Final Township Testing Nitrate Report:

Becker County 2016-2018

April 2019

Minnesota Department of Agriculture

Pesticide and Fertilizer Management Division

ACKNOWLEDGEMENTS

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FUNDING

Project dollars provided by the Clean Water Fund (from the Clean Water, Land and Legacy Amendment).

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EXECUTIVE SUMMARY

Nitrate is a naturally occurring, water soluble molecule that is made up of nitrogen and oxygen. Although nitrate occurs naturally, it can also originate from sources such as fertilizer, animal manure, and human waste. Nitrate is a concern because it can be a risk to human health at elevated levels. The Minnesota Department of Health (MDH) has established a Health Risk Limit (HRL) of 10 mg/L nitrate as nitrogen (nitrate-N) for private drinking water wells in Minnesota.

In response to health concerns over nitrate-N in drinking water the Minnesota Department of Agriculture (MDA) developed the Nitrogen Fertilizer Management Plan (NFMP). The NFMP outlines a statewide plan to assess vulnerable areas for nitrate in groundwater known as the Township Testing Program.

The primary goal of the Township Testing Program is to identify areas that have high nitrate concentrations in their groundwater. The program also informs residents about the health risk of their well water. Areas were selected based on historically elevated nitrate conditions, aquifer vulnerability, and row crop production. The MDA plans to offer nitrate-N tests to more than 70,000 private well owners in over 300 townships by 2019. This will be one of the largest nitrate testing efforts ever conducted and completed.

In 2016, private wells in the Becker County study area (three townships) were sampled for nitrate-N. Samples were collected from private wells using homeowner collection and mail-in methods. These initial samples were collected from 200 wells, representing an average response rate of 45 percent of homeowners. Well log information was obtained when available and correlated with nitrate-N results. Initial well dataset results showed that across the study area, 12.5 percent of private wells sampled were at or above the health standard of 10 mg/L for nitrate-N. Based on the initial results, it is estimated that 197 residents could be consuming well water with nitrate-N at or over the HRL.

The MDA completed follow-up sampling and well site visits at 52 wells in 2017 and 2018. A follow-up sampling was offered to all homeowners with wells that had a detectable nitrate-N result.

A well site visit was conducted to identify wells that were unsuitable for final analysis. The final well dataset is intended to only include private drinking water wells potentially impacted by applied commercial agricultural fertilizer. Therefore, wells with construction issues or nearby potential point sources of nitrogen were removed from the final well dataset. Point sources of nitrogen can include: feedlots, subsurface sewage treatment systems, fertilizer spills, and bulk storage of fertilizer. A total of 17 (8.5 percent) wells were determined to be unsuitable and were removed from the dataset. The final well dataset had a total of 183 wells.

The final well dataset was analyzed to determine the percentage of wells at or over the HRL of 10 mg/L nitrate-N. When analyzed at the township scale the percent of wells at or over the HRL ranged from 6.9 to 12.5 percent. Pine Point Township has significant nitrate problems with more than ten percent of private wells at or over the HRL.

INTRODUCTION

The Minnesota Department of Agriculture (MDA) is the lead agency for nitrogen fertilizer use and management. The Nitrogen Fertilizer Management Plan (NFMP) is the state's blueprint for prevention or minimization of the impacts of nitrogen fertilizer on groundwater. The MDA revised the NFMP in 2015. Updating the NFMP provided an opportunity to restructure county and state strategies for reducing nitrate contamination of groundwater, with more specific, localized accountability for nitrate contamination from agriculture. The NFMP outlines how the MDA addresses elevated nitrate levels in groundwater. The NFMP has four components: prevention, monitoring, assessment and mitigation.

The goal of nitrate monitoring and assessment is to develop a comprehensive understanding of the severity, magnitude, and long term trends of nitrate in groundwater as measured in public and private wells. The MDA established the Township Testing Program to determine current nitrate concentrations in private wells on a township scale. This program is designed to quickly assess a township in a short time window. Monitoring focuses on areas of the state where groundwater nitrate contamination is more likely to occur. This is based initially on hydrogeologically vulnerable areas where appreciable acres of agricultural crops are grown. Statewide the MDA plans to offer nitrate-N tests to more than 70,000 private well owners in over 300 townships by 2019. . As of February 2019, 306 townships in 42 counties have completed the initial sampling.

In 2016, three townships in Becker County were selected to participate in the Township Testing Program (Figure 1). Areas were chosen based on several criteria. Criteria used include: professional knowledge shared by the local soil and water conservation district (SWCD) or county environmental departments, past high nitrate as nitrogen (nitrate-N) results, vulnerable groundwater, and the amount of row crop production. Initial water samples were collected from private wells by homeowners and mailed to a laboratory. Sample results were mailed by the laboratory to the participating homeowners. The sampling, analysis, and results were provided at no cost to participating homeowners and paid for by the Clean Water Fund.

Well owners with detectable nitrate-N results were offered a no cost pesticide sample and a follow-up nitrate-N sample collected by MDA staff. The MDA began evaluating pesticide presence and concentrations in private water wells at the direction of the Minnesota Legislature. The follow-up pesticide and nitrate-N sampling in Becker County occurred in 2017 and 2018. The follow-up included a well site visit (when possible) in order to rule out well construction issues and to identify potential point sources of nitrogen (Appendix B).

Wells that had questionable construction integrity or are near a point source of nitrogen were removed from the final well dataset. After the unsuitable wells were removed, the nitrate-N concentrations of well water were assessed for each area.

For further information on the NFMP and Township Testing Program, visit the following webpages:
www.mda.state.mn.us/nfmp
www.mda.state.mn.us/townshiptesting

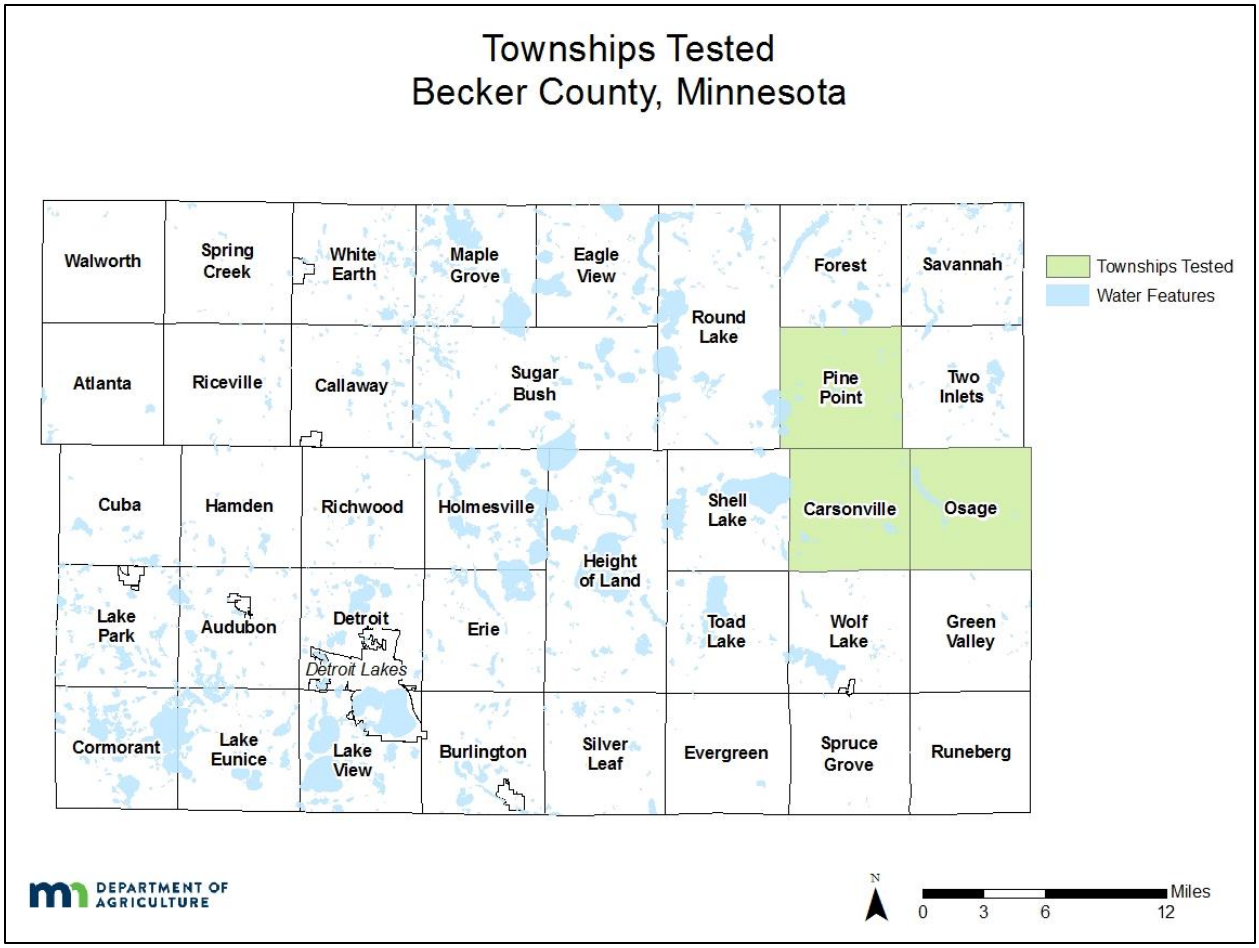

Figure 1. Townships Tested in Becker County

BACKGROUND

In many rural areas of Minnesota, nitrate is one of the most common contaminants in groundwater, and in some localized areas, a significant number of wells have high nitrate levels.

Nitrate is a naturally occurring, water soluble molecule that is made up of nitrogen and oxygen. Although nitrate occurs naturally, it can also originate from other sources such as fertilizer, animal manure, and human waste. Nitrate is a concern because it can have a negative effect on human health at elevated levels. The United States Environmental Protection Agency has established a drinking water Maximum Contaminant Level (MCL) of 10 mg/L for nitrate-N in municipal water systems (US EPA, 2009). The Minnesota Department of Health (MDH) has also established a Health Risk Limit (HRL) of 10 mg/L nitrate-N for private drinking water wells in Minnesota.

Nitrogen present in groundwater can be found in the forms of nitrite and nitrate. In the environment, nitrite generally converts to nitrate, which means nitrite occurs very rarely in groundwater. The nitrite concentration is commonly less than the reporting level of 0.01 mg/L, resulting in a negligible contribution to the nitrate plus nitrite concentration (Nolan and Stoner, 2000). Therefore, analytical methods generally combine nitrate plus nitrite together. Measurements of nitrate plus nitrite as nitrogen and measurements of nitrate as nitrogen will hereafter be referred to as “nitrate”.

NITRATE FATE AND TRANSPORT

Nitrate is considered a conservative anion and is highly mobile in many shallow, coarse-textured groundwater systems. Once in groundwater, nitrate is often very stable and can move large distances from its source. However, in groundwater environments that have organic carbon but lack oxygen, nitrate in groundwater may be converted to nitrogen through a natural process called denitrification. Denitrification occurs when oxygen levels are depleted and nitrate becomes the primary oxygen source for microorganisms (Dubrovsky et al., 2010). In groundwater systems that are either unconfined or have thin layers of confining material above shallow aquifers, contaminants such as nitrate can travel quickly to the aquifer, leaving little chance for denitrification or other attenuating processes (Aller et al. 1987). As a result certain areas of Becker County, with shallow aquifers in sandy soils (Marshall and Gowan, 2016), and intensive row crop agriculture (USDA NASS Cropland Data Layer, 2013), are particularly vulnerable to elevated nitrate concentrations. However, geochemical conditions can be highly variable within an aquifer or region and can change over time (MPCA, 1999).

GEOLOGY AND HYDROGEOLOGY

During the Pleistocene Epoch (beginning 2.5 million years ago), the Laurentide Ice Sheet covered parts of northern North America, and Minnesota was situated at the edge of this ice sheet. During the most recent glacial advance (110,000-11,700 years ago) glacial material was deposited through numerous glacial advances and retreats. This created the surficial geology we see today. During these glaciation periods glacial till was deposited directly by the glaciers. The till is typically poorly sorted clay, silt, sand, gravel, cobbles, and boulders. Glacial outwash and fluvial sediments were deposited by meltwater

associated with these glaciations. The glacial outwash tends to be made of stratified silt, sand, and gravel (Lusardi and Dengler, 2017).

The earliest Pleistocene glacial advances in Becker County were from the Wadena glacial lobe. This lobe moved westward and then terminated in the center of the county, depositing materials at the glacier's edge, which created a ridge known as the Alexandria Moraine (Lusardi and Dengler, 2017). The Alexandria moraine begins just southeast of Detroit Lakes and extends southward into Kandiyohi County. In Becker County the moraine has been buried by successive glacial advances and retreats (Marshall and Gowan, 2016). As the Wadena lobe retreated north, glacial meltwater pooled in the area between the Alexandria moraine and the ice front. During this same period, as the ice retreated, it formed elongated hills of sand and gravel known as drumlins in the southeast corner of Becker County. The Wadena lobe made several more advances and retreats. During this time glacial meltwater poured from the ice and deposited sand and gravel in the Park Rapids outwash plain. This outwash plains covers Osage, Pine Point, and northern parts of Carsonville Townships (Marshall and Gowan, 2016).

The next glacial ice advances were from the Red River lobe and the Des Moines lobe, and both entered into the west side of Becker County. The Red River lobe stagnated in central Becker County and created an east to west moraine in the center of the county. When the Red River lobe melted in western Becker County, it left behind a supraglacier complex composed of unsorted silt and clay layers. Meltwater flowed out of the melting glacial lobe and covered the southwestern corner of Becker County with sand, creating the Detroit Lakes outwash plain (Marshall and Gowan, 2016).

