Final Township Testing Nitrate Report:

Benton County 2013-2017

December 2018

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).

DEPARTMENT OF AGRICULTURE

CLEAN WATER LAND & 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 2013 and 2016, private wells in the Benton County study area (four 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 732 wells representing an average response rate of 35 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, 8.1 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 527 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 186 wells in the summers of 2015 and 2017. 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 42 (6 percent) wells were determined to be unsuitable and were removed from the dataset. The final well dataset had a total of 690 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 1.6 to 14.4 percent. Langola Township revealed significant problems with more than 10 percent of 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 March 2018, 242 townships in 24 counties have completed the initial sampling.

In 2013 and 2016, four townships in Benton County were selected to participate in the Township Testing Program (Figure 1). Areas were chosen based on several criteria. Criteria used includes: 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 Benton County occurred during the summers of 2015 and 2017. 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

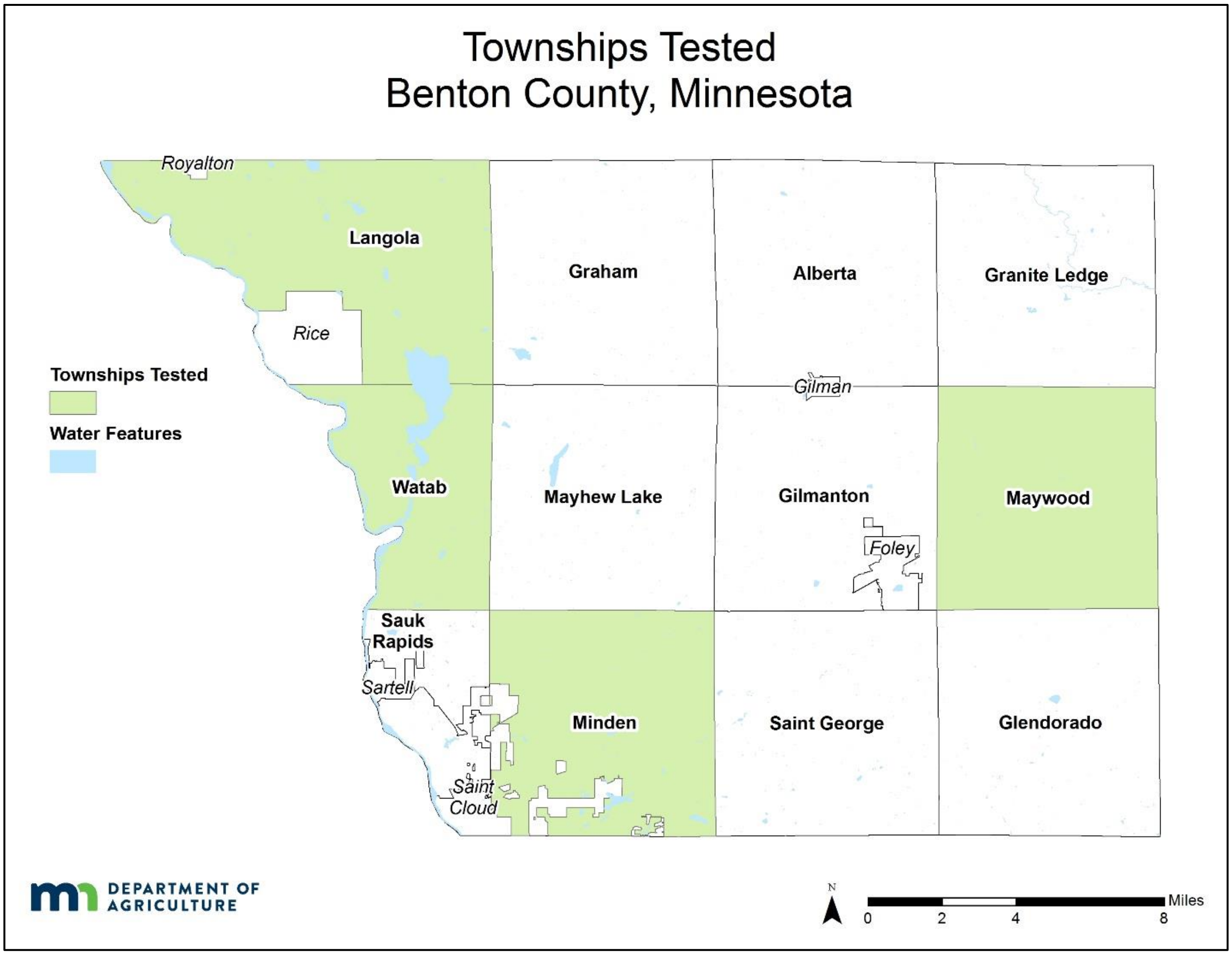

Figure 1. Townships Tested in Benton County

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 (US EPA, 2009) in municipal water systems. 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 considered very stable and can move large distances from its source. However, in some settings nitrate in groundwater may be converted to nitrogen gas in the absence of oxygen and the presence of organic carbon, through a natural process called denitrification. Denitrification occurs when oxygen levels are depleted and nitrate becomes the primary oxygen source for microorganisms. In systems with sandy unconfined aquifers, such as parts of Benton County, contaminants such as nitrate can travel quickly to the aquifer, leaving little chance for denitrification or other attenuating processes. As a result certain areas of Benton County, with shallow unconfined sandy aquifers (Rivord, 2012a; Rivord 2012b), and intensive row crop agriculture, are particularly vulnerable to elevated nitrate concentrations. However, geochemical conditions can be highly variable within an aquifer or region and can also change over-time (MPCA, 1998).

GEOLOGY AND HYDROGEOLOGY

Most private groundwater wells in Benton County withdraw water from either surficial or buried sand and gravel aquifers. Only five percent draw water from bedrock aquifers (Rivord, 2012a). The surficial sand aquifers (also known as water table aquifers) are thickest in the northwestern corner of Benton County in a region known as the Rice Area aquifer system. The surficial sand and gravel in this area was deposited during glacial melting when the Mississippi River was much broader and flowed well outside its current banks (Rivord, 2012b). The surficial sand in the Rice Area aquifers is displayed as “outwash” in Figure 2. The fluvial sediment from this glacial meltwater also created buried aquifers in the same region. Thin glacial till, with a moderate to high hydrologic conductivity, separates the surficial and buried aquifers creating a hydrologically connected aquifer system. The groundwater flow in the Rice Area aquifer system generally flows towards the Mississippi with some local flow towards Little Rock Lake.

There are also substantial water table aquifers along the southern most county border, these are part of the Anoka Sand Plains aquifer system (Rivord, 2012b). Similar to the Rice Area aquifers, the buried aquifers in the Anoka Sand Plain region are only separated from surficial aquifers by thin stretches of glacial till. The groundwater flow in the surficial and buried sand aquifers in this region generally flow south toward Sherburne County. The buried sand aquifers in the Rice Area and Anoka Sand Plain aquifers can be defined as unconfined or semi-confined systems (Rivord, 2012a).

In the north eastern parts of Benton County, east of Little Rock Lake and north of highway 95, there are confined buried aquifers (Rivord, 2012a). These aquifers are typically buried beneath thick layers of till. The extent of the glacial till is depicted in Figure 2. The surficial till in this region is chiefly subglacial till with supraglacial till in the northeast corner. There are also numerous drumlins through throughout the till plains. Drumlins are streamlined hills created by glaciers (Meyer, 2010).

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 Benton County as presented in Figure 2.

