The Intrinsic Vulnerability of Groundwater to Contamination in the Midwest and the Associated Human Health Impacts

Tufts UNIVERSITY

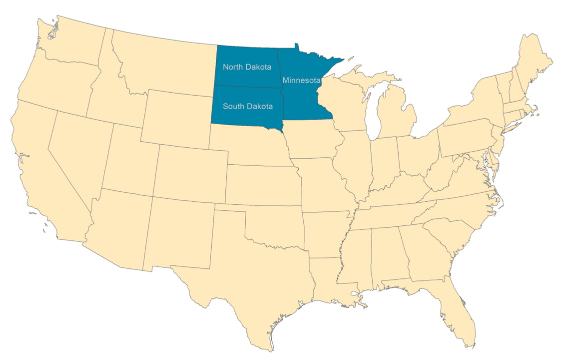
INTRODUCTION

Groundwater sources account for 20% of the United States' total water withdrawals.[1] But more importantly, groundwater is a source of drinking water for approximately half the population, and it provides billions of gallons of water per day for agricultural use.[2] While the rate of water borne diseases has decreased significantly due to advances in water management and sanitation [3], outbreaks continue to occur and the use of contaminated groundwater, often a result of human activities, is one of the top causes of water-related diseases in the United States.[4] Cryptosporidiosis is one of the leading causes of waterborne illness and outbreaks in the United States, with the Midwest experiencing the highest rates of outbreak.[5] As the United States continues to rely on groundwater as a viable source for drinking water and agriculture, it is necessary to evaluate the pollution potential of the groundwater, as well as the impact its use has on the health of the population.

A common way to evaluate the contamination susceptibility of groundwater is through looking at an area's intrinsic vulnerability to contamination.[6] Intrinsic vulnerability, the intrinsic weakness of the hydrogeological system, can be calculated using the DRASTIC index, which evaluates seven different variables related to pollution likelihood: **D**epth to the water table, **R**echarge (net), **A**quifer media, **S**oil media, **T**opography, **I**mpact of the vadose zone media, and hydraulic **C**onductivity of the aquifer.[6] Increased monitoring of areas with high intrinsic vulnerability to contamination of the groundwater, specifically in the Midwest, could reduce the number of outbreaks of water-related diseases, such as cryptosporidiosis, in the United States.

This project aims to answer the following questions:

- What is the intrinsic vulnerability to contamination of the groundwater in North Dakota, South Dakota, and Minnesota?
- Is there a higher number of cryptosporidiosis cases in areas with high intrinsic vulnerability to contamination?
- Is there a higher of number of groundwater wells in areas with high intrinsic vulnerability to contamination?
- Is there a higher number of cryptosporidiosis cases in areas with a high number of groundwater wells?



METHODOLOGY

In order to use the DRASTIC model to estimate the intrinsic vulnerability of the groundwater to contamination in North Dakota, South Dakota, and Minnesota, a raster map was created for each of the seven variables included in the model. Then, each of the seven variables were reclassified in order to assign their different values a rating of 1 to 10, to prioritize certain values with respect to pollution potential. Once each map was created, the seven variables were used in a weighted sum, according to DRASTIC index equation:

$$\text{DRASTIC Index (IV)} = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw$$