Statewide geomorphological mapping conducted by the Minnesota Department of Natural Resources (MDNR), the Minnesota Geological Survey (MGS) and the University of Minnesota at Duluth (MDNR, MGS, and UMD, 1997) indicates the extent of glacial deposits in Becker County as presented in Figure 2. According to the Minnesota Geological Atlas, the unconsolidated glacial deposits described above range in thickness from approximately 190 to 1,175 feet. The thickest deposits are in central and northeast Becker County.

Beneath theses thick glacial deposits is consolidated bedrock. Most wells in Becker County are not drilled into the bedrock, as there are plentiful groundwater sources above the bedrock. Therefore, seismic methods were used to gather data on bedrock and these methods do not detect Cretaceous rocks. However, there were some additional data from previous well drillings that intersected bedrock (Radakovich and Chandler, 2016). These data show some Cretaceous deposits in the western portion of Becker County. Ancient seas were present in this area during the Cretaceous Period (135 to-65 mya) and the consolidated deposits left behind formed shale, mudstone, and some sandstone. Since much of the Cretaceous rock was eroded, the older Precambrian bedrock is the uppermost bedrock in other parts of Becker County (Jirsa and Chandler, 2016).

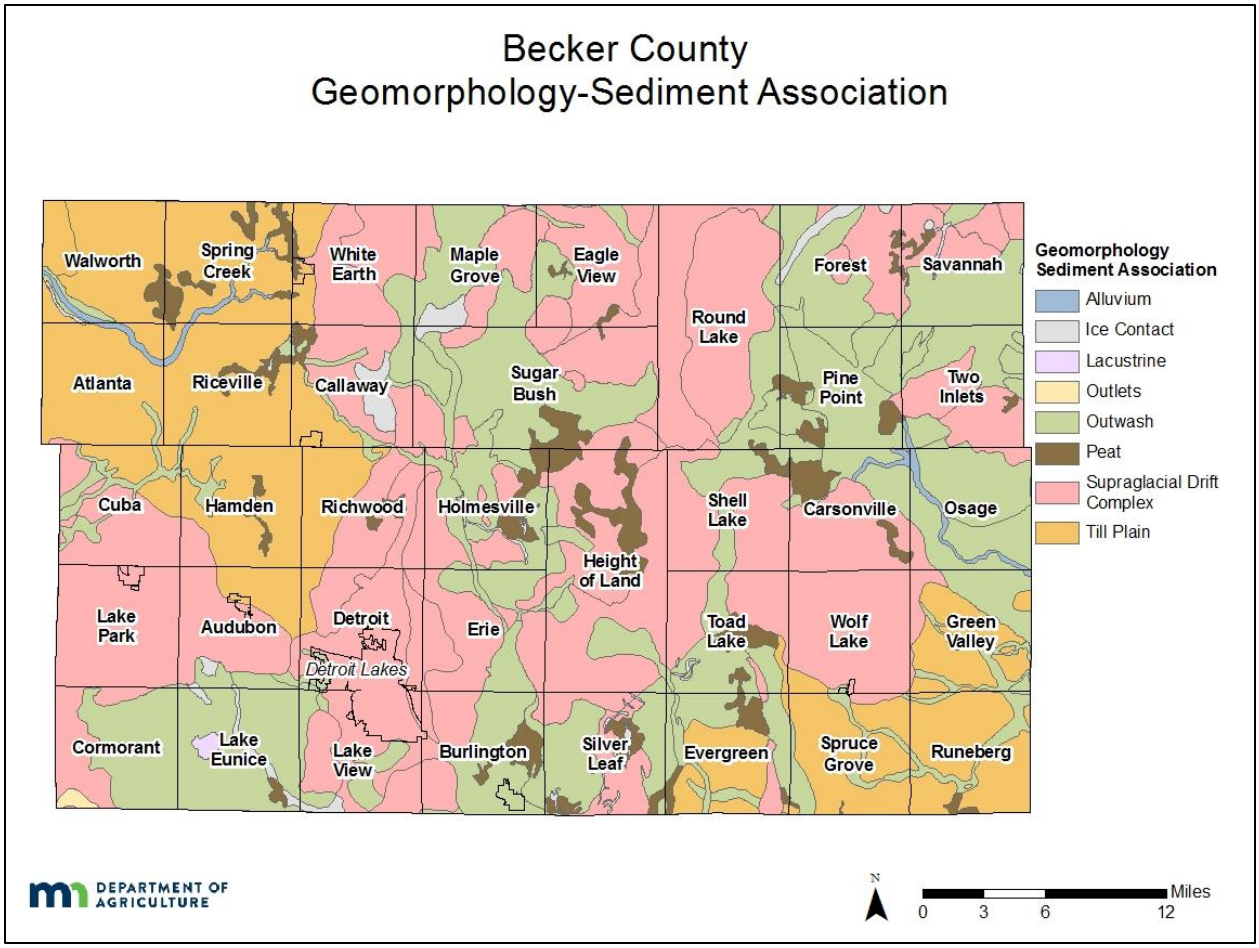

Figure 2. Statewide Geomorphology Layer, Sediment Association in Becker County (DNR, MGS, and UMD, 1997)

Sediments deposited by the glaciers and consolidated bedrock from earlier time periods affects the chemical composition of the groundwater. A broad study of regional groundwater aquifers focused on Northwest Minnesota was completed by the MPCA in 1999. In this report, boron is the chemical of greatest concern in the northwestern region of Minnesota, especially in Cretaceous aquifers. Higher Boron concentrations are correlated with compounds (such as chloride, bromide, fluoride, lithium, potassium, sodium, and sulfate) that are typically high in seawater. Most of the wells with elevated Boron were west of Becker County. Northwest Minnesota also has higher concentrations of arsenic compared to other regions in the state. Arsenic tends to have higher concentration in shale compared to other sedimentary rocks. Elevated (>3 µg/L) concentrations of arsenic were found in wells throughout Becker County (MPCA, 1999).

Historically, nitrate is of lesser concern in Northwest Minnesota, but some elevated levels were still found in surficial aquifers. Reducing conditions and less intensive farming may be protecting the groundwater from excessive nitrate pollution (MPCA, 1999).

NITROGEN POINT SOURCES

The focus of the Township Testing Program is to assess nitrogen contamination in groundwater as a result of commercial nitrogen fertilizer applied to cropland. Any wells potentially impacted by point sources were removed from the final well dataset. Potential point sources such as subsurface sewage treatment systems (more commonly known as septic systems), feedlots, fertilizer spills, and bulk storage of fertilizer are considered in this section. Below is a brief overview of these sources in Becker County. Further details are in Appendix B.

SUBSURFACE SEWAGE TREATMENT SYSTEM

Subsurface sewage treatment systems (SSTS) can be a potential source for contaminants in groundwater, such as nitrate and fecal material (MDH, 2014). The total number of SSTS was not reported for Becker County. Over a recent 15 year period (2002-2016), 4,989 construction permits for new, replacement, or repairs for SSTS were issued. When new SSTS's are installed they are required to be in compliance with the rules at the time of installation. Newer systems meet modern SSTS regulations and must comply with the current well code, which requires a 50 foot horizontal separation from the well (MDH, 2014). Since the total number of septic systems is unknown the percentage of the septic systems that have recently been constructed cannot be determined.

FEEDLOT

Manure produced on a feedlot can be a potential source of nitrogen pollution if improperly stored or spread. In the Becker County study area there are no active feedlots (Appendix B; Figure 7).

FERTILIZER STORAGE LOCATION

Bulk fertilizer storage locations are potential point sources of nitrogen because they store large concentrations of nitrogen based chemicals. Licenses are required for individuals and companies that store large quantities of fertilizer. The Becker County study area has a total of 83 fertilizer storage licenses and all but one were chemigation permits. (Appendix B; Table 11).

FERTILIZER SPILLS AND INVESTIGATIONS

No historic fertilizer spills and investigations occurred in the Becker County study area (Appendix B; Table 13).

TOWNSHIP TESTING METHODS

VULNERABLE TOWNSHIPS

Well water sampling is focused on areas that are considered vulnerable to groundwater contamination by commercial nitrogen fertilizer. Typically, townships and cities are selected for sampling if more than 30 percent of the underlying geology is considered vulnerable and more than 20 percent of the land cover is row crop agriculture. These are not rigid criteria, but are instead used as a starting point for creating an initial plan. A map depicting the areas that meet this preliminary criteria is shown in Figure 3. Additional factors such as previous nitrate results and local knowledge of groundwater conditions were, and continue to be, used to prioritize townships for testing.

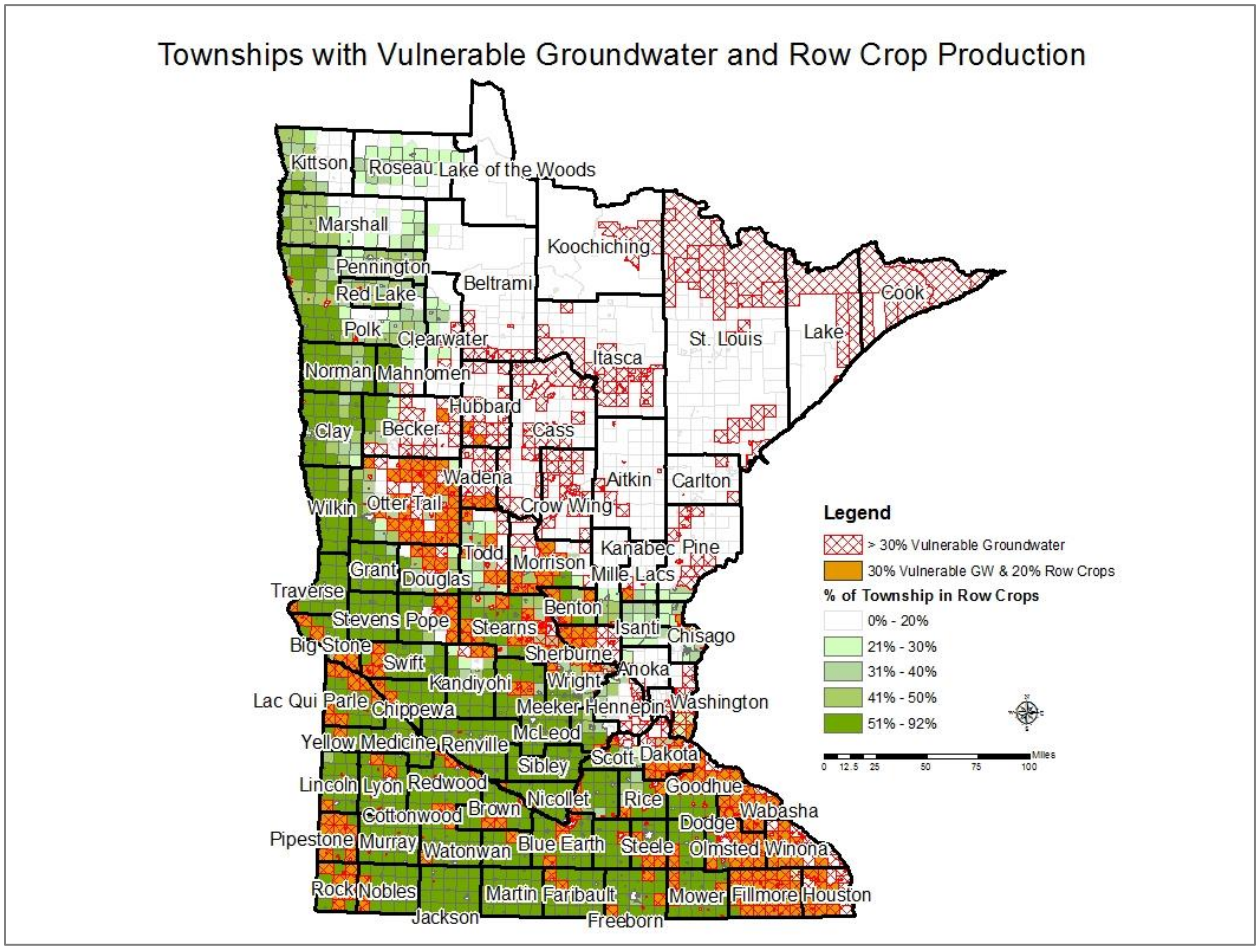

Figure 3. Minnesota Townships with Vulnerable Groundwater and Row Crop Production

Aquifer sensitivity ratings from the Minnesota Department of Natural Resources were used to estimate the percentage of geology vulnerable to groundwater contamination. The same geologic mapping project presented in Figure 2 was used to classify the state into aquifer sensitivity ratings. There are three ratings for aquifer sensitivity: low, medium, and high. Sensitivity ratings are described in Table 1.

The ratings are based upon guidance from the Geologic Sensitivity Project Workshop's report "Criteria and Guidelines for Assessing Geologic Sensitivity in Ground Water Resources in Minnesota" (MDNR, 1991). A map of Becker County depicting the aquifer vulnerabilities is shown in Figure 4.

Table 1. Vulnerability Ratings Based on the Geomorphology of Minnesota, Sediment Association Layer

Sediment Association	Sensitivity/Vulnerability Rating
Alluvium, Outwash, Ice Contact, Terrace, Bedrock: Igneous, Metamorphic, and Sedimentary	High
Supraglacial Drift Complex, Peat, Lacustrine	Medium
Till Plain	Low

The National Agriculture Statistics Service data (USDA NASS, 2013) on cropland was used to determine the percentage of row crop agriculture. A map and table depicting the extent of the cropland in Becker County can be found in Appendix C (Figure 9, Table 14). On average 9 percent of the land cover was row crop agriculture.