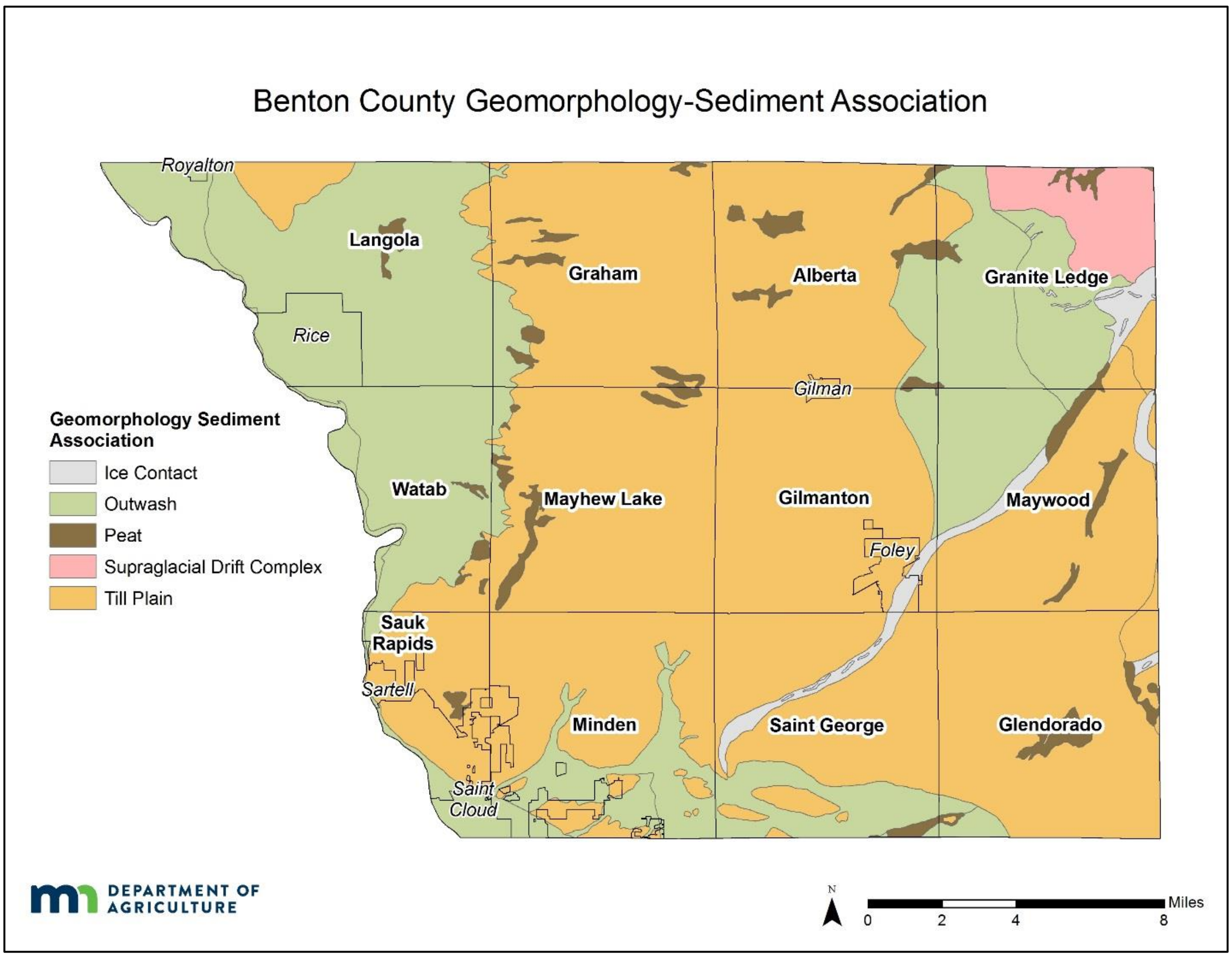

Figure 2. Statewide Geomorphology Layer, Sediment Association in Benton County (DNR, MGS, and UMD, 1997)

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 Benton 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). A total of 3,895 SSTS were reported in Benton County for 2016. Over a recent 15 year period (2002-2016), 1,619 construction permits for new, replacement, or repairs for SSTS were issued. Of all the reported septic systems in Benton County, 42 percent are newer than 2002 or have been repaired since 2002 (MPCA, 2017a). 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).

FEEDLOT

Manure produced on a feedlot can be a potential source of nitrogen pollution if improperly stored or spread. In the Benton County study area there are a total of 19 active feedlots. There are 7 (37%) active feedlots permitted to house 300 or more animal units (AU) (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 Benton County study area has a total of 99 fertilizer storage licenses with the majority (85%) in Langola Township (Appendix B; Table 11).

FERTILIZER SPILLS AND INVESTIGATIONS

A total of 48 historic fertilizer spills and investigations occurred in the Benton County study area. The majority of these were old emergency spills located in Langola Township (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.

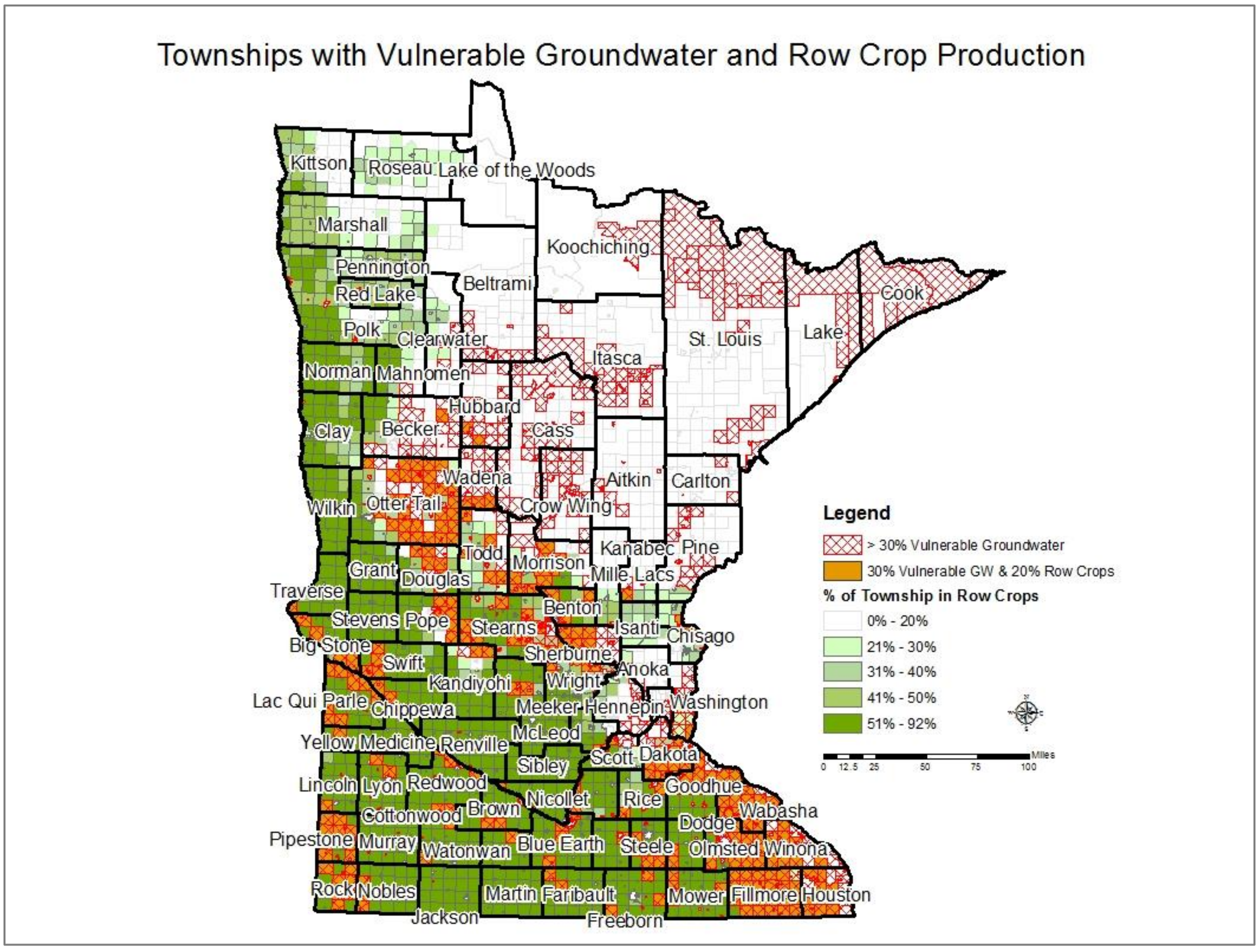

Figure 3. Minnesota Townships with Vulnerable Groundwater and Row Crop Production

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 Benton 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 Benton County can be found in Appendix C (Figure 9, Table 14). On average 32 percent of the land cover was row crop agriculture.

