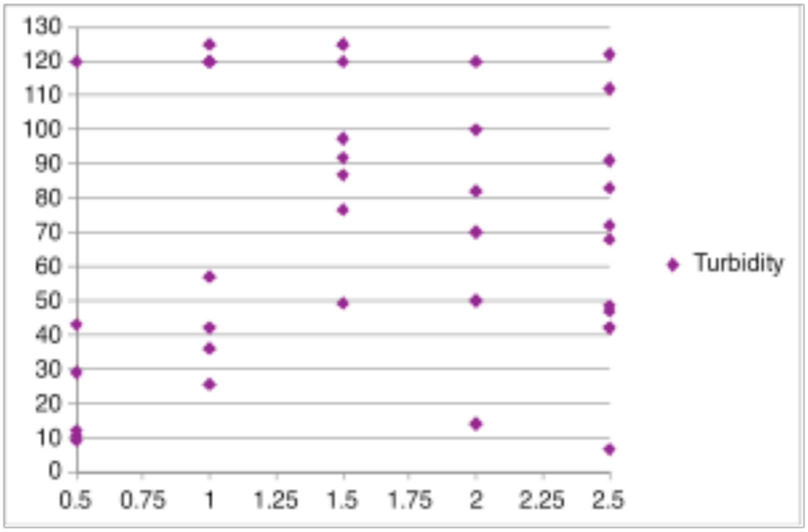


Figure 4: Turbidity According to Land Use

○ = Rural Cannon sample
1 = Ag land
1.5 = samples equidistant from Ag and roads
2 = Roads
2.5 = Residential sample (Lyman Lakes, by Evans).

This chart shows that there is not a strong correlation between land-use type and turbidity. If there was, we would expect to see there to be a distant difference in dispersal between the data points at 1 and the points at 2.  Instead, the data for each land-use type is spread out along its y-axis.

## Discussion

It's documented that increased concentrations of development, specifically an increase in paved surfaces, leads to higher levels of surface runoff. This surface runoff is almost always a source of turbidity as it picks up dirt, oils, trash, and other easily suspended particles and deposits them into nearby waterbodies. The prevalence of these particles is also often increased with pavement as the removal of stabilizing vegetation leads to increased erosion (EPA 2005). According to this principle it would follow that areas of higher development would have waterbodies of higher turbidity. Yet, our results are not entirely conclusive to prove this. Although our study would benefit greatly from increased samples, there also were numerous factors which could contribute to error in collection.  A lot of our data was collected by previous groups who did not describe the land use type of the areas from which they collected. Based on satellite images it would appear that many of them were tiles, areas that would be fairly clear having drained through ground. Most areas classified as either agricultural or developed were also to some extent both. Even the town of Northfield is surrounded by agriculture and feedlots and every waterbody tested off of a field was also nearby to a road. Even if they were perfectly isolated, however, our method of sampling would likely contain a degree of error simply due to the nature of Secchi tube sampling which relies on human sight, an imperfect metric of measurement. Were this experiment to be repeated we'd like to work with a nephelometer and with a much larger team to take more samples. We were unsure about why turbidity wasn't higher in agricultural areas. This time of year -- post-plowing and pre-planting -- we would expect large amounts of loose soil to be exposed, but that is to be explored in later experiments. Overall the data was scattered. No particular correlation jumped out as all types of sites showed varying turbidity levels.

## Conclusion

Our hypothesis was that areas that were more developed would be more turbid, our results were inconclusive. The samples were varied in result and there is definitely concerns about human error which affect the accuracy of our data. Our two most turbid samples came from the same lake at two different locations, one by a road and the other by an agricultural field. Without further testing of sediment it would be impossible to determine which of the two was the major source of suspended particles. However, the turbidity levels in many waterbodies was above what would be considered safe, and so, further testing would be highly recommendable. In conclusion, our results were inconclusive with regards to our initial hypothesis.

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