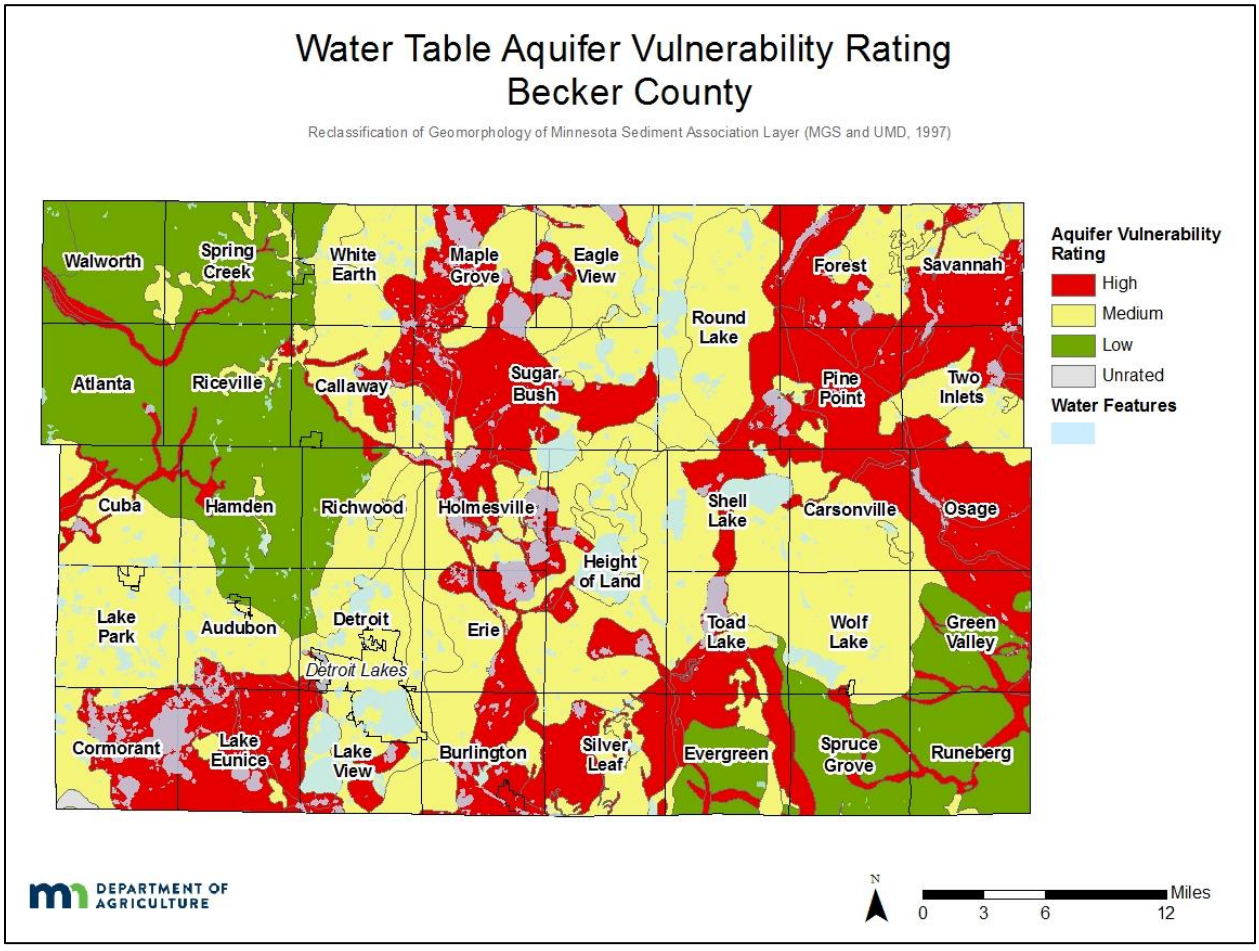

Figure 4. Water Table Aquifer Vulnerability Rating in Becker County

PRIVATE WELL SAMPLING - NITRATE

The testing is done in two steps in each township: "initial" sampling and "follow-up" sampling. The initial nitrate sampling was conducted in 2016. In the initial sampling, all private well owners in the selected townships are sent a nitrate test kit. These kits include instructions on how to collect a water sample, a sample bottle, a voluntary survey, and a prepaid mailer. Each homeowner was mailed the nitrate result for their well along with an explanatory nitrate brochure (Appendix D). Well water samples were collected by 200 homeowners using the mail-in kit (Table 2). These 200 samples are considered the "initial well dataset". On average, 45 percent of the homeowners in these townships responded to the free nitrate test offered by MDA. There was an 80 percent return rate in Pine Point Township, which is higher than the typical response rate in the Township Testing Program.

All of the homeowners with a nitrate detection from the initial sampling were asked to participate in a follow-up well site visit and sampling. The well site visit and follow-up sampling was conducted in 2017 and 2018 by MDA staff. A total of 52 follow-up samples were analyzed (Table 2).

Table 2. Homeowner Participation in Initial and Follow-Up Well Water Sampling, Becker County

Township	Kits Sent	Initial Well Dataset	Well Site Visits & Follow-Up Sampling Conducted
Carsonville	93	32	7
Osage	307	131	39
Pine Point	46	37	6
Total	446	200	52

Each follow-up visit was conducted at the well site by a trained MDA hydrologist. Well water was purged from the well for 15 minutes before a sample was collected to ensure a fresh water sample. Additionally, precautions were taken to ensure no cross-contamination occurred. A more thorough explanation of the sampling process is described in the sampling and analysis plan (MDA, 2016). As part of the follow-up sampling, homeowners were offered a no cost pesticide test. As pesticide results are finalized, they will be posted online in a separate report (www.mda.state.mn.us/pwps).

The well site visit was used to collect information on potential nitrogen point sources, well characteristics (construction type, depth, and age), and the integrity of the well construction. Well site visit information was recorded on the Private Well Field Log & Well Survey Form (Appendix A).

WELL ASSESSMENT

All wells testing higher than 5 mg/L were carefully examined for well construction, potential point sources, and other potential concerns.

Using the following criteria, a total of 17 wells were removed to create the final well dataset. See Appendix E (Tables 17 and 18) for a summary of the removed wells.

HAND DUG

All hand dug wells were excluded from the dataset, regardless of the nitrate concentration. Hand dug wells do not meet well code and are more susceptible to local surface runoff contamination. Hand dug wells are often very shallow, typically just intercepting the water table, and therefore are much more sensitive to local surface runoff contamination (feedlot runoff), point source pollution (septic system effluent), and chemical spills.

POINT SOURCE

Well code in Minnesota requires wells to be at least 50 feet away from most possible nitrogen point sources such as SSTS (septic tanks and drain fields), animal feedlots, etc. Wells with a high nitrate (>5 mg/L) concentration that did not maintain the proper distance from these point sources were removed from the final well dataset. Information gathered from well site visits was used to assess these distances. If a well was not visited by MDA staff, the well survey information provided by the homeowner and aerial imagery was reviewed.

WELL CONSTRUCTION PROBLEM

The well site visits allowed the MDA staff to note the well construction of each well. Some wells had noticeable well construction problems. For instance, wells with a cap missing or a crack in the cap can make the groundwater in that well susceptible to pollution. Other examples include wells buried underground and wells with cracked casing. Wells with significant problems such as these were excluded from the final well dataset.

UNSURE OF WATER SOURCE

If the water source of the sample was uncertain, or from an unwanted source, then data pertaining to the sample was removed. For example, these samples include water that may have been collected from an indoor tap with a reverse osmosis system. Water samples that were likely collected from a municipal well were also removed from the dataset. This study examines raw well water not treated water or municipal water.

SITE VISIT COMPLETED - WELL NOT FOUND & CONSTRUCTED BEFORE 1975 OR AGE UNKNOWN & NO WELL ID

Old wells with no validation on the condition of well construction were removed from the dataset. These wells were installed before the well code was developed in Minnesota (mid-1975), did not have a well log, and MDA staff could not locate the well during a site visit. Additionally, if the age of the well could not be determined it was assumed to an older well.

NO SITE VISIT & CONSTRUCTED BEFORE 1975 OR AGE UNKNOWN & NO WELL ID

If no site visit was conducted, and the well is an older well (pre-1975), the well was not used in the final analysis. If the age of the well could not be determined these were again assumed to be older wells.

NO SITE VISIT & INSUFFICIENT DATA & NO WELL ID

Wells that were clearly lacking necessary background information were also removed from the dataset. These wells did not have an associated well log, were not visited by MDA staff, and the homeowner did not fill out the initial well survey or the address could not be found.

INITIAL RESULTS

INITIAL WELL DATASET

Approximately 200 well owners returned water samples for analysis across the three townships (Figure 5). These wells represent the initial well dataset. The following paragraphs provide a brief discussion of the statistics presented in Table 3.

The minimum values of nitrate for all townships were less than the detection limit (<DL) which is 0.03 mg/L. The maximum values range from 17.9 to 28.2 mg/L with Pine Point Township having the highest result. Median values were low and range from <DL to 0.4 mg/L. The 90th percentiles range from 7.3 to 17.6 mg/L with Pine Point Township having the highest 90th percentile.

Initial results showed that in Osage and Pine Point Townships ten percent or more of the wells were at or over 10 mg/L nitrate. These results contrast findings from a 2010 USGS report on nitrate concentrations in private wells across the upper United States (US) in which less than five percent of sampled private wells had nitrate concentrations greater than 10 mg/L (Warner and Arnold, 2010). Data from the Township Testing Program suggest that private well water in Osage and Pine Point Townships are more heavily impacted by nitrate than other areas of the upper United States.

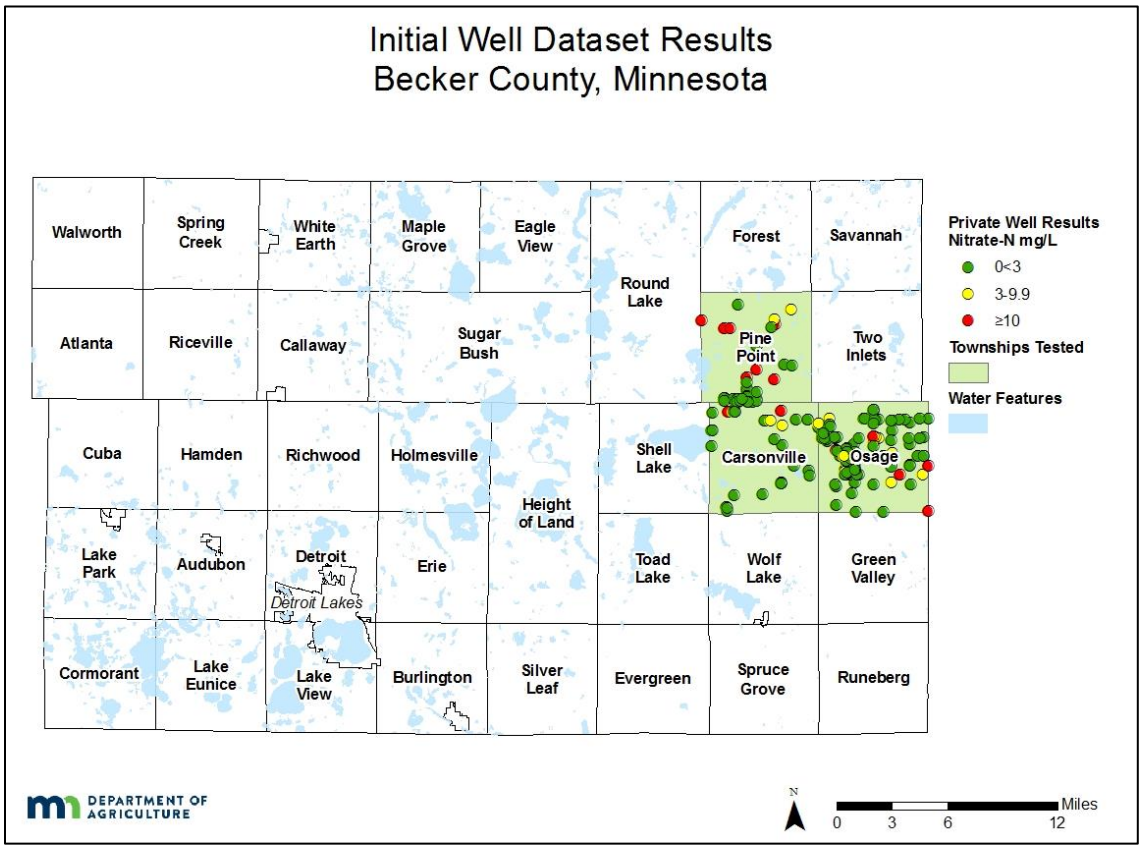

Figure 5. Well Locations and Nitrate Results from Initial Dataset in Becker County

Table 3. Becker County Township Testing Summary Statistics for Initial Well Dataset

Township	Total Wells	Values				Percentiles				Number of Wells					Percent of Wells				
		Min	Max	Mean	Median	75th	90th	95th	99th	<3 mg/L	3<10 mg/L	≥5 mg/L	≥7 mg/L	≥10 mg/L	<3 mg/L	3<10 mg/L	≥5 mg/L	≥7 mg/L	≥10 mg/L
		Nitrate-N mg/L or PPM																	
Carsonville	32	<DL	17.9	2.1	<DL	1.8	7.3	12.5	17.9	25	4	4	3	3	78.1%	12.5%	12.5%	9.4%	9.4%
Osage	131	<DL	22.4	3.0	0.4	3.2	10.5	16.5	22.4	97	19	24	21	15	74.0%	14.5%	18.3%	16.0%	11.5%
Pine Point	37	<DL	28.2	3.9	<DL	2.0	17.6	22.0	28.2	28	2	9	9	7	75.7%	5.4%	24.3%	24.3%	18.9%
Total	200	<DL	28.2	3.0	0.1	3.1	12.2	17.9	22.4	150	25	37	33	25	75.0%	12.5%	18.5%	16.5%	12.5%

<DL stands for less than a detectable limit. This means results are less than 0.03 mg/L. The 50th percentile (75th, 90th, 95th, and 99th) is the value below which 50 percent (75%, 90%, 95%, and 99%) of the observed values fall.