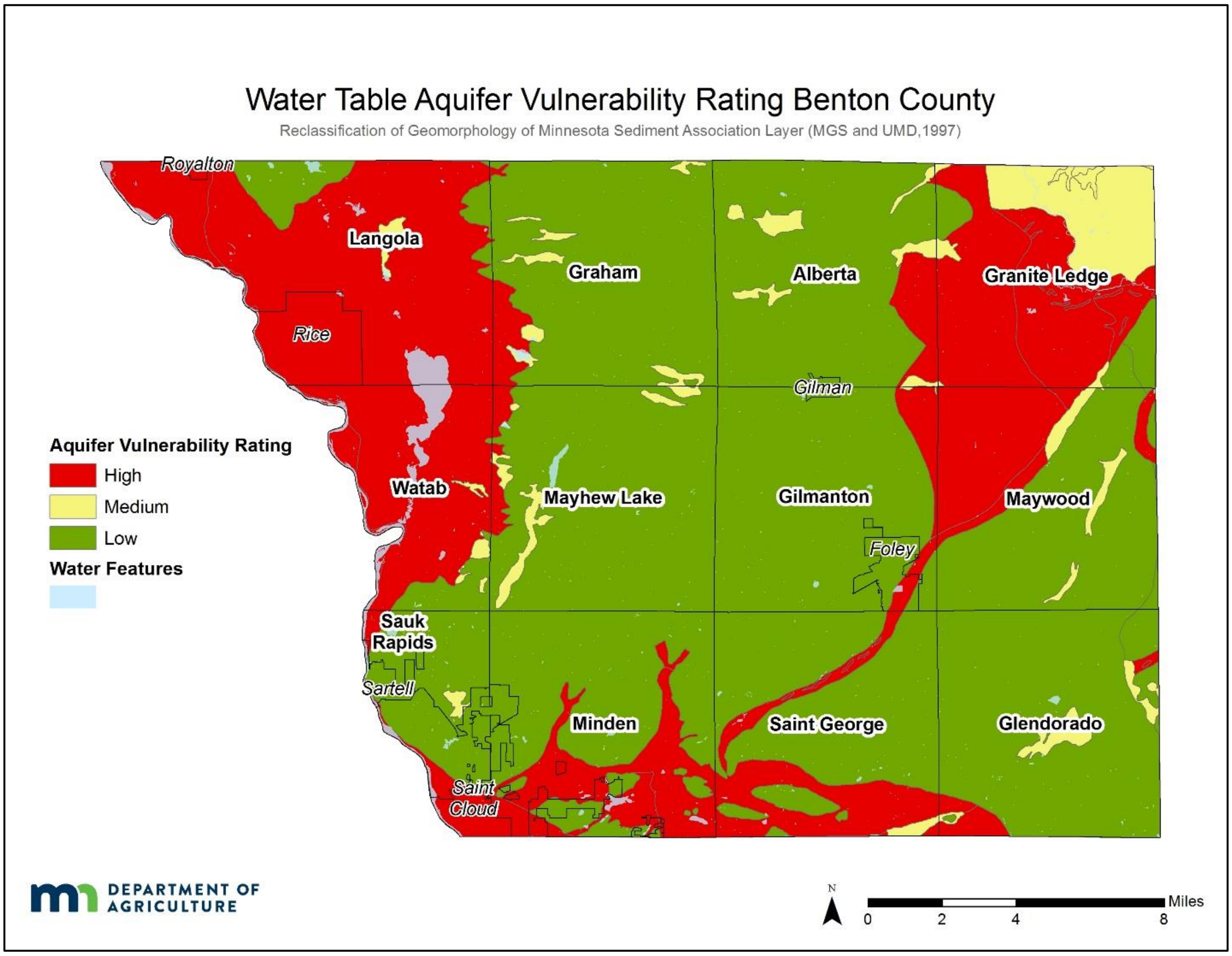

Figure 4. Water Table Aquifer Vulnerability Rating in Benton County

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 2013 and 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 732 homeowners using the mail-in kit (Table 2). These 732 samples are considered the "initial well dataset". On average, 35 percent of the homeowners in these townships responded to the free nitrate test offered by MDA.

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 2015 and 2017 by MDA staff. A total of 186 follow-up samples were analyzed (Table 2).

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

Township	Kits Sent	Initial Well Dataset	Well Site Visits & Follow-Up Sampling Conducted
Langola	231	103	25
Maywood	298	75	18
Minden	665	230	41
Watab	922	324	102
Total	2,116	732	186

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, 2018). 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 42 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), or 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 makes the groundwater in that well susceptible to pollution. Other examples include wells buried underground or wells with cracked casing. Wells with significant problems such as these were excluded from the final well dataset.

IRRIGATION WELL

If the water sample from the initial homeowner sample was likely collected from an irrigation well, it was removed from the dataset. This study is focused on wells that supply drinking water.

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 would not be 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 final well 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.

OUTSIDE THE STUDY AREA

This study is only focused on four townships (Langola, Maywood, Minden, and Watab) within Benton County. Any wells that were sampled outside of these four townships will not be included in the final analysis.

DUPLICATE / EXTRA KIT

Wells that were later found to be duplicates or extra kits were removed from the final well dataset.

INITIAL RESULTS

INITIAL WELL DATASET

A total of 732 well owners returned water samples for analysis across the four townships (Figure 5). These wells represent the initial well dataset. The values in these tables will not all align with older reports. Several wells were incorrectly labeled with the wrong township, corrections have been made, and the corrected data is reported below.

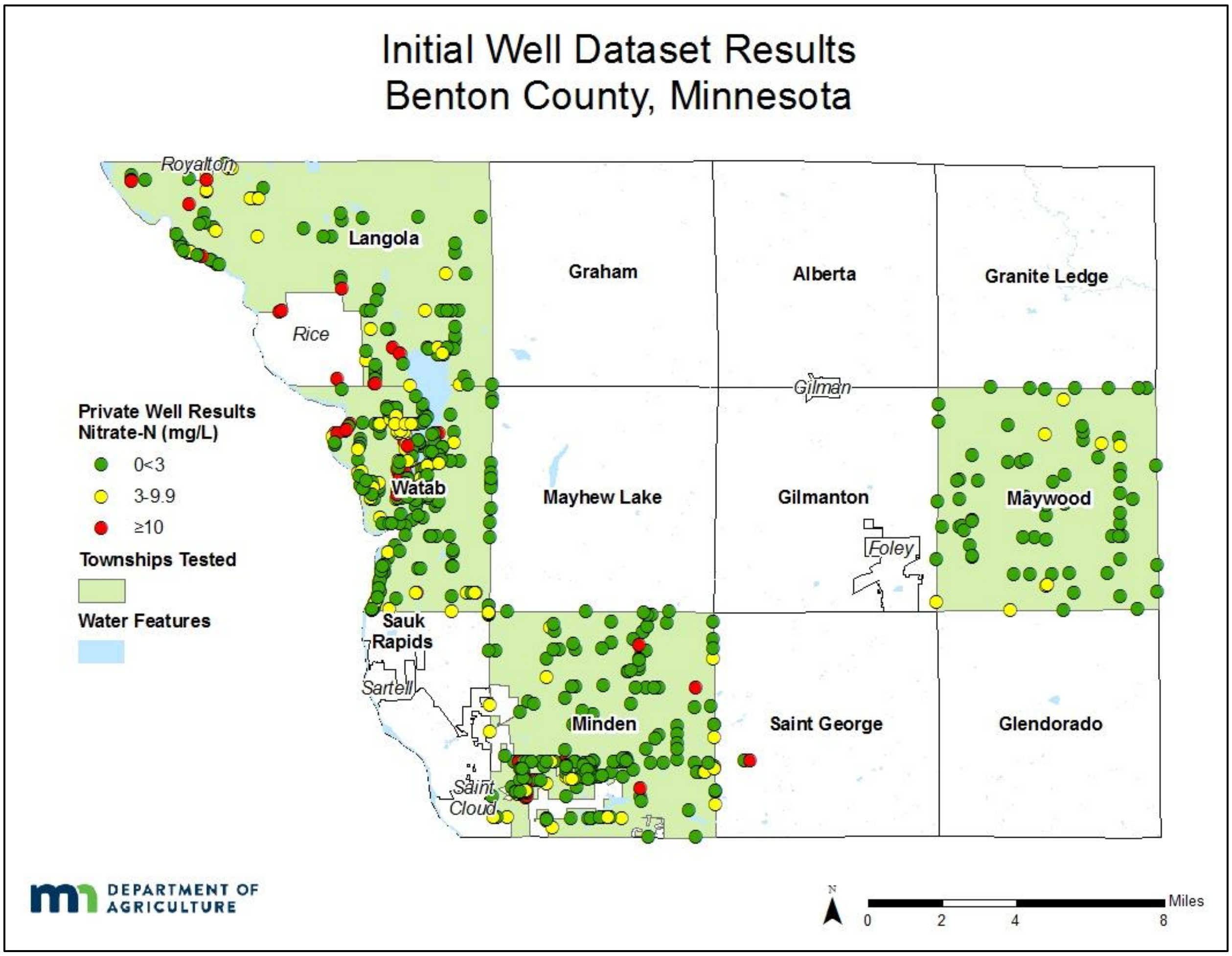

Figure 5. Well Locations and Nitrate Results from Initial Dataset in Benton County

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 10.7 to 40.9 mg/L, with Watab Township having the highest result. Median values ranged from 0.03 to 0.59 mg/L, with Watab having the highest median. The 90th percentiles range from 3.7 to 18.3 mg/L, with Langola Township having the highest 90th percentile.

Initial results from the sampling showed that in Langola Township ten percent or more of the wells were at or over 10 mg/L nitrate. The township testing results contrast findings from a 2010 USGS report on nitrate concentrations in private wells in the glacial aquifer systems 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 suggests that private well water in Langola Township is more heavily impacted by nitrate than other areas of the upper United States. Both the USGS and the township testing studies indicate that nitrate concentrations can vary considerably over short distances.

Table 3. Benton 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																	
Langola	103	<DL	37.5	4.7	0.07	6.7	18.3	21.3	34.2	66	20	31	25	17	64.1%	19.4%	30.1%	24.3%	16.5%
Maywood	75	<DL	10.7	1.0	0.04	0.3	3.7	5.7	9.9	66	8	5	2	1	88.0%	10.7%	6.7%	2.7%	1.3%
Minden	230	<DL	27.2	2.0	0.03	1.9	7.1	11.2	25.4	185	30	29	23	15	80.4%	13.0%	12.6%	10.0%	6.5%
Watab	324	<DL	40.9	3.4	0.59	4.4	7.8	14.8	35.7	216	82	66	42	26	66.7%	25.3%	20.4%	13.0%	8.0%
Total	732	<DL	40.9	2.9	0.10	3.4	8.2	14.6	29.4	533	140	131	92	59	72.8%	19.1%	17.9%	12.6%	8.1%

<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 527 people in Benton County's study area have drinking water over the nitrate HRL (Table 4). Nitrate contamination is a significant problem for many wells in Benton County.