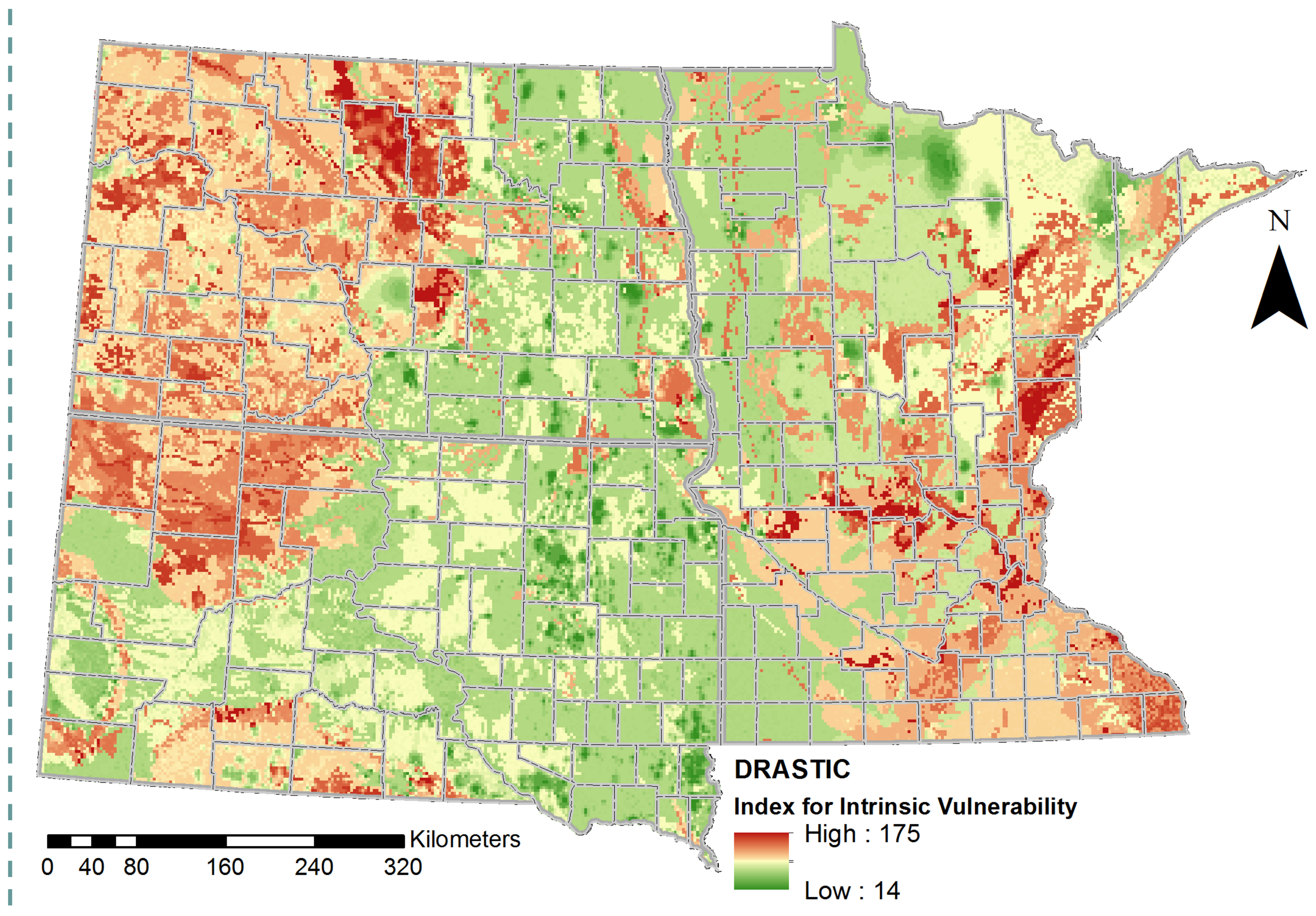
Where D, R, A, S, T, I, and C are the seven variables, r is the variable's rating for different values, and w is the weight assigned to each variable. The weights for each variable are as follows:

Variable	Weight
Depth to the Water Table	5
Net Recharge	4
Aquifer Media	3
Soil Media	2
Topography	1
Impact of the Vadose Zone Media	5
Hydraulic Conductivity of the Aquifer	3

This weighted index created the final groundwater intrinsic vulnerability map for the three states in question.

Once the DRASTIC model was complete, zonal statistics were used to calculate the average DRASTIC Index (IV) for each county in North Dakota, South Dakota, and Minnesota. Then, exploratory spatial data analysis was used to determine the relationship between the three variables at the county level: the number of cryptosporidiosis cases, the number of groundwater wells, and the DRASTIC index for intrinsic vulnerability. Bivariate clustering, using local Moran's I, was conducted to create a bivariate LISA (BiLISA) cluster map for each pairing of the three variables. This determined whether cryptosporidiosis cases, groundwater wells, and high intrinsic vulnerability were clustered in the same counties in the Midwest.

The Intrinsic Vulnerability of Groundwater to Contamination



This map details the areas in North Dakota, South Dakota, and Minnesota where the groundwater is most intrinsically vulnerable to contamination, the red being the most vulnerable, the green being the least, based on the seven DRASTIC variables.