ESTIMATES OF POPULATION AT RISK

The human population at risk of consuming well water at or over the HRL of 10 mg/L nitrate was estimated based on the sampled wells. An estimated 197 people in Becker County's study area have drinking water over the nitrate HRL (Table 4). Nitrate contamination is a significant problem for many wells in Becker County.

Table 4. Estimated Population with Water Wells Over 10mg/L Nitrate-N, Becker County

Township	Estimated Households on Private Wells*	Estimated Population on Private Wells*	Estimated Population ≥10 mg/L Nitrate-N**
Carsonville	91	223	21
Osage	364	877	100
Pine Point	125	402	76
Total	580	1,502	197

*Data collected from the Minnesota State Demographic Center, 2017
**Estimates based off of the 2016 estimated households per township gathered from Minnesota State Demographic Center and percentage of wells at or over the HRL from the initial well dataset

WELL SETTING AND CONSTRUCTION

MINNESOTA WELL INDEX AND WELL LOGS

The Minnesota Well Index (MWI) (formerly known as the "County Well Index") is a database system developed by the Minnesota Geological Survey and the Minnesota Department of Health (MDH) for the storage, retrieval, and editing of water-well information. The database contains basic information on well records (e.g. location, depth, static water level) for wells constructed in Minnesota.

The database also contains information on the well log and the well construction for many private drinking water wells. The MWI is the most comprehensive Minnesota well database available, but contains only information for wells in which a well log is available. Most of the records in MWI are for wells drilled after 1974, when water-well construction code required well drillers to submit records to the MDH (MGS, 2012). The MWI does contain data for some records obtained by the MGS through the cooperation of drillers and local government agencies for wells drilled before 1974 (MDH, 2018).

In some cases, well owners were able to provide unique well identification numbers for their wells. When the correct unique IDs are provided, a well log can be used to identify the aquifer that the well withdraws water from. The well logs were obtained from the MWI for 78 documented wells (Table 5). Therefore, approximately 39 percent of the sampled wells had corresponding well logs and only 64 of these wells had an aquifer identified. Thus, the data gathered on aquifers represents approximately one third of the total sampled wells.

The aquifers in Table 5 are arranged from the geologically youngest units on the top to the older units. According to the well log data, the most commonly utilized aquifer in the sampled wells was the Quaternary Water Table Aquifer. This majority reflects the overall findings for all documented wells in the study area (Appendix F, Table 19). Below is a brief description of the aquifers characterized in Table 5.

In Becker County, all Quaternary aquifers are composed of unconsolidated sediments that overlie the bedrock. These sediments were deposited during the last glacial period, which occurred during the Pleistocene Epoch. (Marshall and Gowan, 2016).

The Quaternary Water Table (QWTA) wells are defined as having less than ten feet of confining material (typically clay) between the land surface and the well screen (MPCA, 1999). When there is less than ten feet of clay, surface contaminants can travel more quickly to the water table aquifers. In general, shallower wells completed in the QWTA are more susceptible to nitrate contamination.

The Quaternary Buried aquifers are surficial and similar to the QWTA except that the confining materials (typically clay) are more than 10 feet thick (MPCA, 1999).

Quaternary buried artesian wells are wells that are withdraw water that is under pressure and below a confining unit (MPCA, 1999).

Table 5. Nitrate Concentrations within Sampled Groundwater Aquifers, Becker County

Aquifer Group/Formation	Total Wells	Ave Depth (Feet)	Number of wells			Percent of wells		
			<3	3<10	≥10	<3	3<10	≥10
			Nitrate-N mg/L					
Quaternary Water Table	42	59	34	5	3	81.0%	11.9%	7.1%
Quaternary Buried Unconfined	2	78	1	1	0	50.0%	50.0%	0.0%
Quaternary Buried Artesian	20	135	19	1	0	95.0%	5.0%	0.0%
Not Available	14	83	9	3	2	64.3%	21.4%	14.3%

WELL OWNER SURVEY

The private well owner survey, sent out with the sampling kit, provided additional information about private wells that were sampled. The survey included questions about the well construction, depth and age, and questions about nearby land use. A blank survey can be found in Appendix G. It is important to note that well information was provided by the well owners and may be approximate or potentially erroneous. The following section is a summary of information gathered from the well owner survey (complete well survey results are located in Appendix H at the end of this document, Tables 20-34).

The vast majority of wells (57.5 percent) are located on “rural” property. In the township of Osage a significant number of wells (28.2 percent) were located on lake properties.

Approximately 55.0 percent of sampled wells are of drilled construction and a significant proportion (22.5 percent) are sand point wells. Sand point (also known as drive-point) wells are typically completed at shallower depths than drilled wells (MDH, 2014). Sand point wells are also usually installed in areas where sand is the dominant geologic material and where there are no thick confining units such as clay. This makes sand point wells more vulnerable to contamination from the surface. As mentioned previously hand dug wells are also shallow and more sensitive to local surface runoff contamination than deeper drilled wells. There were only two hand dug wells sampled in the townships.

Most of the sampled wells (60.5 percent) are less than 100 feet deep. Less than 1 percent of homeowners have wells over 300 feet deep. Approximately, 26.5 percent of homeowners did not know or did not response to this question.

Most of the wells had not been tested for nitrate within the last ten years, or homeowners were unsure if they had been tested. Less than ten percent of homeowners responded that their well had been tested for nitrate in the last year. Therefore, the results from this study will provide new information to most homeowners.

POTENTIAL NITRATE SOURCE DISTANCES

The following summary relates to isolation distances of potential point sources and non-point sources of nitrate that may contaminate wells. This information was obtained from the well surveys completed by the homeowner. Complete well survey results are located in Appendix H at the end of this document (Tables 20-34).

- On average, farming takes place on ten percent of the properties.
- Agricultural fields are less than 100 feet from wells at less than 3 percent of the properties.
- Approximately two percent well owners across all the townships responded that they have livestock (greater than ten head of cattle or other equivalent) on their property.
- The majority of wells (over 62 percent) are over 300 feet from an active or inactive feedlot. Additionally 30.5 percent of people did not respond to this survey question.
- None of the well owners in the study townships responded that they store more than 500 pounds of fertilizer on their property.
- A small minority of wells (less than four percent) are less than 50 feet away from septic systems.

FINAL RESULTS

FINAL WELL DATASET

A total of 200 well water samples were collected by homeowners across three townships. After thorough analysis, 17 (8.5 percent) wells were found to be unsuitable and were removed to create the final well dataset. The final analysis was conducted on the remaining 183 wells (Table 6). The wells in the final well dataset represent drinking water wells potentially impacted by applied commercial agricultural fertilizer.

WELL WATER NITROGEN ANALYSIS

The final analysis was based on the number of wells at or over the nitrate HRL of 10 mg/L.

Table 6 shows the results for all townships sampled. The percent of wells at or over the HRL ranged from 6.6 to 12.5 percent.

Table 6. Initial and Final Well Dataset Results, Becker County

Township	Initial Well Dataset	Final well Dataset	Final Wells ≥10 mg/L Nitrate-N	
			Count	Percentage
Carsonville	32	29	2	6.9%
Osage	131	122	8	6.6%
Pine Point	37	32	4	12.5%
Total	200	183	14	7.7%

The individual nitrate results from this final well dataset are displayed spatially in Figure 6. Due to the inconsistencies with geocoding the locations, the accuracy of the points is variable.

The final well dataset summary statistics are shown in Table 7. The minimum values were all below the detection limit. The maximum values ranged from 17.9 to 22.4 mg/L nitrate, with Osage and Pine Point Townships having the highest results. The 90th percentile ranged from 4.2 to 15.5 mg/L nitrate-N, with Carsonville Township having the lowest result and Pine Point Township having the highest result.

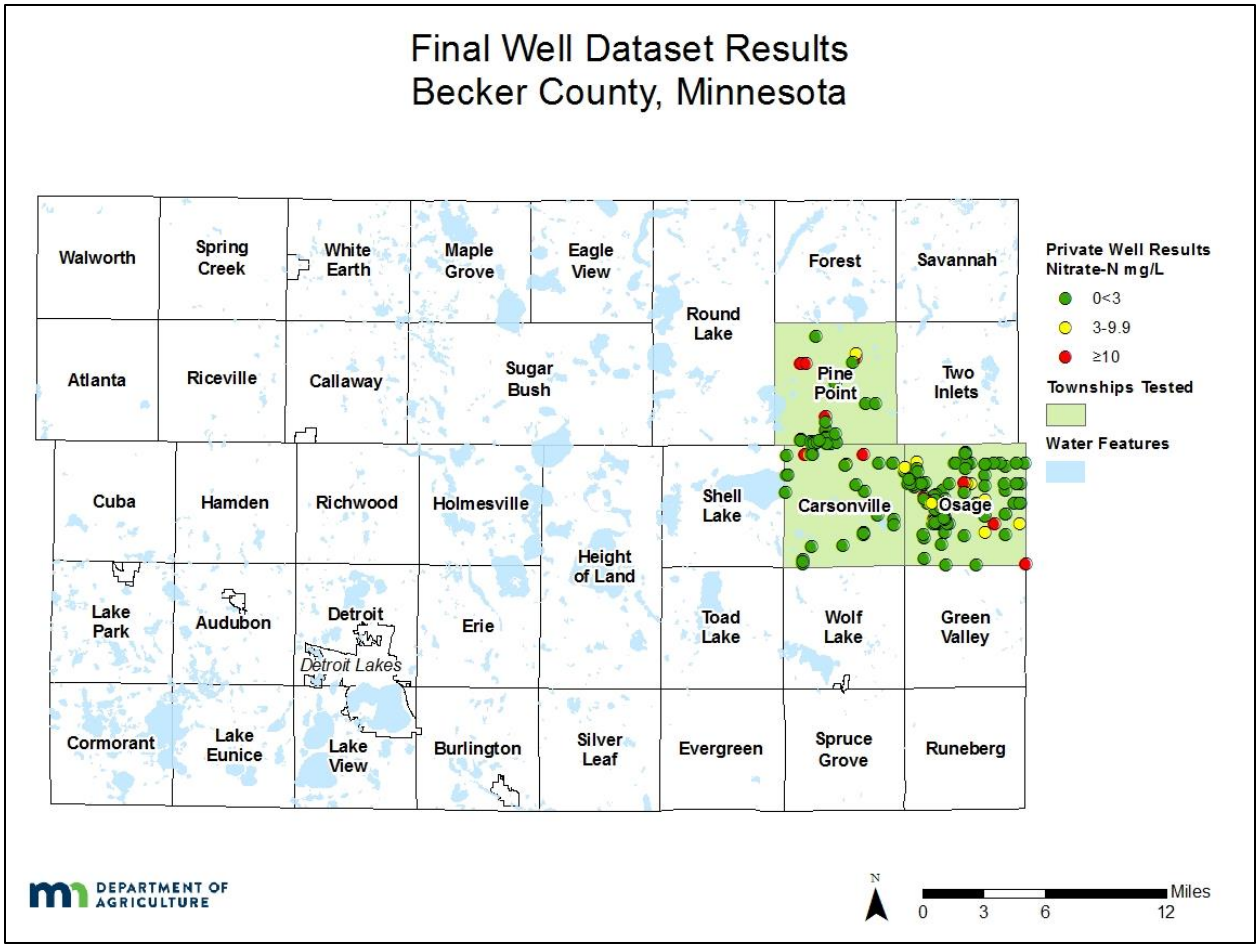

Figure 6. Well Locations and Nitrate Results from Final Well Dataset in Becker County

Table 7. Becker County Township Testing Summary Statistics for Final Well Dataset

Township	Total Wells	Values			Percentiles					Number of Wells					Percent of Wells				
		Min	Max	Mean	50th (Median)	75th	90th	95th	99th	<3	3<10	≥5	≥7	≥10	<3	3<10	≥5	≥7	≥10
		Nitrate-N mg/L or parts per million (ppm)																	
Carsonville	29	<DL	17.9	1.5	<DL	0.5	4.2	12.3	17.9	25	2	2	2	2	86.2%	6.9%	6.9%	6.9%	6.9%
Osage	122	<DL	22.4	2.1	0.3	2.2	7.3	10.5	20.0	97	17	15	13	8	79.5%	13.9%	12.3%	10.7%	6.6%
Pine Point	32	<DL	22.4	2.6	<DL	0.1	15.5	21.0	22.4	27	1	5	5	4	84.4%	3.1%	15.6%	15.6%	12.5%
Total	183	<DL	22.4	2.1	<DL	1.8	7.4	13.2	22.0	149	20	22	20	14	81.4%	10.9%	12.0%	10.9%	7.7%

<DL stands for less than detectable limit. The detectable limit is <0.03 to nitrate-N. The 50th percentile (75th, 90th, 95th, and 99th, respectively) is the value below which 50 percent (75%, 90%, 95% and 99%) of the observed values fall

As discussed previously, the areas selected were deemed most vulnerable to nitrate contamination of groundwater. Table 8 compares the final results to the percent of vulnerable geology (MDNR, 1991) and row crop production (USDA NASS, 2013) in each township. The percent land area considered vulnerable geology and in row crop production was estimated using a geographic information system known as ArcGIS.