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

Township	2013 Estimated Households on Private Wells*	2013 Estimated Population on Private Wells*	Estimated Population ≥10 mg/L Nitrate-N**
Langola	343	929	153
Maywood	350	952	13
Minden	654	1,672	109
Watab	1,173	3,138	252
Total	2,520	6,691	527

*Data collected from the Minnesota State Demographic Center, 2017

**Estimates based off of the 2013 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 426 documented wells (Table 5). Therefore, approximately 58 percent of the sampled wells had corresponding well logs with an aquifer identified. Thus, the data gathered on aquifers represents approximately half of the total sampled wells.

The aquifers in Table 5 are arranged from the geologically youngest units on the top to the older units, with the expectation of the Weathering Residuum and Multiple aquifers. According to the well log data, the most commonly utilized aquifer in the sampled wells was from the Quaternary aquifers. This predominance of these aquifers reflects the overall findings for all documented wells in the study area (Appendix F, Table 19). The average well depth was 77 feet deep which is typical for the central sands region. The central sands region is relatively shallow when compared to other areas of Minnesota.

Below is a brief description of the aquifers characterized in Table 5.

The Quaternary aquifers represent the youngest geological aquifer formation identified in Benton County. These aquifers are comprised of unconsolidated sand and gravel deposits (MPCA, 1998).

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, 1998). When there is less than ten feet of clay, it allows surface contaminants to 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 similar to the QWTA except that the confining materials (typically clay) are more than 10 feet thick. Quaternary buried artesian wells are wells that are withdraw water that is under pressure and below a confining unit (MPCA, 1998).

The Prairie Du Chien formation was created during the Paleozoic Era and is buried below Quaternary deposits. This aquifer is mainly comprised of dolomite and sandstone (Setterholm et al., 1991).

The Foley Granite was formed when magma cooled and crystalized. Most of the bedrock in Benton County is comprised of Foley Granite. Outcrops of this rock can be in northeastern Benton County in Granite Ledge Township. This granite is pink or salmon in color and is a medium to very course grained stone (Jirsa and Chandler, 2010).

Sartell Gneiss is a bedrock formation can be found in the northwestern portion of Benton County (Jirsa and Chandler, 2010).

Weathering Residuum is formed when parent material breaks down into unconsolidated sediments. Only six wells from this study draws from an aquifer created by this weathered material (Cummins and Grigal, 1981).

Table 5. Nitrate Concentrations within Sampled Groundwater Aquifers

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	82	63	37	27	18	45.1%	32.9%	22.0%
Quaternary Buried	4	65	3	1	0	75.0%	25.0%	0.0%
Quaternary Buried Artesian	168	83	125	30	13	74.4%	17.9%	7.7%
Prairie Du Chien Group	1	232	1	0	0	100.0%	0.0%	0.0%
Foley Granite	5	90	4	1	0	80.0%	20.0%	0.0%
Sartell Gneiss	1	100	0	1	0	0.0%	100.0%	0.0%
Weathering Residuum	6	84	6	0	0	100.0%	0.0%	0.0%
Multiple	2	80	2	0	0	100.0%	0.0%	0.0%
Total	426	77	306	79	41	71.8%	18.5%	9.6%

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 from the initial sampling in 2013 can be found in Appendix G. An updated survey was used in 2015 for Minden Township, and some of the survey answers differ from those used in 2013, the differences are noted below each table in Appendix H. 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 majority of wells in each township are located on "rural" property. In Township of Watab a significant number of wells (23.1 percent) were located on lake home properties.

Approximately 80.5 percent of sampled wells are of drilled construction and 5.7 percent are sand point wells. Sand point (also known as drive-point) wells are typically completed at shallower depths than drilled wells. 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. Two percent of the sampled wells were hand dug wells.

Most of the sampled wells are between 51-100 feet deep, and very few wells are over 300 feet deep. Approximately 15 percent of homeowners did not know or did not response to this question.

Most of the wells (62.4 percent) had not been tested for nitrate within the last ten years or homeowners were unsure if they had been tested. Only three percent of homeowners responded that their well had been tested for nitrate in the last year. Therefore, the results most homeowners receive from this study will provide new information.

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 16.8 percent of the properties.
- Agricultural fields are less than 300 feet from wells at about 28.6 percent of the properties.
- The majority of well owners (88.0 percent) across all the townships responded that they have do not livestock (greater than ten head of cattle or other equivalent) on their property.
- The majority of wells (72.0 percent) are over 300 feet from an active or inactive feedlot.
- Very few well owners (1.0 percent) across all townships store more than 500 pounds of fertilizer on their property.
- A small minority of wells (2.5 percent) are less than 50 feet away from septic systems.

FINAL RESULTS

FINAL WELL DATASET

A total of 732 well water samples were collected by homeowners across four townships. Forty-two wells (5.7 percent) were found to be unsuitable and were removed to create the final well dataset. The final analysis was conducted on the remaining 690 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 for the final well dataset ranged from 1.6 to 14.4 percent.

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

Township	Initial Well Dataset	Final well Dataset	Final Wells ≥10 mg/L Nitrate-N	
			Count	Percentage
Langola	103	97	14	14.4%
Maywood	75	64	1	1.6%
Minden	230	218	9	4.1%
Watab	324	311	26	8.4%
Total	732	690	50	7.2%

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 10.7 to 40.9 mg/L nitrate, with Watab Township having the highest result. The 90th percentile ranged from 2.9 to 16.4 mg/L nitrate-N, with Maywood Township having the lowest result and Langola Township having the highest result.

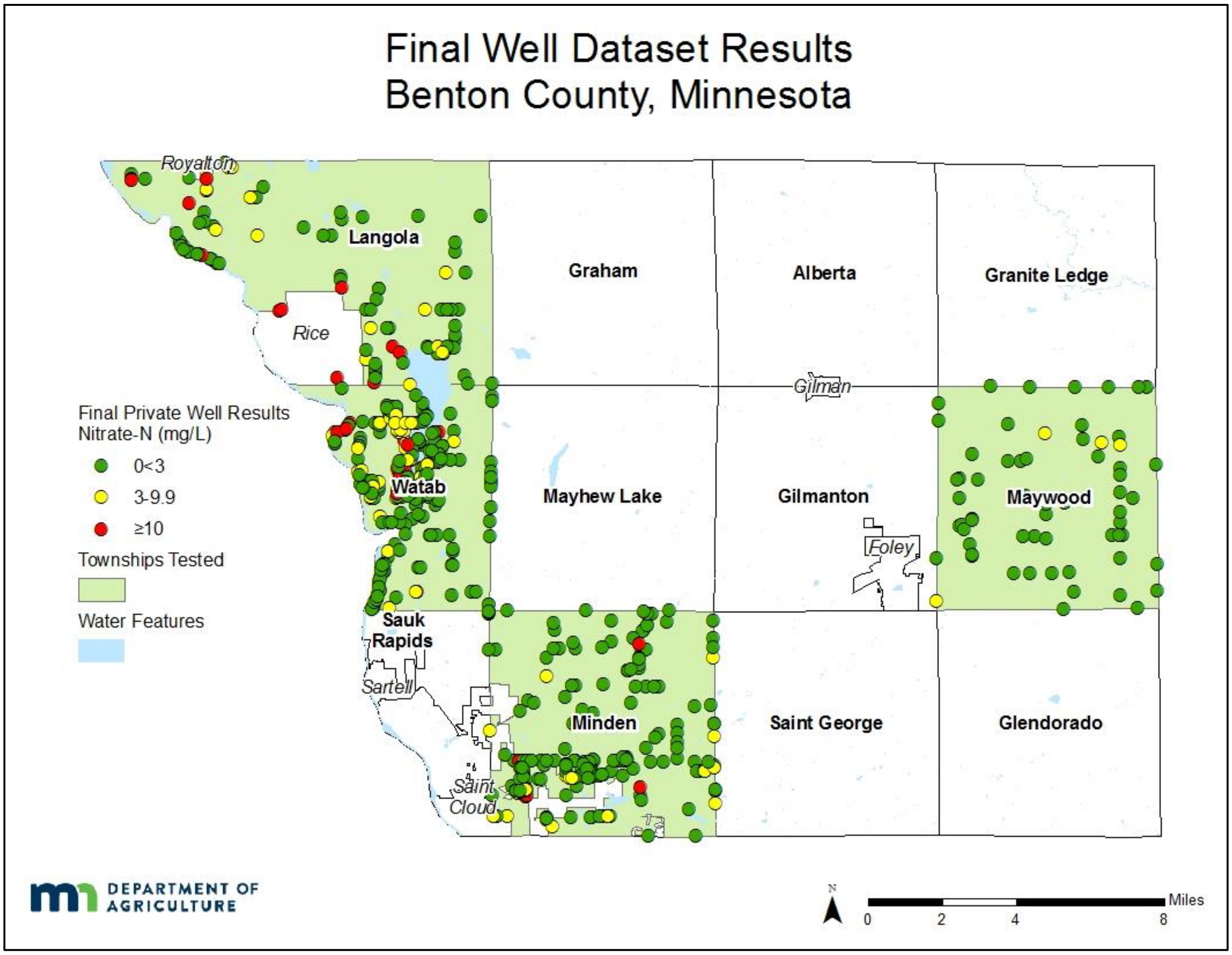

Figure 6. Well Locations and Nitrate Results from Final Well Dataset in Benton County