CONCLUSIONS

In North Dakota, South Dakota, and Minnesota, there is a positive spatial correlation between groundwater contamination vulnerability, the location of groundwater wells, and cases of cryptosporidiosis. Areas with significant clustering of the three variables, such as the counties surrounding Minneapolis, Minnesota, should be the focus of groundwater contamination monitoring in the future. Given that groundwater is a primary source of water and water-borne diseases are particularly prevalent in these counties, there is a higher risk of adverse health effects if the groundwater were to become contaminated.

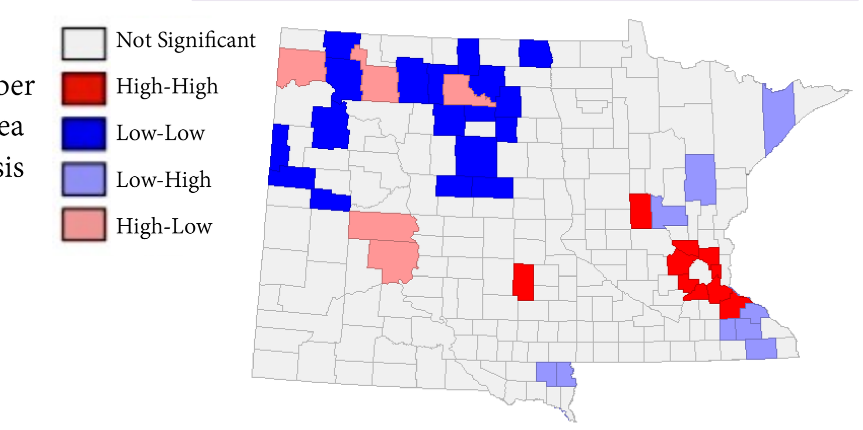
Additionally, the resulting DRASTIC model of North Dakota, South Dakota, and Minnesota shows that certain areas in the Midwest are extremely intrinsically vulnerable to groundwater contamination. Moving forward, it is important to do more in-depth analysis of the groundwater contamination susceptibility in the Midwest to get a clearer idea of which areas need to be closely monitored for contamination. The DRASTIC model is by no means the catch-all way to evaluate the pollution potential of groundwater, and it is necessary to combine the DRASTIC intrinsic vulnerability index with other aspects that influence groundwater pollution probability, such as land cover and the location of wastewater plants. With this in mind, this initial model still gives a good idea of which areas in the three states need to be monitored for groundwater contamination, seeing as they are the areas most likely to negatively impact the surrounding environment and cause outbreaks of water-borne diseases, such as cryptosporidiosis.

RESULTS & LIMITATIONS

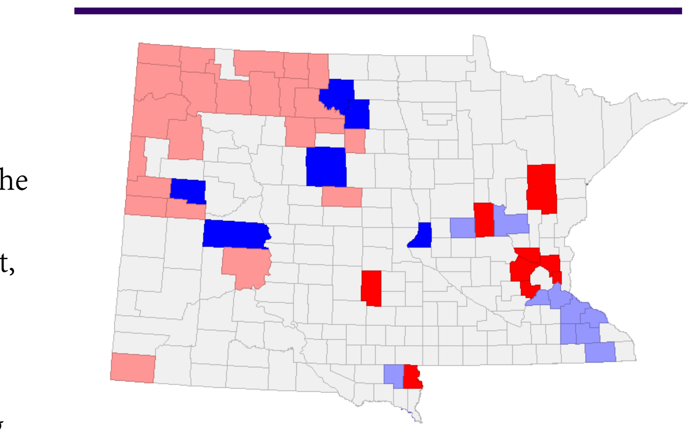
- There are counties, primarily located in Minnesota, that have a high number of groundwater wells and a high number of cryptosporidiosis cases clustered in the same area as counties with a high mean DRASTIC intrinsic vulnerability (IV) index
- In North Dakota, many counties with a low number of groundwater wells are clustered in the same area as counties with a low number of cryptosporidiosis cases
- In North Dakota, there is a notable number of counties with a high mean DRASTIC IV index clustered in the same area as counties with a low number of cryptosporidiosis cases
- Nearly all the high-high clustering in all three variable pairings occur near Minneapolis, Minnesota
- The majority of counties in North Dakota, South Dakota, and Minnesota did not have significant clustering of any pairing of the three variables