Table 8. Township Nitrate Results Related to Vulnerable Geology and Row Crop Production, Becker County

Township	Final Well Dataset	Percent of Land in Row Crop Production 2013*	Percent of Land in Vulnerable Geology	Percent ≥7 Nitrate-N mg/L or parts per million (ppm)	Percent ≥10 Nitrate-N mg/L or parts per million (ppm)
Carsonville	29	3%	31%	6.9%	6.9%
Osage	122	8%	91%	10.7%	6.6%
Pine Point	32	17%	88%	15.6%	12.5%
Total	183	9%	70%	10.9%	7.7%

*Data retrieved from USDA NASS Cropland Data Layer, 2013

WELL AND WATER CHARACTERISTICS

WELL CONSTRUCTION

Unique identification numbers from well logs were compiled for the wells in the Becker County final well dataset. The well logs provided information on the well age, depth, and construction type (MDH Minnesota Well Index Database; https://apps.health.state.mn.us/cwi/). These well characteristics for the final well dataset were also provided by some homeowners. The well characteristics are described below and a more comprehensive view is provided in Appendix I (Tables 35-37).

- The majority of wells were drilled (62 percent), and 38 wells (21 percent) were identified as sand point wells.
- The median depth of wells was 65 feet, and the shallowest was 40 feet.
- The median year the wells were constructed in was 2002.

WELL WATER PARAMETERS

MDA staff conducted the follow-up sampling and well site surveys at 52 wells. Only 44 follow-up wells are included in the final well dataset. Of these, two did not have DO recorded and one did not have any field measurements recorded. Field measurements of the well water parameters were recorded on the first page of the Private Well Field Log & Well Survey Form (Appendix J). The measurements included temperature, pH, specific conductivity, and dissolved oxygen. The well was purged for 15 minutes, so that the measurements stabilized, ensuring a fresh sample of water was collected. The stabilized readings for the final well dataset are described below and a more comprehensive view is available in Appendix K (Tables 38-41).

- The temperatures ranged from 7.61 °C to 19.96 °C
- The median specific conductivity was 502 µS/cm, and was as high as 659 µS/cm
- The water from the wells had a median pH of 7.50
- The dissolved oxygen readings ranged from 0.11 mg/L to 8.72 mg/L

Water temperature can affect many aspects of water chemistry. Warmer water can facilitate quicker chemical reactions, and dissolve surrounding rocks faster; while cooler water can hold more dissolved gases such as oxygen (USGS, 2016).

Specific conductance is the measure of the ability of a material to conduct an electrical current at 25°C. Thus the more ions present in the water, the higher the specific conductance measurement (Hem, 1985). Rainwater and freshwater range between 2 to 100 µS/cm. Groundwater is between 50 to 50,000 µS/cm (Sanders, 1998).

The United States Environmental Protection Agency has set a secondary pH standard of 6.5-8.5 in drinking water. These are non-mandatory standards that are set for reasons not related to health, such as taste and color (40 C.F.R. §143).

Dissolved oxygen concentrations are important for understanding the fate of nitrate in groundwater. When dissolved oxygen concentrations are low (<0.5 mg/L) (Dubrovsky et al., 2010), bacteria will use electrons on the nitrate molecule to convert nitrate into nitrogen gas (N_2). Thus nitrate can be removed from groundwater through the process known as bacterial denitrification (Knowles, 1982).

SUMMARY

The focus of this study was to assess nitrate concentrations in groundwater impacted by row crop production in selected townships in Becker County. In order to prioritize testing, the MDA looked at townships with significant row crop production and vulnerable geology. Approximately 9 percent of the land cover is row crop agriculture and 20 percent of the land is considered pastureland or hay. There is about 13,169 acres of agricultural groundwater irrigation within the study area. In total the three townships sampled cover over 68,000 acres.

The initial (homeowner collected) nitrate sampling resulted in 200 samples. The 200 households that participated represent approximately 45 percent return rate of homeowner offered sampling kit. Well owners with measureable nitrate results were offered a follow-up nitrate sample and a pesticide sample. The MDA visited and collected follow-up samples at 52 wells.

The MDA conducted a nitrogen source assessment and identified wells near potential point sources and wells with poor construction. A total of 17 (8.5 percent) wells were found to be unsuitable and were removed from the final well dataset of 183 wells. The remaining 183 wells were wells believed to be impacted by nitrogen fertilizer and were included in the final well dataset.

In the final dataset a majority of wells (62 percent) are drilled; and 21 percent are sand point wells. The median depth of the wells is 65 and depths range from 40 to 298 feet.

For the final well dataset, only Pine Point Township had more than 10 percent of wells at or over the nitrate Health Risk Limit of 10 mg/L. The percent of wells at or over the nitrate Health Risk Limit in each township ranged from 6.6 to 12.5 percent.

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APPENDIX A

Well information and Potential Nitrate Source Inventory Form

Site ID_____Unique ID_____ Date _____

MDA -Private Well Field Log & Well Survey Form

Water Treatment Information

1. Is this well used for drinking water? ☐ Yes ☐ No
2. Is there an indoor water treatment system? ☐ Yes ☐ No

   If yes, check system: ☐ Activated Carbon ☐ Distilled ☐ Iron Filter
   ☐ Reverse Osmosis ☐ Sediment Filter ☐ Softened
   ☐ Other_____
3. Is there water treatment on the outdoor spigot? ☐ Yes ☐ No

   If yes, what type?_____

Well Construction Information

	HO Survey	Homeowner or Observation (circle one or both)	Well Log
Construction Type			
Construction Date			
Well Depth			
Well Diameter			
Well/Pump Installer			

1. Have you made any changes to your well in the last year? ☐ Yes ☐ No

   If yes, what type? ☐ Upgraded Well Casing ☐ Raised Well ☐ Replaced Piping
   ☐ Replaced Pump ☐ Replaced Well ☐ Other_____

Field Survey Information

1. Are there any other wells on this property? ☐ Yes ☐ No

   If yes, list well type, use, and UID if available_____
2. Is fertilizer stored on this property? ☐ Yes ☐ No

   If yes, what is the distance and direction from the well?_____
3. Historical fertilizer storage? ☐ Yes ☐ No

   If yes, what is the distance and direction from the well?_____
4. Historic/Abandoned septic system? ☐ Yes ☐ No

   If yes, what is the distance and direction from the well?_____
5. Have pesticides been used in the last month? ☐ Yes ☐ No

   If yes, what type/brand name, when, and location_____

Updated: March, 2017

Site ID_____**Unique ID**_____ **Date** _____

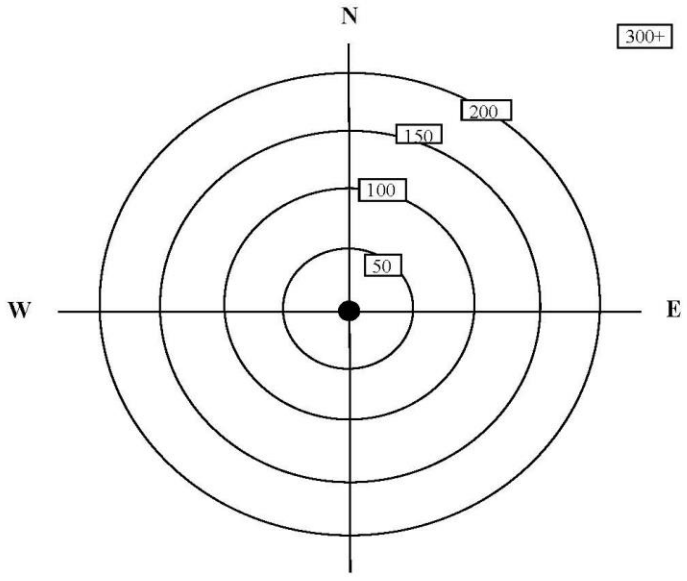
MDA -Private Well Field Log & Well Survey Form

DIRECTIONS

Describe the type, position and distance to potential nitrate sources within 300 feet of the well. Use the bullseye to draw in and label nitrate sources relative to the well (center dot). Indicate house location when applicable.

AFL: Animal Feedlot
AGG: Dry Well, Leaching Pit, Seepage Pit, Injection Well, Ag Drainage Well
APB: Animal/Poultry Building
DRA: Drain field - Above or Below Grade
FIELD: Agricultural Field
FSA: Fertilizer Storage Area
FWP: Feeding or Watering Area
GOLF: Golf Course
LAP: Land Application of Manure, Septage, Sewage
MSA: Manure Storage Area
PRV: Privy (Old Outhouse)
SAA: Small Animal Area (chicken coop, rabbit pen, etc)
SET: Septic Tank

6. Does water drain toward the well? ☐ Yes ☐ No
7. Which direction does the landscape slope? (Draw arrow across bullseye through well)
8. Is the slope: ☐ Steep ☐ Shallow ☐ Flat
9. Are there any *obvious* problems with the well? ☐ Yes ☐ No ☐ No Access ☐ Not Found
   Describe any well issues seen_____
10. Distance from ground surface to bottom of well cap (round to nearest inch)_____
11. Source codes, distances, and direction (<300ft)_____
    _____
12. Source codes, distances, and direction (>300ft)_____



ADDITIONAL SURVEY NOTES

Updated: March, 2017

APPENDIX B

SUBSURFACE SEWAGE TREATMENT SYSTEM

Most homes that have private wells also have private subsurface sewage treatment systems (SSTS). These treatment systems can be a potential point source for contaminants such as nitrate, and fecal material. To protect drinking water supplies in Minnesota, SSTS septic tanks and the associated drain fields are required to be at least 50 feet away from private drinking water wells. The minimum required distance doubles for wells that have less than ten feet of a confining layer or if the well has less than 50 feet of watertight casing (MDH, 2014).

Technical and design standards for SSTS systems are described in Minnesota Rules Chapter 7080 and 7081. Some local government units (LGU) have their own statutes that may be more restrictive or differ from these standards.

Many LGUs collect information on the condition of SSTS in their jurisdiction. Often information is collected when a property is transferred, but this is not a requirement in Becker County (MPCA, 2017a). A SSTS inspection determines if a system is compliant or non-compliant. A non-compliant treatment system can be further categorized as "failing to protect groundwater (FTPGW)" or "imminent threat to public health and safety (ITPHS)". A system is considered FTPGW if it is a seepage pit, cesspool, the septic tanks are leaking below their operating depth, or if there is not enough vertical separation to the water table or bedrock. A system is considered ITPHS if the sewage is discharging to the surface water or groundwater, there is sewage backup, or any other condition where the SSTS would harm the health or safety of the public (Minnesota Statutes, section 115.55.05; MPCA, 2013a).

In 2016 Becker County completed 558 SSTS inspections for compliance (MPCA, 2017a). Compliance inspections are conducted in Becker County upon completion of new or replacement SSTS, when there is a change in use of a building or an expansion that may impact the SSTS, and any other time deemed appropriate such as when a complaint is received (Becker County Zoning Ordinance, 2015).

According to the Draft Becker County Local Water Management Plan 2017-2027, "Becker Planning and Zoning office estimates that the countywide failure rate could exceed 50%" (Becker County SWCD, 2016). Any SSTS determined to be "failing to protect groundwater (FTPGW)" or must be upgraded, repaired, replaced, or abandoned by the homeowner within 10 months of notice. SSTS that are an "Imminent Threat to Public Health or Safety" have 30 days for corrective action from the time of notice, but must be pumped within 24 hours (Becker County Zoning Ordinance, 2015).

FEEDLOT

The amount of nitrogen in manure depends on the species of animal. For example, there are approximately 31 pounds of nitrogen in 1,000 gallons of liquid dairy cow manure, and 53-63 pounds in 1,000 gallons of liquid poultry manure. Most of the nitrogen in manure is in organic nitrogen or in ammonium (NH_4^+) forms (Hernandez and Schmitt, 2012).

Under the right conditions organic nitrogen can be converted into ammonium and then eventually transformed into nitrate. Nitrate is a highly mobile form of nitrogen that can move into groundwater and become a contamination concern (MPCA, 2013b).

Government agencies regulate feedlots to reduce the risk of contamination to water resources. Rules pertaining to feedlots have been in place since the 1970's; they were revised in 2000 and 2014 (MPCA, 2017c). The degree of regulation of a feedlot is dependent on the amount of manure that is produced; measured in animal units (AU) (MPCA, 2011). One AU is equal to the amount of manure produced by one beef cow (Table 9) (MPCA, 2017c).

Table 9. Animal Unit Calculations (MPCA, 2017c)

Animal Type	Number of Animal Units (AU)
Mature dairy cow (over 1,000 lbs.)	1.4
Cow/calf pair	1.2
Stock cow/steer	1.0
Horse	1.0
Dairy heifer	0.7
Swine (55-300 lbs.)	0.3
Sheep	0.1
Broiler (over 5 lbs., dry manure)	0.005
Turkey (over 5 lbs.)	0.018

Animal feedlots with 1-300 AU require a 50 foot setback from private water wells. Larger feedlots (≥300 AU) must be at least 100 feet away from private water wells. The minimum required distance doubles for wells that have less than ten feet of a confining layer or if the well has less than 50 feet of watertight casing (MDH, 2014).