Table 7. Benton 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)																	
Langola	97	<DL	37.5	4.2	0.04	5.2	16.4	21.5	34.5	66	17	25	19	14	68.0%	17.5%	25.8%	19.6%	14.4%
Maywood	64	<DL	10.7	0.7	<DL	0.2	2.9	3.9	10.1	59	4	2	1	1	92.2%	6.3%	3.1%	1.6%	1.6%
Minden	218	<DL	25.4	1.4	<DL	0.8	4.1	8.8	18.1	184	25	18	14	9	84.4%	11.5%	8.3%	6.4%	4.1%
Watab	311	<DL	40.9	3.4	0.5	4.1	7.8	15.0	35.7	212	73	59	39	26	68.2%	23.5%	19.0%	12.5%	8.4%
Total	690	<DL	40.9	2.6	0.1	2.9	7.3	12.7	30.3	521	119	104	73	50	75.5%	17.2%	15.1%	10.6%	7.2%

<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, Benton County

Township	Final Well Dataset	Percent of Land in Row Crop Production 2013*	Percent of Land in Vulnerable Geology	Percent ≥7 mg/L	Percent ≥10 mg/L
				Nitrate-N mg/L or parts per million (ppm)	
Langola	97	45.20%	87.80%	19.6%	14.4%
Maywood	64	28.80%	31.80%	1.6%	1.6%
Minden	218	32.70%	30.10%	6.4%	4.1%
Watab	311	14.90%	87.40%	12.5%	8.4%
Total	690	30.40%	59.28%	10.6%	7.2%

*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 Benton 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 (85 percent), and only 37 wells (5 percent) were identified as sand point wells.
- The median depth of wells was 72 feet, and the deepest was 232 feet.
- The median year the wells were constructed in was 1996.

WELL WATER PARAMETERS

MDA staff conducted the follow-up sampling and well site surveys at 186 wells. Only 174 follow-up wells are included in the final well dataset, and seven of these did not have field measurements collected. 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 9.05 °C to 13.83 °C
- The median specific conductivity was 464 µS/cm, and was as high as 2,510 µS/cm
- The water from the wells had a median pH of 7.78
- The dissolved oxygen readings ranged from 0.08 mg/L to 15.96 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 Benton County. In order to prioritize testing, the MDA looked at townships with significant row crop production and vulnerable geology. Approximately 32 percent of the land cover is row crop agriculture and 13,466 acres (13 percent of land cover) of groundwater irrigation in the study area.

Four townships were sampled covering nearly 85,000 acres. The initial (homeowner collected) nitrate sampling resulted in 732 samples. The 732 households that participated represent approximately 35 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 186 wells.

The MDA conducted a nitrogen source assessment and identified wells near potential point sources and wells with poor construction. A total of 42 (5.7 percent) wells were found to be unsuitable and were removed from the final well dataset of 690 wells. The remaining 690 wells were wells believed to be impacted by nitrogen fertilizer and were included in the final well dataset.

In the final well dataset majority of wells (85 percent) are drilled; about five percent are sand points. The median depth of the wells is 72 and depths range from 19 to 232 feet.

For the final well dataset, only Langola 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 1.6 to 14.4 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

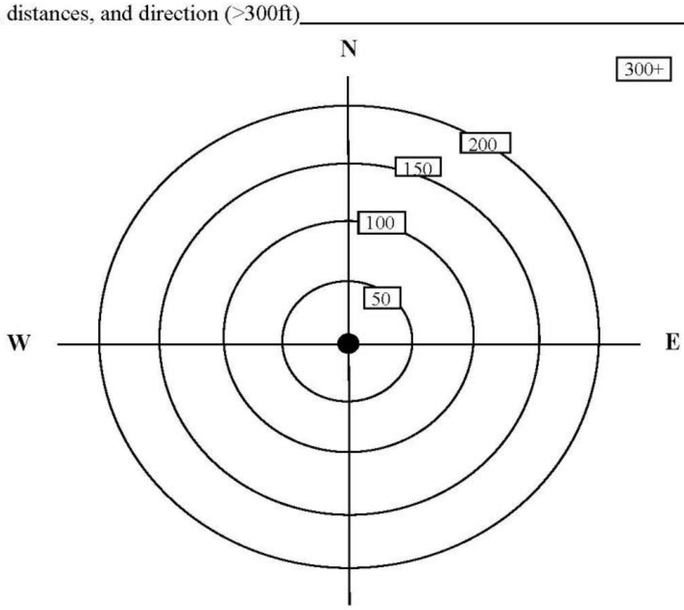
DIRECTIONS

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 inspections can occur at other times as well. 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 Benton County reported a total of 3,895 SSTS and 5.7 percent were inspected for compliance (MPCA, 2017a). Benton County has the third highest rate of compliance inspections in the state. Compliance inspections are conducted in Benton County during property transfers, which is not a requirement in all counties. Additionally, Benton County performs inspections when construction permits are required for work on the existing system, when there is a change in use for the property, “any time deemed appropriate such as upon receipt of a complaint” and other situations that could affect the performance of the SSTS. If the SSTS is an ITPHS then it must be replaced or repaired within 120 days. If a system is out of compliance the owners have 12 months to get their system up to compliance standards (Benton County Ordinance No. 457(2016)).

FEEDLOT

The amount of nitrogen in manure depends on the species of animal. For example, there is 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 Benton County study area can be found below (Figure 7; Table 10).

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

Township	Total Feedlots	Active Feedlots	Inactive Feedlots	Average AU Permitted** Per Feedlot	Total Permitted** AU	Total Square Miles	Permitted** AU per Square Mile
Langola	33	11	22	531	5,837	41	143
Maywood	40	7	33	193	1,349	36	38
Minden	22	0	22	0	0	34	0
Watab	7	1	6	26	26	22	1
Total	102	19	83	380*	7,211	133	54*

*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 livestock than permitted.

On average there are 54 AU per square mile (0.08 AU/acre) over the entire study area (Table 10). Manure is often applied to cropland so it is pertinent to look at the AU per cropland acre. In the Benton County study area livestock densities average 0.26 AU per acre of row crops (MPCA, 2018; USDA NASS, 2013).

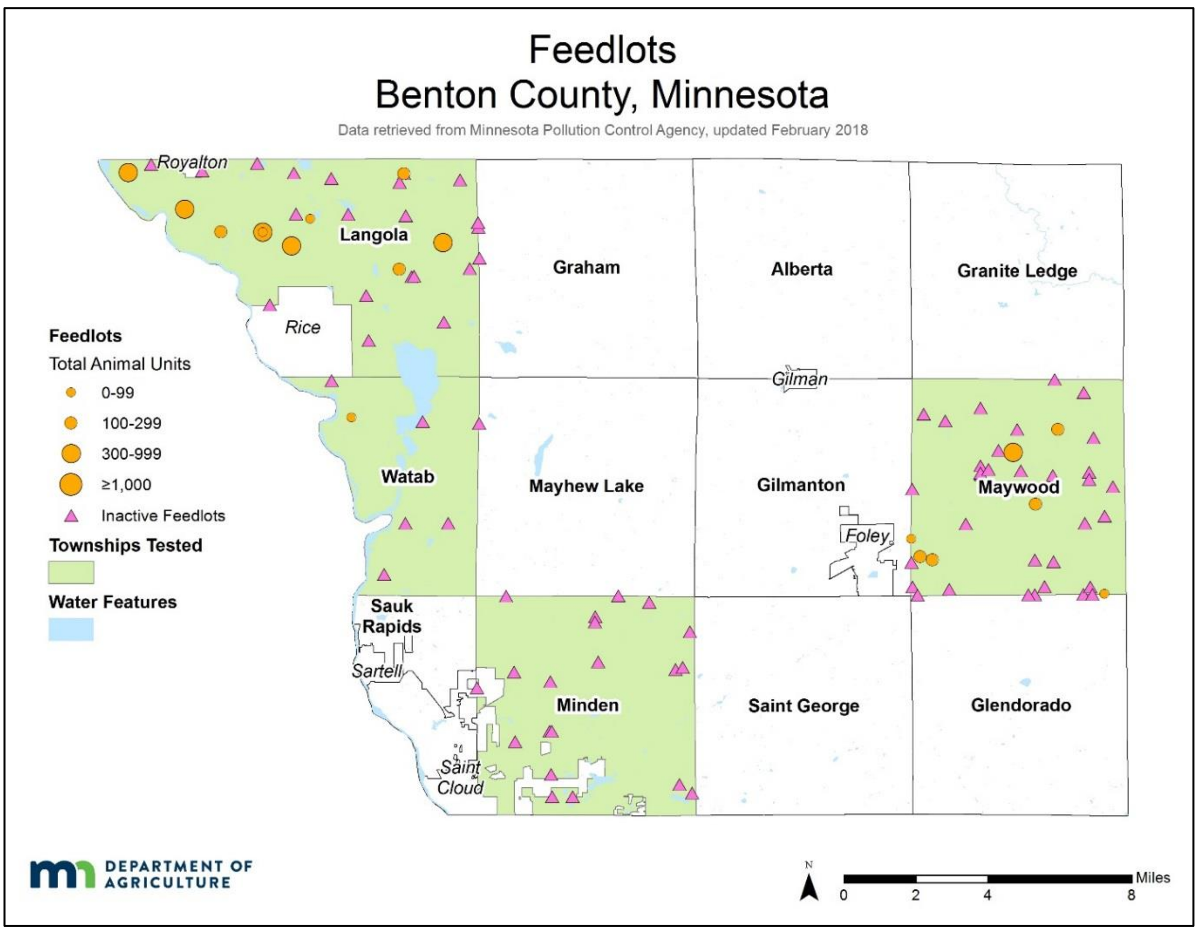


Figure 7. Feedlot Locations in Benton County (MPCA, 2018)

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, Benton County

Township	Bulk Fertilizer Storage	Anhydrous Ammonia	Chemigation Sites	Abandoned Sites	Total
Langola	2	0	82	0	84
Maywood	0	0	0	0	0
Minden	0	0	2	2	4
Watab	0	0	11	0	11
Total	2	0	95	2	99

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 fertilizer spills within the Benton County study area. 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 two 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 41 in the study area. Small spills and investigations are typically smaller emergency spills such as a truck spilling chemicals. There are 5 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). 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.