BiLISA Cluster Maps

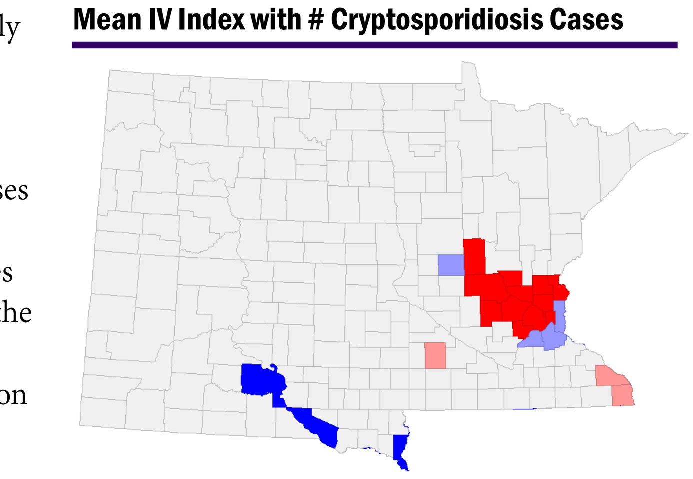
 # Groundwater Wells with # Cryptosporidiosis Cases



Mean IV Index with # Groundwater Wells



Mean IV Index with # Cryptosporidiosis Cases



Given these results, there is evidence of a positive spatial correlation between groundwater contamination susceptibility, the location of groundwater wells, and cryptosporidiosis cases. But this spatial correlation between the three variables is inconsistent, as there are outliers that showcase a negative spatial correlation between pairings of the three variables.

Additionally, there were many limitations while conducting this analysis. The limited availability of data for both the DRASTIC model and the water-borne diseases made it difficult to accurately conduct the analysis. Data was not found for the impact of the vadose zone media or the hydraulic conductivity of the aquifer DRASTIC variables, so soil media and aquifer media data were used to make an estimate for the two. Also, cryptosporidiosis cases could not be found on a scale smaller than the county level. Analyzing the data for the three variables at the county-level does not provide enough detail and likely reduces the significance of the actual clustering occurring. Looking at the final DRASTIC intrinsic vulnerability map, it is clear that there is notable variation of pollution probability within each county, meaning that taking the mean IV index for a county oversimplifies the actual groundwater contamination vulnerability.

SOURCES

References:

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2. USGS. (n.d.). Groundwater depletion. Retrieved February 02, 2016
3. Cutler D, Miller G. The role of public health improvements in health advances: the twentieth-century United States. Demography 2005;42:1–22
4. Center for Disease Control and Prevention. (2013, September 06). Surveillance for waterborne disease outbreaks associated with drinking water and other nonrecreational water — United States, 2009–2010. Retrieved February 02, 2016
5. Center for Disease Control and Prevention. (2015, May 01). Cryptosporidiosis surveillance — United States, 2011–2012. Retrieved April 24, 2016
6. Voudouris, K., Kazakis, N., Polemio, M., & Kareklas, K. (2010). Assessment of intrinsic vulnerability using DRASTIC model and GIS in Kiti aquifer, Cyprus. European Water, 30, 13-24. Retrieved April 24, 2016

Data sources:

Groundwater wells: USGS Groundwater Watch, 2016; *Depths to water table:* USGS National Water Information System, 2016; *Natural recharge rates, aquifer media:* USGS Water Resources NSDI Node, 2003; *Soil media:* USDA Web Soil Survey, 2006; *North Dakota cryptosporidiosis:* North Dakota DOH Disease Control, 2015; *South Dakota cryptosporidiosis: South* Dakota DOH Statistics, 2013; *Minnesota cryptosporidiosis:* Minnesota DOH IDEPC Division, 2014; *Well image:* https://pixabay.com/en/water-pump-old-man-hand-well-1008977/; *Drinking image:* https://www.flickr.com/photos/dfid/5951436978