Farmers must register a feedlot through the Minnesota Pollution Control Agency (MPCA) if they have at least 50 AU, or 10 AU if the feedlot is located near shoreline. Larger feedlots must follow additional regulations. Feedlots with more than 300 AU must submit a manure management plan if they do not

use a licensed commercial applicator. Feedlots with more than 1,000 AU are regulated through federal National Pollutant Discharge Elimination (NPDES) permits (MPCA, 2011) and must submit an annual manure management plan as part of their permit (MPCA, 2015).

As part of new feedlot construction, an environmental assessment must be completed for feedlots with a proposed capacity of greater than 1,000 AU. If the feedlot is located in a sensitive area the requirement for an environmental assessment is 500 AU (MPCA, 2017c). Farmers must register their feedlot if it is in active status. Feedlots are considered active until no animals have been present on the feedlot for five years. To register, farmers fill out paperwork which includes a chart with the type and maximum number of animals on the feedlot (MPCA, 2017b). Registration is required to be completed at least once during a set four year period; the current period runs from January 2018 to December 2021. As of November 2017, approximately 24,000 feedlots were registered in Minnesota (MPCA, 2017c). A map and table of the feedlots located in the Becker County study area can be found below (Figure 7; Table 10). As of February 2018 there are no active feedlots in the Becker County study area townships.

Table 10. Feedlots and Permitted Animal Unit Capacity, Becker County

Township	Total Feedlots	Active Feedlots	Inactive feedlots	Average AU Permitted** Per Feedlot	Total Permitted** AU	Total Square Miles	Permitted** AU per Square Mile
Carsonville	1	0	1	0	0	36	0
Osage	0	0	0	0	0	36	0
Pine Point	1	0	1	0	0	36	0
Total	2	0	2	*0	0	108	*0

* Represents an average value

** Animals permitted may not be the actual animals on site. The total animals permitted is the maximum number of animals that are permitted for a registered feedlot. It is common for feedlots to be have less

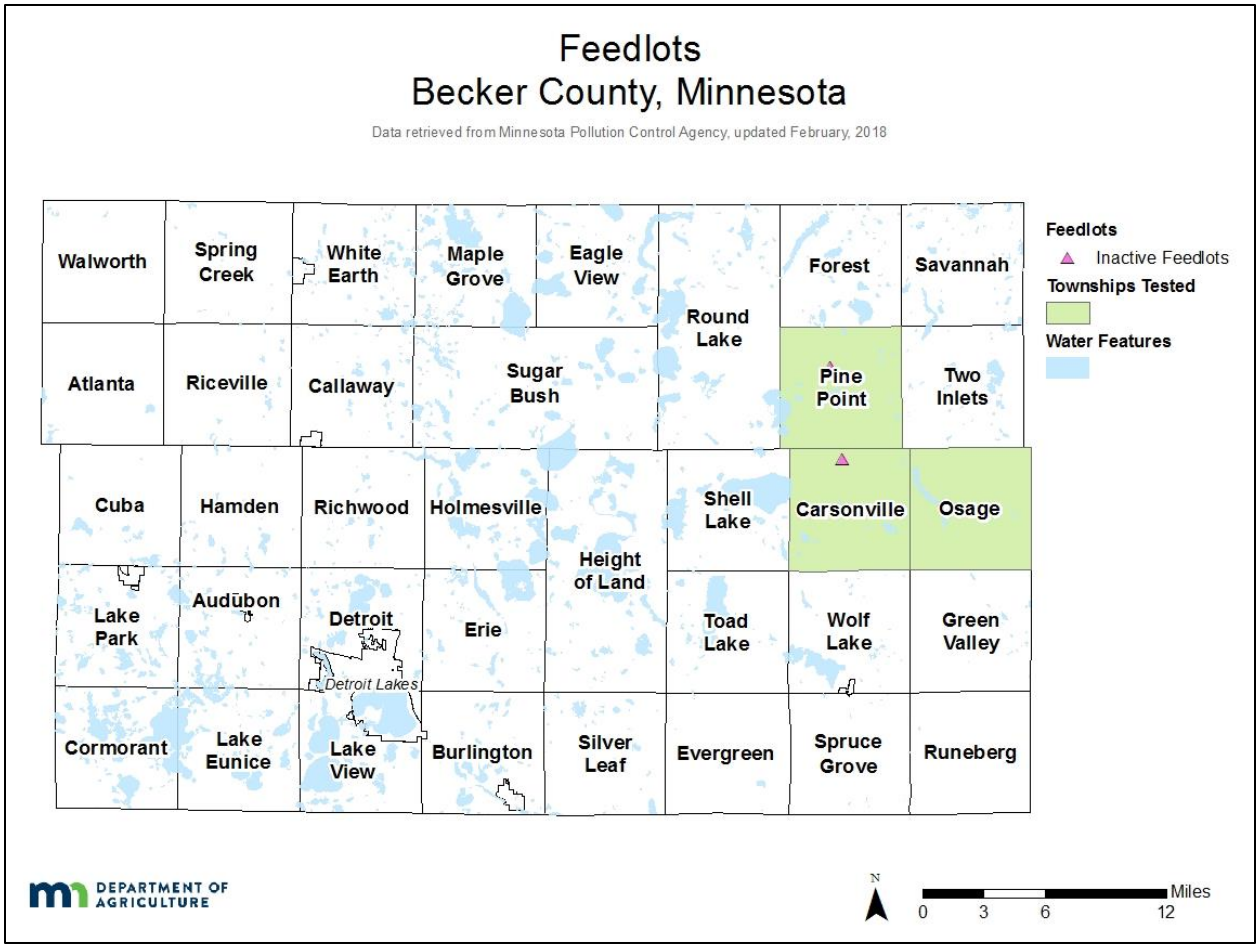


Figure 7. Feedlot Locations in Becker County (MPCA, 2018)

FERTILIZER STORAGE LOCATION

MDA tracks licenses for bulk fertilizer storage facilities, anhydrous ammonia, and chemigation sites (Table 11). Abandoned sites are facilities that once housed fertilizer chemicals. These sites are also noted and tracked by the MDA as they are potential contamination sources.

Table 11. Fertilizer Storage Facility Licenses and Abandoned Sites, Becker County

Township	*Bulk Fertilizer Facility	*Anhydrous Ammonia	*Abandoned Sites	*Chemigation Sites	Total
Carsonville	0	0	0	15	15
Osage	1	0	0	29	30
Pine Point	0	0	0	38	38
Total	1	0	0	82	83

*Data retrieved from MDA Pesticide and Fertilizer Management Division, 2018; updated March 2018

SPILLS AND INVESTIGATIONS

The MDA is responsible for investigating any fertilizer spills within Minnesota. Figure 8 shows the locations of mapped historic spills within the Becker County study area from fertilizer. While other types of spills are recorded, only sites that are potential point sources of nitrogen to the groundwater are reported here (MDA, 2017).

The MDA tracks several types of incidents. Incident investigations are typically for larger spills. There are none in the study area. Contingency areas are locations that have not been remediated because they were inaccessible or the contaminant could not be removed for some other reason. They are often a part of an incident investigation. There are no contingency areas in this study area. Old emergency incidents were closed prior to March 1st, 2004 (MDA, 2017), but they can still be a point source. At most of these older sites, the contaminants are unknown and their location may not be precise. There are none in the study area. Small spills and investigations are typically smaller emergency spills such as a truck spilling chemicals. There are none in the study area. It is important to note that while the locations of the incidents described are as accurate as possible, it is an incomplete dataset (MDA, 2017). Many types of spills are reported to the MDA, however only spills that potentially contain nitrogen are reported here. A breakdown of chemical type of these incidents can be found in Table 12. A breakdown of the fertilizer specific spills and investigations, by township, can be found in Table 13.

Table 12. Spills and Investigations by Chemical Type, Becker County

Contaminant	Incident Investigations	Contingency Areas	Small Spills and Investigations	Old Emergency Incidents	Total
Fertilizer	0	0	0	0	0
Pesticides & Fertilizer	0	0	0	0	0
Anhydrous Ammonia	0	0	0	0	0
Total	0	0	0	0	0

Table 13. Fertilizer Related Spills and Investigations by Township, Becker County

Township	Incidents and Spills
Carsonville	0
Osage	0
Pine Point	0
Total	0

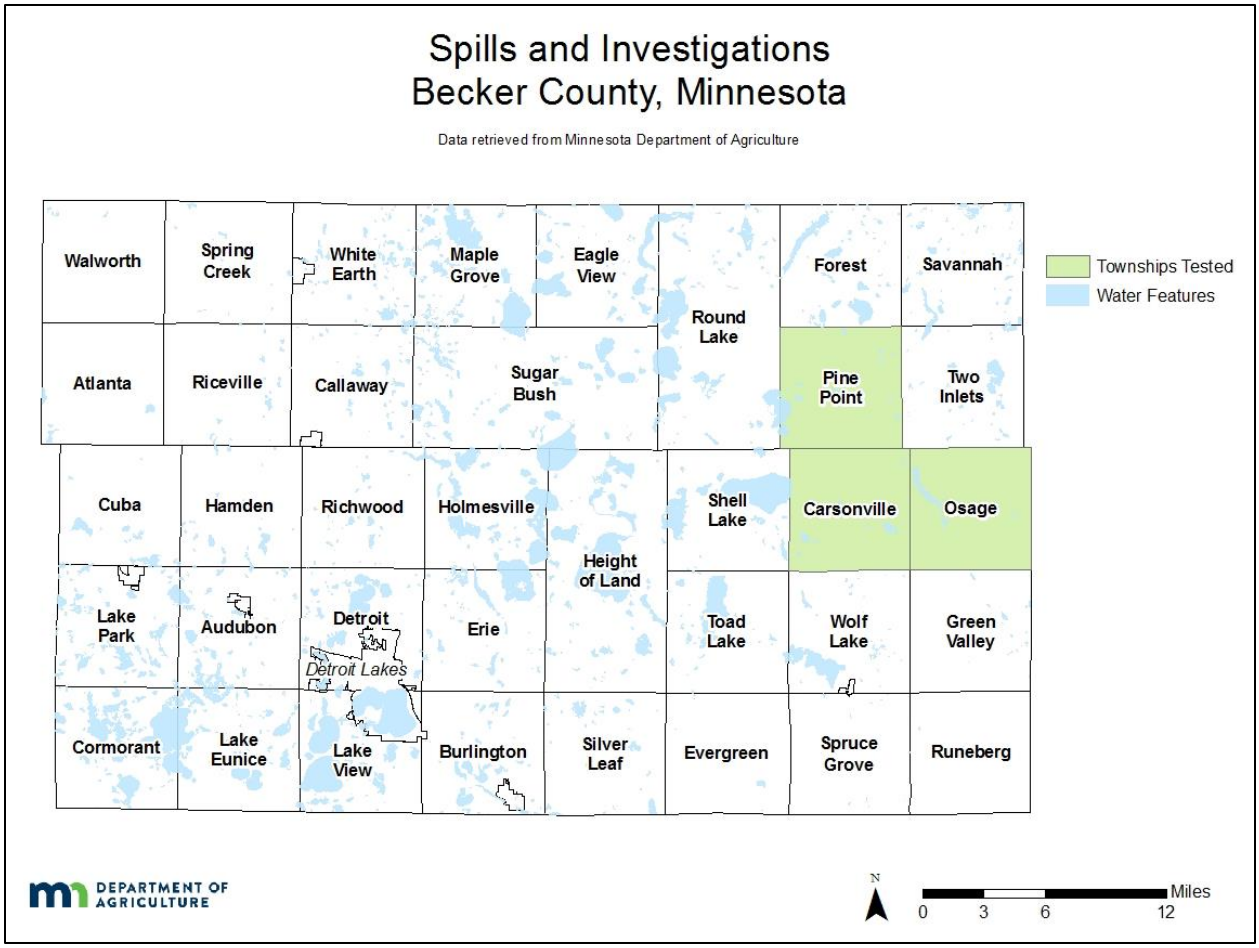


Figure 8. Fertilizer Spills and Investigations in Becker County (MDA, 2018)

APPENDIX C

LAND AND WATER USE

LAND COVER

Typically locations were selected for the Township Testing Program if at least 20 percent of the land cover was in row crop production. Overall, Becker County is not dominated by row crop agriculture. However, there is a high density of row crops in the northwest part of the county and a small band that cuts diagonally through Pine Point, Carsonville and Osage Townships (Figure 9; Table 14). Row crops can include: corn, sweet corn, soybeans, alfalfa, sugar beets, potatoes, durum wheat, dry beans and double crops involving corn and soybeans.

Becker County is located in northwest Minnesota and in the heart of "cabin country". There are many lakes and expanses forested land. In Carsonville, 70% of the land is classified as forest and in the other study townships more than 1/3 of land is forested. Only 8% of the land from the study area is classified as open water or wetland, as many of the larger lakes are in central Becker County.