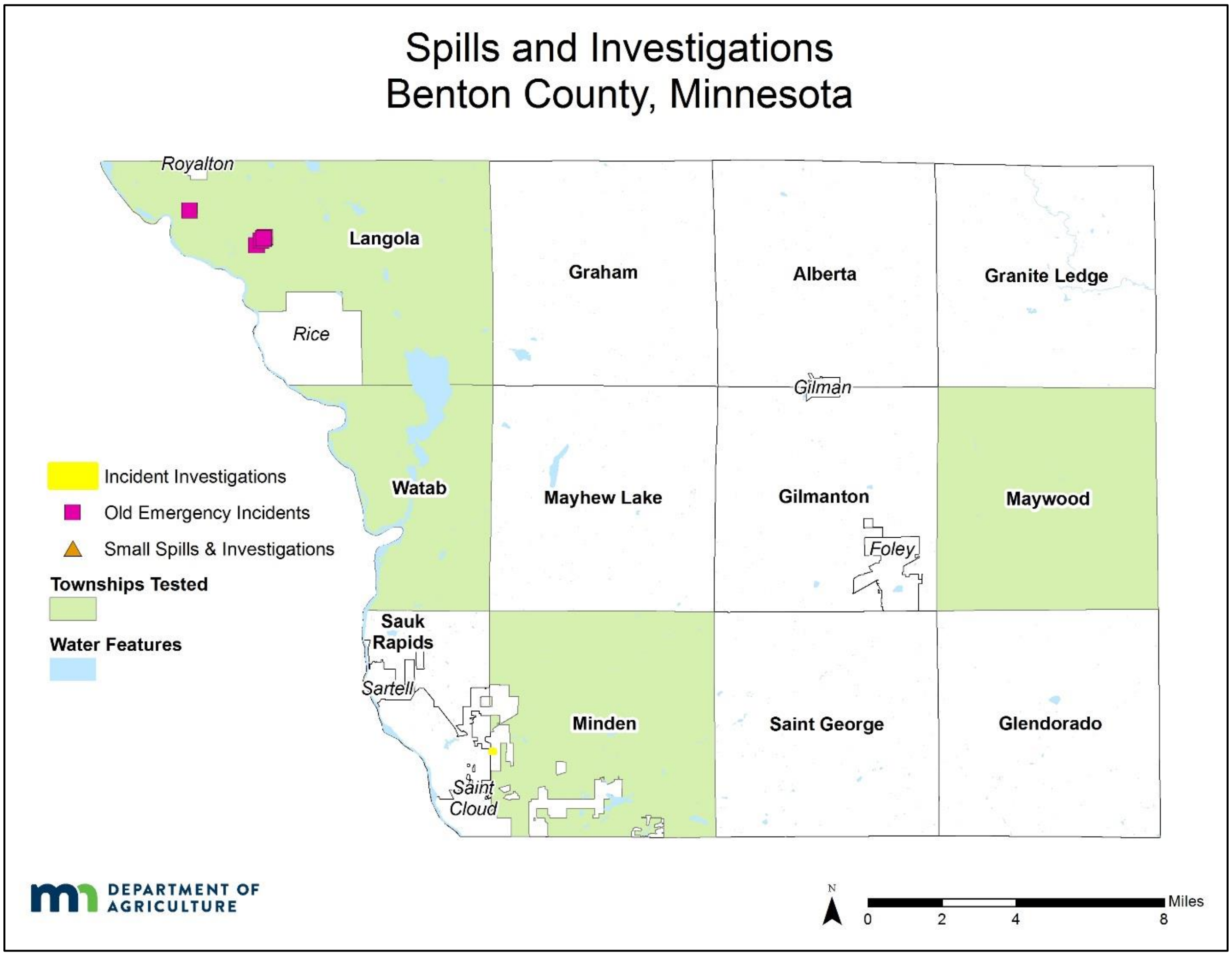
Table 12. Spills and Investigations by Chemical Type, Benton County

Contaminant	Incident Investigations	Contingency Areas	Small Spills and Investigations	Old Emergency Incidents	Total
Fertilizer	2	0	2	1	5
Pesticides & Fertilizer	0	0	0	0	0
Anhydrous Ammonia	0	0	3	40	43
Total	2	0	5	41	48

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

Township	Incidents and Spills
Langola	46
Maywood	1
Minden	1
Watab	0
Total	48

Figure 8. Fertilizer Spills and Investigations in Benton County (MDA, 2017)



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. Benton County is mostly rural and is dominated by row crop agriculture and pasture lands (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.

Benton County is northwest of the Twin Cities, and abuts St. Cloud in the southwestern part of the county. Relatively little land (5%) in the study area is considered developed. Benton County's western border is shaped by the Mississippi River. Watab is a western township and at 17% it has the most open water and wetland of the townships in the study area (Figure 9; Table 14).

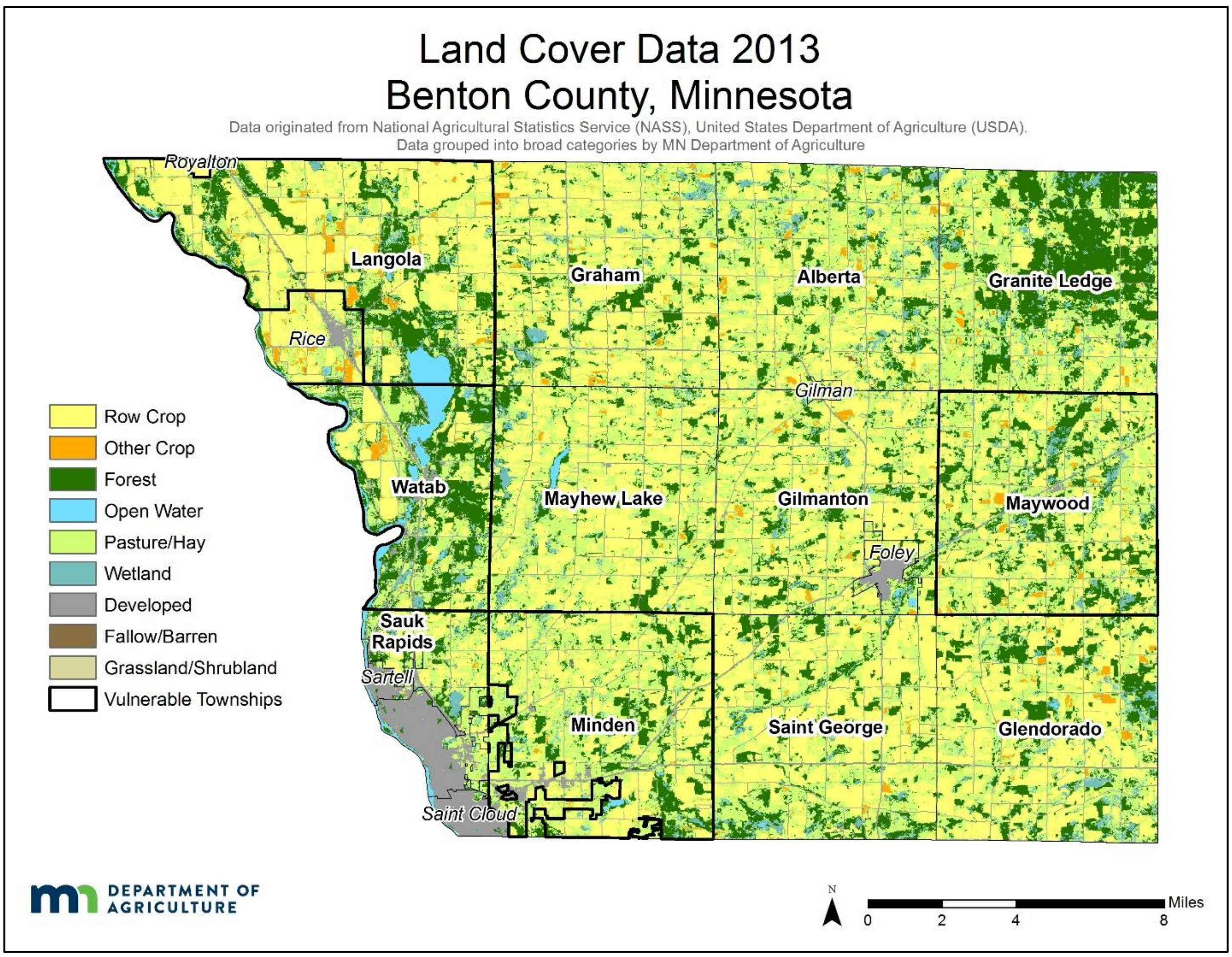


Figure 9. Land Cover in Benton County (USDA NASS Cropland Data Layer, 2013)