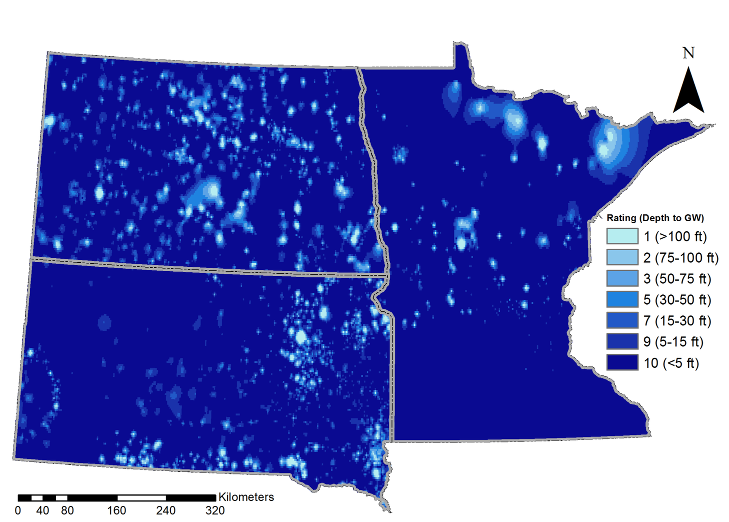
GIS 102, Advanced GIS, Spring 2016

Map projection: NAD_1983_Albers

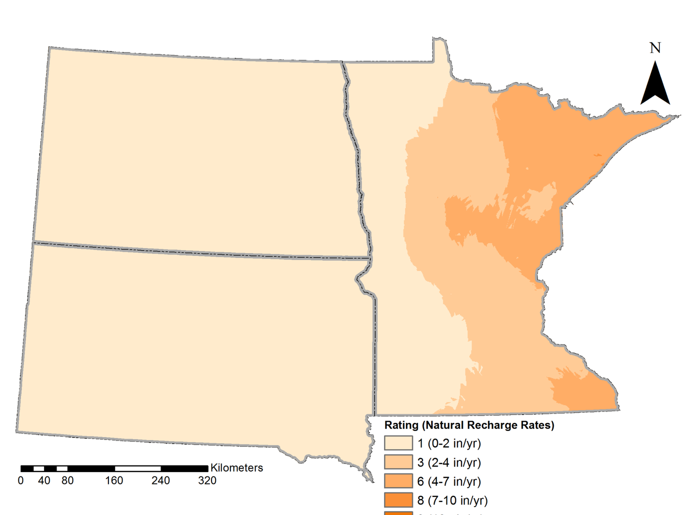
Map produced on: 10 May 2016

Stephanie Cleland

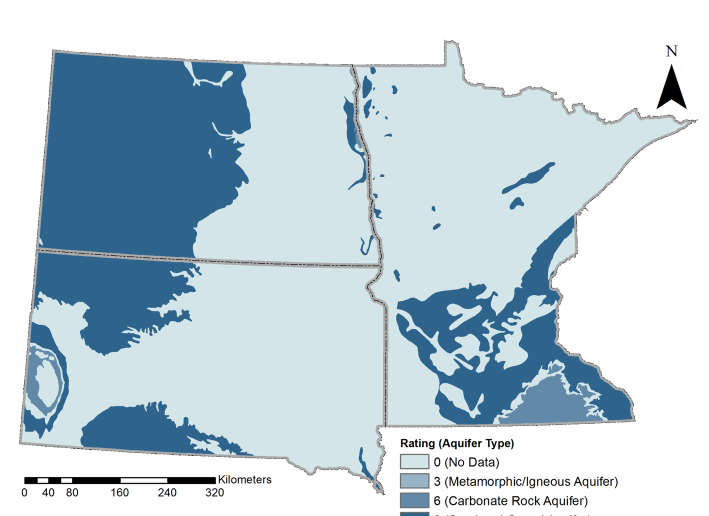
DRASTIC PARAMETERS