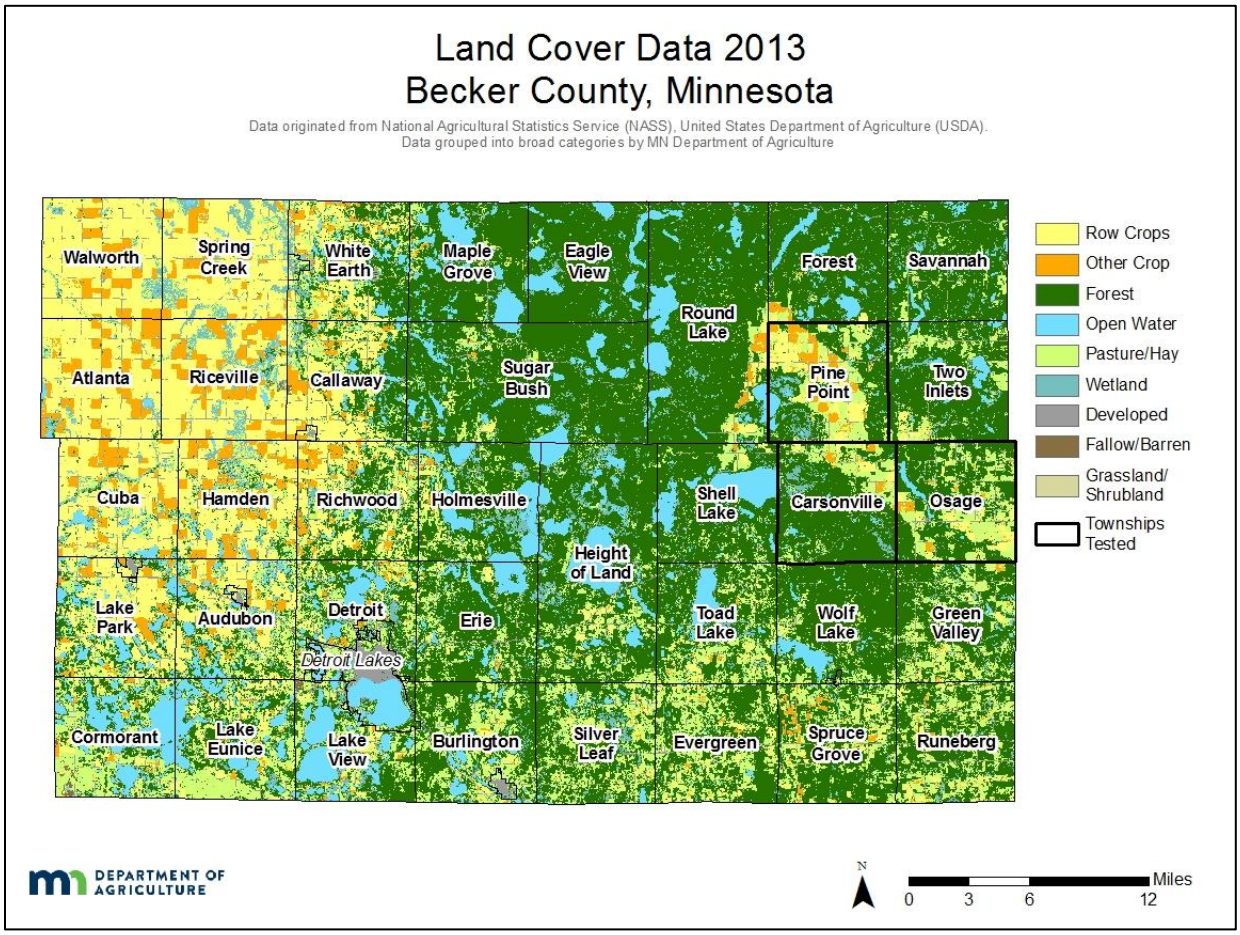


Figure 9. Land Cover in Becker County (USDA NASS Cropland Data Layer, 2013)

Table 14. Land Cover Data (2013) by Township, Becker County (USDA NASS Cropland Data Layer, 2013)

Township	Total Acres	Row Crops	Other Crops	Forest	Open Water	Pasture/ Hay	Wetland	Developed	Fallow/ Barren	Grassland/ Shrubland
Carsonville	22,854	3%	2%	70%	2%	14%	6%	3%	0%	1%
Osage	22,961	8%	3%	54%	2%	25%	2%	4%	0%	2%
Pine Point	23,066	17%	11%	36%	4%	22%	6%	3%	0%	1%
Average	68,881*	9%	5%	53%	3%	20%	5%	3%	0%	1%

* Represents a total

WATER USE

Water use permits are required for wells withdrawing more than 10,000 gallons of water per day or 1,000,000 gallons of water per year (MDNR, 2016). There are a total of 108 active groundwater well permits in the study area, and all are used for agricultural irrigation (Figure 10). Typically groundwater use permits are granted for other uses such as non-crop irrigation, municipal water supply, industrial processing, and livestock watering. About 13,169 acres of cropland are permitted for groundwater irrigation in this area (Table 15). Most permitted wells are withdrawing groundwater from water table aquifers (Table 16; MDNR, 2017).

Table 15. Active Groundwater Use Permits by Township, Becker County

Township	Major Crop Irrigation Well Permits	Average Depth (feet)	Irrigated Acres Permitted
Carsonville	14	109	1,725
Osage	39	119	4,435
Pine Point	55	99	7,009
Total	108	107	13,169

Table 16. Active Groundwater Use Permits by Aquifer, Becker County

Water Use Well Permits	Total	Average Depth (feet)	Aquifer			
			Water Table	Quaternary	Paleozoic	Not Classified
Agricultural Irrigation	108	107	78	28	0	2
Total	108	107	78	28	0	2

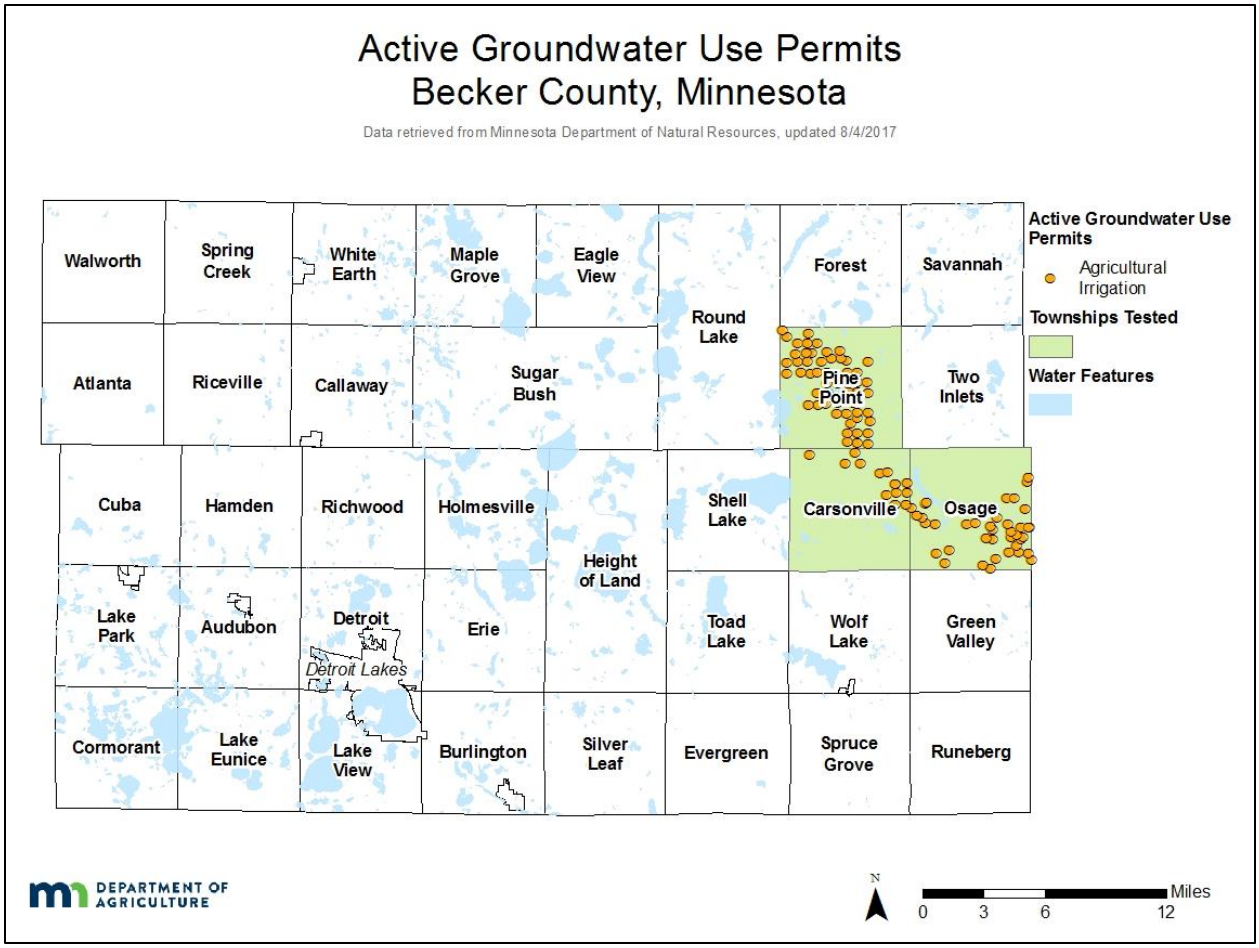


Figure 10. Active Groundwater Use Permits in Becker County (MDNR, 2017)

APPENDIX D

Nitrate Brochure

The Minnesota Department of Agriculture and the Becker County SWCD would like to **thank you** for participating in the private well volunteer nitrate monitoring. The results of your water sample are enclosed. Results from this sampling event will be reviewed and summarized and a summary report will be issued to the counties. In addition, the data will be used to determine the need and the design of a long-term monitoring network. Below is general information regarding nitrate result ranges.

If the Nitrate result is between 0 to 4.9 mg/L:

- Continue to test your water for nitrate every year or every other year.
- Properly manage nitrogen sources when used near your well.
- Continue to monitor your septic tank. Sewage from improperly maintained septic tanks may contaminate your water.
- Private wells should be tested for bacteria at least once a year. A Minnesota Department of Health (MDH) certified water testing lab can provide nitrate and bacteria testing services. Search for the lab nearest you at www.health.state.mn.us/labsearch.

If the Nitrate result is between 5 to 9.9 mg/L:

- Presently the nitrate nitrogen level in your water is below the nitrate health standard for drinking water. However, you have a source of contamination which may include: contributions from fertilized lawns or fields, septic tanks, animal wastes, and decaying plants.
- Test annually for both nitrate and bacteria. As nitrate levels increase, especially in wells near cropped fields, the probability of detecting pesticides also increases. MDA monitoring data indicates that pesticide levels are usually below state and federal drinking water guidelines. For more information on testing and health risks from pesticides and other contaminants in groundwater go to: http://www.mda.state.mn.us/protecting/waterprotection/pesticides.aspx
- In addition to pesticides, high nitrate levels may suggest an increased risk for other contaminants. For more information go to: http://www.health.state.mn.us/divs/eh/wells/waterquality/test.html

If the Nitrate result is above 10 mg/L:

- **Do not allow this water to be consumed by infants**, Over 10 mg/L is not safe for infants younger than 6 months of age
- **Pregnant women** also may be at risk along with **other people with specific metabolic conditions.** Find a safe alternative water supply.
- Consider various options including upgrading the well if it was constructed before the mid 1970's.
- Be sure to retest your water prior to making any significant financial investment in your existing well system. See link to MDH certified labs listed above.
    - ***Boiling your water increases the nitrate concentration in the remaining water.***

Infants consuming high amounts of nitrates may develop Blue Baby Syndrome (Methemoglobinemia). This disease is potentially fatal and first appears as blue coloration of the fingers, lips, ears, etc. Seek medical assistance immediately if detected

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If you have additional questions about wells or well water quality in Minnesota, contact your local Minnesota Department of Health office and ask to talk with a well specialist or contact the Well Management Section Central Office at health.wells@state.mn.us or at 651-201-4600 or 800-383-9808. If you have questions regarding the private well monitoring contact Nikol Ross at 651-201-6443 or Nikol.Ross@state.mn.us.

APPENDIX E

Table 17. Reasons Wells Were Removed from the Final Well Dataset by Township, Becker County

Township	Point Source	Well Construction Problem	Hand Dug well	Unsure of water source	Site Visit Completed - Well Not Found & Constructed before 1975 & No Well ID	No Site Visit & Constructed before 1975 & No Well ID	No Site Visit & Insufficient Data & No Well ID	Total
Carsonville	0	0	1	0	1	1	0	3
Osage	2	1	0	0	2	2	2	9
Pine Point	1	0	0	1	1	1	1	5
Total	3	1	1	1	4	4	3	17

Table 18. Completed Site Visits for Wells Removed from the Final Well Dataset by Township, Becker County

Township	Site Visit	No Site Visit	Total
Carsonville	2	1	3
Osage	4	5	9
Pine Point	2	3	5
Total	8	9	17

APPENDIX F

MINNESOTA WELL INDEX

The MWI was used to gather information about the three townships in Becker County included in the study. This section includes all drinking water wells in the study area, not just wells MDA sampled. Table 19 summarizes the general aquifer types, while the following is a brief summary of the major aquifer types with the average well depth. According to the information from the MWI (MDH, 2018):

In these townships, there are 346 documented (have a verified location in the MWI), active, domestic wells:

- All wells with an identified aquifer were completed in Quaternary aquifers.
    - The majority of wells were completed in Quaternary Water Table Aquifers. These are the shallowest wells with an average depth of 56.8 feet deep.
    - Only 11 wells (3.2%) were completed in a Quaternary Buried Aquifer, and the average depth is 71.5 feet deep.
    - Approximately 30.3% of the wells withdraw water from the Quaternary Buried Artesian Aquifer. At an average of 136.2 feet, this is the deepest aquifer used locally.
- Very few wells (3.5%) documented wells were missing an aquifer designation. These wells may have a record of completed depth, date drilled or other information, but the aquifer was not identified.
- No documented wells were completed in aquifers from the Mesozoic, Paleozoic, or Precambrian Era.