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

Township	Total Acres	Row Crop	Other Crops	Forest	Open Water	Pasture/ Hay	Wetland	Developed	Fallow/ Barren	Grassland/ Shrubland
Langola	26,144	45%	3%	19%	3%	20%	4%	4%	0%	1%
Maywood	22,813	29%	2%	18%	0%	40%	6%	5%	0%	1%
Minden	21,660	33%	1%	15%	0%	40%	4%	6%	0%	1%
Watab	14,371	15%	2%	30%	10%	27%	7%	8%	0%	2%
Average	84,988*	32%	2%	20%	3%	32%	5%	5%	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 147 active groundwater well permits in the study area, 126 of which are used for agricultural irrigation (Figure 10). About 13,466 acres of cropland are permitted for groundwater irrigation in this area (Table 15). Most permitted wells are withdrawing groundwater from Quaternary aquifers (Table 16; MDNR, 2017).

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

Township	Major Crop Irrigation Well Permits	Average Depth (feet)	Acres Permitted
Langola	101	111	11,010
Maywood	0	NA	0
Minden	12	89	1,215
Watab	13	100	1,241
Total	126	108	13,466

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

Water Use Well Permits	Total	Average Depth (feet)	Aquifer			
			Water Table	Quaternary	Paleozoic	Not Classified
Major Crop Irrigation	126	108	35	84	0	7
Non-Crop Irrigation	6	114	1	4	0	1
Waterworks	13	107	1	10	0	2
Special Categories*	2	161	0	2	0	0
Total	147	109	37	100	0	10

* All Special Categories displayed in the figure and table are for Livestock Watering.

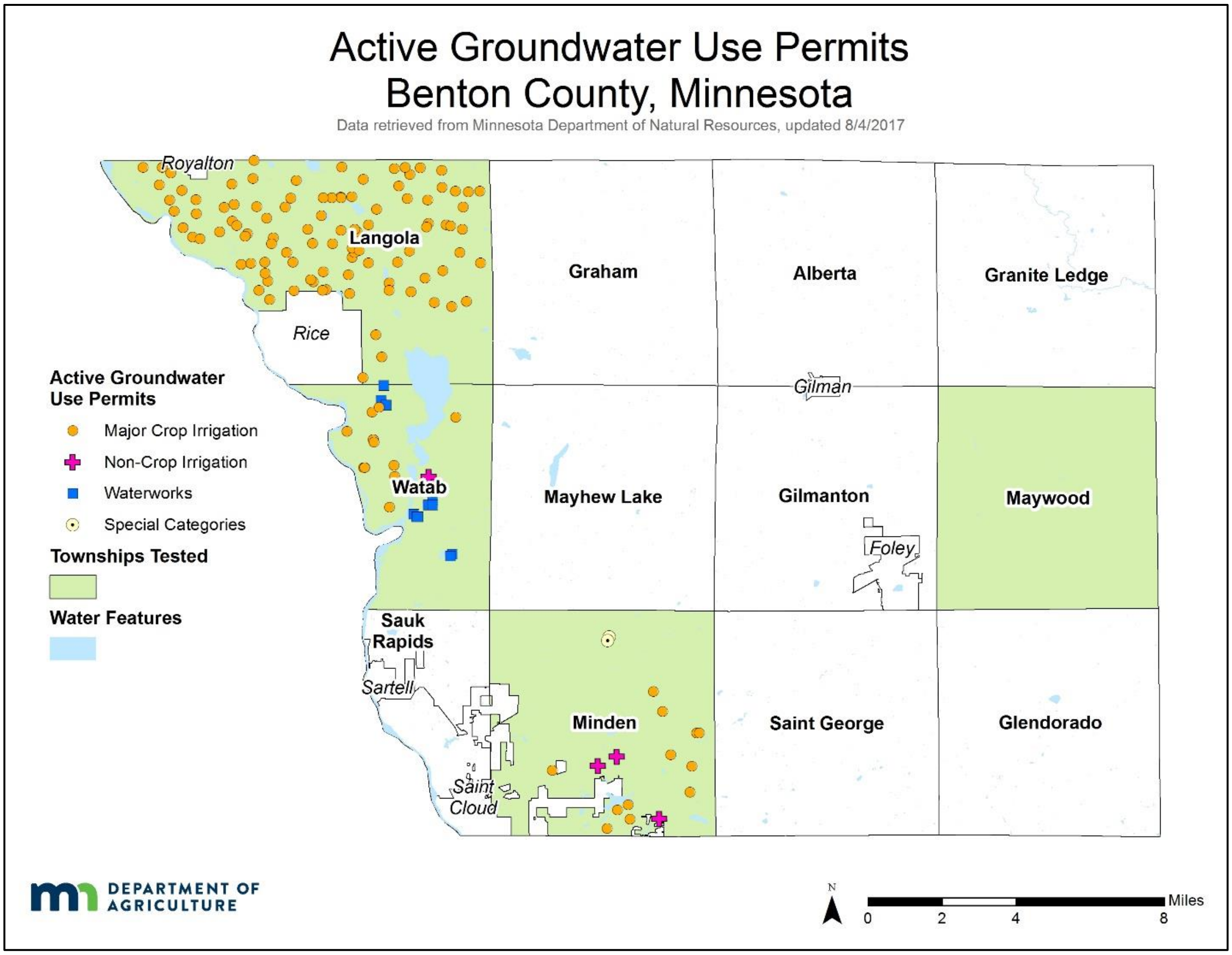


Figure 10. Active Groundwater Use Permits in Benton County (MDNR, 2017)

APPENDIX D

Nitrate Brochure

The Minnesota Department of Agriculture and the Benton 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, Benton County

Township	Point Source	Well Construction Problem	Hand Dug Well	Unsure of water source	Site Visit Completed - Well Not Found & Constructed before 1975 or Age Unknown & No Well ID	No Site Visit & Constructed before 1975 or Age Unknown & No Well ID	No Site Visit & Insufficient Data & No Well ID	Duplicate/ Extra Kit	Outside Study Area	Total
Langola	1	0	0	0	1	2	0	2	0	6
Maywood	1	0	10	0	0	0	0	0	0	11
Minden	1	2	2	1	0	2	3	0	1	12
Watab	0	1	5	1	1	3	0	2	0	13
Total	3	3	17	2	2	7	3	4	1	42

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

Township	Site Visit	No Site Visit	Total
Langola	1	5	6
Maywood	3	8	11
Minden	3	9	12
Watab	5	8	13
Total	12	30	42

APPENDIX F

MINNESOTA WELL INDEX

The MWI was used to gather information about the four study area townships in Benton County. This section includes all documented 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 1,284 documented (have a verified location in the MWI) drinking water wells:

- A quarter of the drinking water wells are completed in the Quaternary Water Table aquifer.
- The majority of wells (67.4 percent) withdraw water from Quaternary Buried aquifers.
- The Precambrian (Early Proterozoic) wells are the deepest recorded drinking water wells on average. They represent 2.6 percent of the wells within the Benton County study area.
- Three aquifer types (Quaternary Undifferentiated, Cretaceous, and Precambrian (Archean)) were poorly represented with only 1 or 2 wells withdrawing from these aquifers.
- Less than two percent of wells were drilled into weathering residuum.
- Only 19 wells were completed in multiple aquifers. The average depth of these wells is 80.5 feet.

Table 19. Aquifer Type Distribution of Active Drinking Water Wells in Minnesota Well Index by Township, Benton County

Aquifer Group/Formation	Langola	Maywood	Minden	Watab	Total Wells	Ave Depth (Feet)
Quaternary Water Table	73	6	13	240	332	63.1
Quaternary Buried	140	161	301	264	866	80.9
Quaternary Undifferentiated	1	0	0	1	2	33.5
Cretaceous	0	1	0	0	1	97.0
Precambrian (Early Proterozoic)*	0	22	2	10	34	190.5
Precambrian (Archean)**	0	0	0	1	1	100.0
Weathering Residuum	2	6	11	10	29	99.4
Multiple	1	7	2	9	19	80.5
Total	217	203	329	535	1,284	79.6

* The majority of these aquifers have been further classified as Foley Granite.