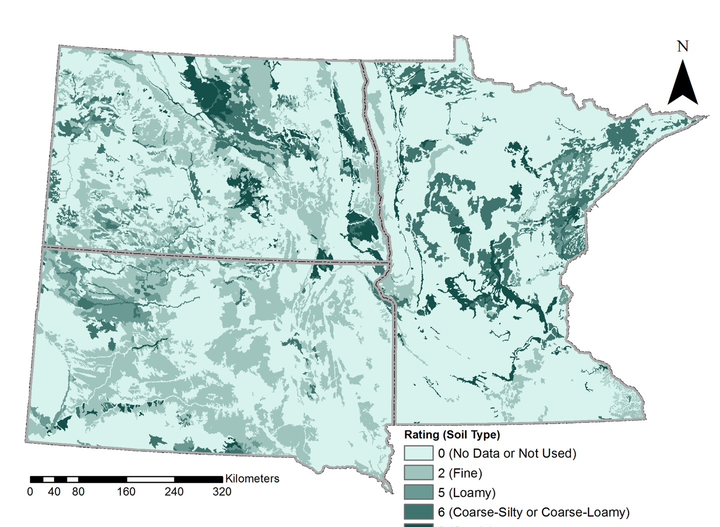
Depth to Water Table



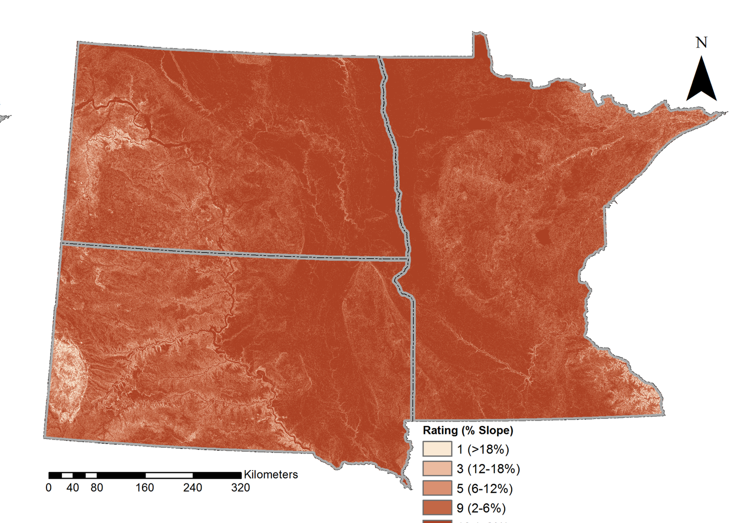
Net Recharge



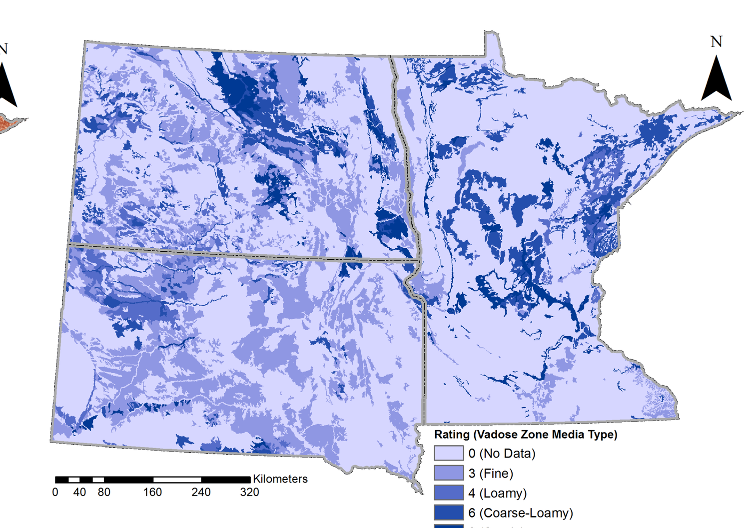
Aquifer Media



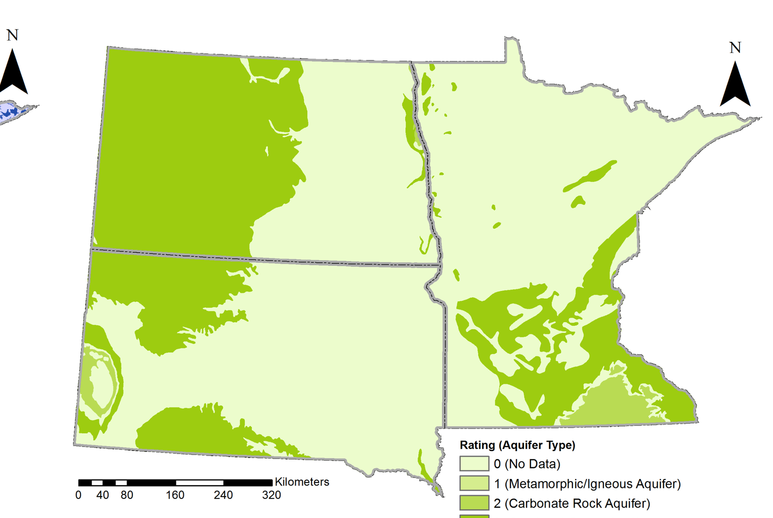
Soil Media



Topography



Impact of Vadose Zone Media



Hydraulic Conductivity