Table 19. Aquifer Type Distribution of Wells in Minnesota Well Index by Township, Becker County

Township	Quaternary Water Table	Quaternary Buried Unconfined	Quaternary Buried Artesian	Not Available	Total
	Number of wells drawing water from an aquifer				
Carsonville	21	3	41	2	67
Osage	160	8	57	10	235
Pine Point	37	0	7	0	44
Total	218	11	105	12	346
Average Well Depth (feet)	56.8	71.5	136.2	61.5	82.1

APPENDIX G

Example – "Participation Letter and Well Survey"

Private Well Survey for Township Testing Program

The Minnesota Department of Agriculture appreciates you taking the time to answer a few questions about your well. These questions are voluntary, but will help in the analysis of your nitrate results and provide information as to nitrate concentrations across Minnesota. Your name, addresses, telephone numbers, and e-mail addresses are considered private under Minnesota Statutes Chapter 13. Only data from sample results, general location data and unique well number are considered public. Only people with a need to access your data in support of the private well nitrate sampling program will have authority to access your data unless you provide MDA with an informed consent to release the data, upon court order or provided to the state or legislative auditor to review the data. If you don't know an answer to a question, skip it and go on to the next question. Please make corrections to contact information if needed.

First name _____ **Last name**_____

Parcel Number_____ **Township**_____

Physical address_____ **City**_____ **State**_____ **Zip**_____

Mailing address _____ **City**_____ **State**_____ **Zip**_____

Phone number _____ **(in case we have questions about your survey) Email**_____

1. What setting did the water sample home from? Please choose only one.
   ☐ Sub-division ☐ Lake Home ☐River Home ☐ Country ☐Municipal/City* ☐ Other

*** If municipal/City well, stop here, your well will not be included in the private well sampling.**

2. Are there livestock on this property?
   (more than 10 head of cattle, 30 head of hogs or an equivalent number of other livestock)
   ☐ Yes ☐ No
3. Do you mix or store fertilizer (500 lb. or more) on the farm site? ☐ Yes ☐ No
4. Does farming take place on this property? ☐ Yes ☐ No

WELL INFORMATION

It is extremely helpful if you can go to your well and look for the Unique Well Number - this is a *6 digit number* found on a metal tag attached to your well casing.

5. Does your well have a Unique Well ID number? ☐ Yes ☐ No ☐Don't Know

6. If **yes**, what is the Unique Well ID? _____ (*6 digit number* found on a metal tag attached to your well casing)

7. Type of **well construction**?	☐ Drilled	☐ Sand point	☐ Hand Dug Well	☐Don't Know	☐ Other
8. Approximate **age** of your well?	☐ 0 - 10 years	☐ 11 - 20 years	☐ 21 - 40 years	☐ over 40 years	
9. Approximate **depth** of your well?	☐ 0 - 49 Feet	☐ 50 -99 feet	☐ 100 - 299 feet	☐ >=300 feet	
10. Distance to an active or inactive feedlot?	☐ 0 - 49 Feet	☐ 50 -99 feet	☐ 100 - 299 feet	☐ >=300 feet	
11. Distance to a septic system?	☐ 0 - 49 Feet	☐ 50 -99 feet	☐ 100 - 299 feet	☐ >=300 feet	
12. Distance to an agricultural field?	☐ 0 - 49 Feet	☐ 50 -99 feet	☐ 100 - 299 feet	☐ >=300 feet	

13. Is this well currently used for human consumption (Drinking or Cooking)? ☐ Yes ☐ No

14. Please check any water treatment you have **other than a water softener**.
   ☐ None ☐ Reverse Osmosis ☐ Distillation ☐ Filtering system ☐ Other

15. When did you last have your well tested for nitrates?
   ☐ Never tested ☐ Within the last year ☐ Within the last 3 years
   ☐ Within the last 10 years ☐ Greater than 10 years ☐ Not sure

16. What was the result of your **last** nitrate test?
   ☐ <3 mg/L (ppm) ☐ 3<10 mg/L(ppm) ☐ >=10 mg/L (ppm) ☐ Don't Know

9

APPENDIX H

Table 20. Property Setting for Well Location

Township	Total	Country	Municipal	River home	Lake Home	Sub-division	Other	Not Available
Carsonville	32	84.4%	0.0%	3.1%	6.3%	0.0%	0.0%	6.3%
Osage	131	54.2%	0.8%	1.5%	28.2%	0.8%	4.6%	9.9%
Pine Point	37	45.9%	0.0%	0.0%	0.0%	0.0%	2.7%	51.4%
Total	200	57.5%	0.5%	1.5%	19.5%	0.5%	3.5%	17.0%

Table 21. Well Construction Type

Township	Total	Drilled	Sand point	Hand dug	Not Available
Carsonville	32	46.9%	40.6%	3.1%	9.4%
Osage	131	63.4%	21.4%	0.0%	15.3%
Pine Point	37	35.1%	10.8%	0.0%	54.1%
Total	200	55.5%	22.5%	0.5%	21.5%

Table 22. Age of Well

Township	Total	1994-Present	1985 to 1993	1975 to 1984	before 1975	Not Available
Carsonville	32	43.8%	9.4%	6.3%	21.9%	18.8%
Osage	131	49.6%	7.6%	13.0%	7.6%	22.1%
Pine Point	37	13.5%	8.1%	13.5%	5.4%	59.5%
Total	200	42.0%	8.0%	12.0%	9.5%	28.5%

Table 23. Depth of Well

Township	Total	0-15 Feet Deep	16-49 Feet Deep	50-99 Feet Deep	100-299 Feet Deep	≥ 300 Feet Deep	Not Available
Carsonville	32	6.3%	37.5%	25.0%	15.6%	3.1%	12.5%
Osage	131	2.3%	22.9%	44.3%	13.7%	0.0%	16.8%
Pine Point	37	2.7%	10.8%	8.1%	5.4%	0.0%	73.0%
Total	200	3.0%	23.0%	34.5%	12.5%	0.5%	26.5%

Table 24. Unique Well ID Known

Township	Total	No, Unique Well ID not known	Yes, Unique Well ID known	Not Available
Carsonville	32	28.1%	28.1%	43.8%
Osage	131	25.2%	34.4%	40.5%
Pine Point	37	18.9%	2.7%	78.4%
Total	200	24.5%	27.5%	48.0%

Table 25. Livestock Located on Property

Township	Total	No Livestock	Yes Livestock	Not Available
Carsonville	32	90.6%	3.1%	6.3%
Osage	131	89.3%	1.5%	9.2%
Pine Point	37	43.2%	2.7%	54.1%
Total	200	81.0%	2.0%	17.0%

Table 26. Fertilizer Stored on Property

Township	Total	No Fertilizer Stored	Yes Fertilizer Stored	Not Available
Carsonville	32	93.8%	0.0%	6.3%
Osage	131	90.1%	0.0%	9.9%
Pine Point	37	48.6%	0.0%	51.4%
Total	200	83.0%	0.0%	17.0%

Table 27. Farming on Property

Township	Total	No Farming	Yes Farming	Not Available
Carsonville	32	81.3%	12.5%	6.3%
Osage	131	81.7%	6.9%	11.5%
Pine Point	37	27.0%	18.9%	54.1%
Total	200	71.5%	10.0%	18.5%

Table 28. Distance to an Active or Inactive Feedlot

Township	Total	0-49 Feet to Feedlot	50-99 Feet to Feedlot	100-299 Feet to Feedlot	Over 300 Feet to Feedlot	Not Available
Carsonville	32	0.0%	0.0%	6.3%	78.1%	15.6%
Osage	131	3.8%	0.8%	1.5%	69.5%	24.4%
Pine Point	37	5.4%	5.4%	0.0%	24.3%	64.9%
Total	200	3.5%	1.5%	2.0%	62.5%	30.5%

Table 29. Distance to Septic System

Township	Total	0-49 Feet to Septic	50-99 Feet to Septic	100-299 Feet to Septic	Over 300 Feet to Septic	Not Available
Carsonville	32	0.0%	28.1%	50.0%	6.3%	15.6%
Osage	131	5.3%	35.1%	38.9%	6.9%	13.7%
Pine Point	37	0.0%	5.4%	24.3%	5.4%	64.9%
Total	200	3.5%	28.5%	38.0%	6.5%	23.5%

Table 30. Distance to an Agricultural Field

Township	Total	0-49 Feet to Field	50-99 Feet to Field	100-299 Feet to Field	Over 300 Feet to Field	Not Available
Carsonville	32	0.0%	0.0%	9.4%	75.0%	15.6%
Osage	131	1.5%	2.3%	6.9%	72.5%	16.8%
Pine Point	37	0.0%	0.0%	8.1%	29.7%	62.2%
Total	200	1.0%	1.5%	7.5%	65.0%	25.0%

Table 31. Drinking Water Well

Township	Total	Not Drinking Water	Yes, Drinking Water	Not Available
Carsonville	32	0.0%	93.8%	6.3%
Osage	131	2.3%	88.5%	9.2%
Pine Point	37	0.0%	45.9%	54.1%
Total	200	1.5%	81.5%	17.0%

Table 32. Treatment System Present (Treatment System Used for Drinking Water)

Township	Total	None	Distillation	Filtering System	Reverse Osmosis	Other	Not Available
Carsonville	32	71.9%	0.0%	6.3%	0.0%	3.1%	18.8%
Osage	131	69.5%	0.8%	10.7%	4.6%	0.0%	14.5%
Pine Point	37	32.4%	0.0%	8.1%	2.7%	2.7%	54.1%
Total	200	63.0%	0.5%	9.5%	3.5%	1.0%	22.5%

Table 33. Last Tested for Nitrate

Township	Total	Within the past year	Within the last 3 years	Within the last 10 years	Greater than 10 years	Never Tested	Homeowner Unsure	Not Available
Carsonville	32	0.0%	3.1%	18.8%	28.1%	28.1%	15.6%	6.3%
Osage	131	6.9%	9.9%	6.9%	15.3%	29.8%	22.9%	8.4%
Pine Point	37	10.8%	0.0%	5.4%	5.4%	10.8%	16.2%	51.4%
Total	200	6.5%	7.0%	8.5%	15.5%	26.0%	20.5%	16.0%

Table 34. Last Nitrate Test Result

Township	Total	<3 mg/L Nitrate-N	3<10 mg/L Nitrate-N	≥10 mg/L Nitrate-N	Not Available
Carsonville	32	6.3%	3.1%	0.0%	90.6%
Osage	131	13.0%	5.3%	1.5%	80.2%
Pine Point	37	0.0%	0.0%	8.1%	91.9%
Total	200	9.5%	4.0%	2.5%	84.0%

APPENDIX I

Table 35. Well Construction Type for Final Well Dataset

Township	Total Wells	Drilled	Sand Point	Other	Not Available
Carsonville	29	15	12	0	2
Osage	122	85	24	0	13
Pine Point	32	13	2	0	17
Total	183	113	38	0	32

Data compiled from well logs and homeowner responses.

Table 36. Well Depth for Final Well Dataset

Township	Total Wells	Min	Max	Median	Mean
Carsonville	11	45	298	86	135
Osage	62	40	215	64	76
Pine Point	5	55	70	57	60
Total	78	40	298	65	83

Data compiled from well logs only; homeowner responses are not included.

Table 37. Year of Well Construction for Final Well Dataset

Township	Total Wells	Min	Max	Median	Mean
Carsonville	11	1987	2012	1999	1999
Osage	62	1975	2016	2003	2002
Pine Point	5	1997	2012	2001	2002
Total	78	1975	2016	2002	2001

Data compiled from well logs only; homeowner responses are not included. Most wells do not have a well log if they were constructed before 1974.

APPENDIX J

Private Well Field Log

Site ID_____**Unique ID**_____ **Date** _____

MDA -Private Well Field Log & Well Survey Form

Sample#_____

Duplicate#_____**Field Blank#**_____

Additional Samples_____

Well Owner Contact Information

Name_____

Address_____

Phone #_____Township_____County_____

Sampling Information

Sampler_____Time Arrived_____

Pump Start Time_____Discharge Rate_____Time Collected_____

Sample Point Location_____

Well Location_____

GPS Location_____UTM Easting (X)_____UTM Northing (Y)_____

Weather_____Wind Speed/Direction (mph)_____Air Temp (°F)_____

Nearest possible pesticide source (type, dist., dir.)_____☐ None noticeable

Time	Temp °C (1.0)	Specific Cond µs/cm (10%)	DO mg/L (10%)	pH (0.1)	Appearance/Odor/Notes

Field Comments - sample specific notes

Updated: March, 2017

APPENDIX K

Table 38. Temperature (°C) of Well Water for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Carsonville	4	8.45	12.72	10.66	10.62
Osage	35	7.61	19.96	8.49	8.96
Pine Point	4	8.00	9.48	8.80	8.77
Total	43	7.61	19.96	8.57	9.10

Table 39. pH of Well Water for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Carsonville	4	7.40	7.95	7.68	7.68
Osage	35	7.32	7.81	7.50	7.51
Pine Point	4	7.27	7.60	7.45	7.44
Total	43	7.27	7.95	7.50	7.52

Table 40. Specific Conductivity (µS/cm) of Well Water for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Carsonville	4	199	485	386	364
Osage	35	358	659	512	515
Pine Point	4	429	635	598	565
Total	43	199	659	502	506

Table 41. Dissolved Oxygen (mg/L) of Well Water for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Carsonville	4	0.22	3.13	1.68	1.68
Osage	35	0.11	8.72	4.17	4.02
Pine Point	3	2.41	4.06	3.82	3.43
Total	42	0.11	8.72	3.34	3.76