** Sartell Gneiss is the only aquifer type within the Precambrian (Archean) category.

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
Langola	103	75.7%	0.0%	0.0%	9.7%	9.7%	0.0%	4.9%
Maywood	75	96.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%
Minden	230	70.9%	0.4%	0.0%	0.0%	13.9%	1.7%	13.0%
Watab	324	49.7%	0.3%	0.0%	23.1%	18.5%	0.0%	8.3%
Total	732	64.8%	0.3%	0.0%	11.6%	13.9%	0.5%	8.9%

Table 21. Well Construction Type

Township	Total	Drilled	Sand point	Hand dug	Not available
Langola	103	85.4%	8.7%	0.0%	5.8%
Maywood	75	80.0%	1.3%	12.0%	6.7%
Minden	230	78.7%	4.3%	0.9%	16.1%
Watab	324	80.2%	6.8%	1.2%	11.7%
Total	732	80.5%	5.7%	2.0%	11.7%

Table 22. Age of Well

Township	Total	0-10 years†	11-20 years ago‡	21-40 years ago§	Over 40 years ago‖	Not available
Langola	103	13.6%	37.9%	34.0%	7.8%	6.8%
Maywood	75	24.0%	34.7%	18.7%	17.3%	5.3%
Minden*	179	27.4%	17.3%	20.1%	35.2%	0.3%
Watab	324	10.2%	25.9%	47.2%	9.0%	7.7%
Total	681	16.7%	26.4%	34.9%	16.6%	5.4%

*Minden survey responses are: †"1994 to present", ‡"1985 to 1993", §"1975 to 1984", and ‖"before 1975".

Table 23. Depth of Well

Township	Total	0-50 feet deep	51-100 feet deep	101-300 feet deep	Over 300 feet deep	Not Available
Langola	103	14.6%	55.3%	21.4%	1.0%	7.8%
Maywood	75	28.0%	53.3%	8.0%	1.3%	9.3%
Minden*	230	8.3%	43.5%	28.7%	0.0%	19.6%
Watab	324	14.5%	55.9%	13.0%	0.9%	15.7%
Total	732	13.9%	51.6%	18.6%	0.7%	15.2%

* Ranges for Minden are 0-15 feet, 16-49 feet, 50-99 feet, 100-299 feet, and ≥300 feet. The ranges 0-15 feet and 16-49 feet are displayed under the 0-50 feet category. There were no responses for 0-16 feet.

Table 24. Unique Well ID Known

Township	Total	No, Unique Well ID not known	Yes, Unique Well ID known	Not Available
Langola	103	21.4%	9.7%	68.9%
Maywood	75	21.3%	10.7%	68.0%
Minden	230	30.0%	13.5%	56.5%
Watab	324	25.9%	15.7%	58.3%
Total	732	26.1%	13.7%	60.2%

Table 25. Livestock Located on Property

Township	Total	No Livestock	Yes Livestock	Not available
Langola	103	84.5%	5.8%	9.7%
Maywood	75	90.7%	6.7%	2.7%
Minden	230	83.0%	5.2%	11.7%
Watab	324	88.0%	1.2%	10.8%
Total	732	86.2%	3.7%	10.1%

Table 26. Fertilizer Stored on Property

Township	Total	No Fertilizer Stored	Yes Fertilizer Stored	Not Available
Langola	103	94.2%	2.9%	2.9%
Maywood	75	93.3%	0.0%	6.7%
Minden	230	86.5%	1.7%	11.7%
Watab	324	90.7%	0.0%	9.3%
Total	732	90.2%	1.0%	8.9%

Table 27. Farming on Property

Township	Total	No Farming	Yes Farming	Not available
Langola	103	78.6%	18.4%	2.9%
Maywood	75	44.0%	50.7%	5.3%
Minden	230	66.1%	22.2%	11.7%
Watab	324	87.3%	4.6%	8.0%
Total	732	75.0%	16.8%	8.2%

Table 28. Distance to an Active or Inactive Feedlot

Township	Total	0-50 feet to Feedlot	51-100 feet to Feedlot	101-300 feet to Feedlot	Over 300 feet to Feedlot	Not Available
Langola	103	4.9%	2.9%	7.8%	70.9%	13.6%
Maywood	75	4.0%	6.7%	8.0%	76.0%	5.3%
Minden*	230	5.2%	3.0%	2.6%	64.3%	24.8%
Watab	324	2.8%	0.0%	1.5%	76.9%	18.8%
Total	732	4.0%	2.0%	3.4%	72.0%	18.6%

*Ranges for Minden are 0-49 feet, 50-99 feet, 100-299 feet, and ≥300 feet.

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
Langola	103	0.0%	35.9%	54.4%	4.9%	4.9%
Maywood	75	0.0%	22.7%	58.7%	16.0%	2.7%
Minden*	230	2.6%	33.9%	42.2%	8.3%	13.0%
Watab	324	3.7%	38.3%	42.6%	7.4%	8.0%
Total	732	2.5%	35.0%	45.8%	8.2%	8.6%

*Ranges for Minden are 0-49 feet, 50-99 feet, 100-299 feet, and ≥300 feet.

Table 30. Distance to an Agricultural Field

Township	Total	0-50 feet to Field	51-100 feet to Field	101-300 feet to Field	Over 300 feet to Field	Not Available
Langola	103	4.9%	3.9%	25.2%	57.3%	8.7%
Maywood	75	8.0%	12.0%	41.3%	36.0%	2.7%
Minden*	230	3.0%	7.4%	25.2%	47.4%	17.0%
Watab	324	1.9%	2.5%	9.9%	73.1%	12.7%
Total	732	3.3%	5.2%	20.1%	59.0%	12.4%

*Ranges for Minden are 0-49 feet, 50-99 feet, 100-299 feet, and ≥300 feet.

Table 31. Drinking Water Well

Township	Total	Not Drinking Water	Yes, Drinking Water	Not Available
Langola	103	0.0%	92.2%	7.8%
Maywood	75	0.0%	96.0%	4.0%
Minden	230	0.4%	89.1%	10.4%
Watab	324	1.2%	93.2%	5.6%
Total	732	0.7%	92.1%	7.2%

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

Township	Total	None	Distillation	Filtering System	Reverse Osmosis	Iron Filter	Other	Not Available
Langola	103	66.0%	1.9%	13.6%	6.8%	0.0%	1.9%	9.7%
Maywood	75	74.7%	0.0%	14.7%	6.7%	0.0%	0.0%	4.0%
Minden	230	64.3%	0.4%	11.7%	3.0%	0.0%	0.9%	19.6%
Watab	324	60.2%	0.6%	12.3%	9.9%	0.6%	1.5%	14.8%
Total	732	63.8%	0.7%	12.6%	7.0%	0.3%	1.2%	14.5%

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
Langola	103	3.9%	7.8%	24.3%	27.2%	16.5%	16.5%	3.9%
Maywood	75	2.7%	8.0%	29.3%	21.3%	22.7%	13.3%	2.7%
Minden	230	2.6%	4.8%	11.3%	26.1%	20.0%	24.3%	10.9%
Watab	324	3.1%	9.3%	23.5%	20.7%	20.4%	17.6%	5.6%
Total	732	3.0%	7.5%	20.4%	23.4%	19.9%	19.1%	6.7%

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
Langola	103	19.4%	16.5%	2.9%	61.2%
Maywood	75	24.0%	4.0%	0.0%	72.0%
Minden	230	7.4%	2.2%	0.9%	89.6%
Watab	324	17.0%	7.1%	2.2%	73.8%
Total	732	15.0%	6.6%	1.6%	76.8%

APPENDIX I

Table 35. Well Construction Type for Final Well Dataset

Township	Samples	Drilled	Sand Point	Not Available
Langola	97	85	8	4
Maywood	64	60	1	3
Minden	218	181	10	27
Watab	311	263	18	30
Total	690	589	37	64

Data compiled from well logs and homeowner responses.

Table 36. Well Depth for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Langola	62	38	149	71	77
Maywood	36	28	232	61	71
Minden	81	40	175	94	93
Watab	113	19	180	65	68
Total	292	19	232	72	77

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

Table 37. Year of Well Construction for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Langola	62	1977	2014	1998	1997
Maywood	36	1981	2010	1998	1998
Minden	81	1975	2014	1995	1995
Watab	113	1966	2008	1995	1994
Total	292	1966	2014	1996	1995

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
Langola	23	9.05	11.82	10.35	10.27
Maywood	13	9.32	12.10	10.40	10.55
Minden	37	9.51	13.31	10.87	10.93
Watab	94	9.20	13.83	10.61	10.72
Total	167	9.05	13.83	10.62	10.69

Table 39. pH of Well Water for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Langola	23	6.61	8.26	7.73	7.72
Maywood	13	7.92	8.73	8.31	8.34
Minden	37	7.32	8.24	7.81	7.78
Watab	94	6.23	8.96	7.75	7.78
Total	167	6.23	8.96	7.78	7.82

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

Township	Samples	Min	Max	Median	Mean
Langola	23	243	916	452	469
Maywood	13	257	501	361	374
Minden	37	263	950	393	469
Watab	94	227	2,510	498	538
Total	167	227	2,510	464	500

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

Township	Samples	Min	Max	Median	Mean
Langola	23	0.41	8.34	2.18	2.88
Maywood	13	0.08	5.86	0.77	1.49
Minden	37	0.08	7.22	1.05	2.22
Watab	94	0.09	15.96	3.77	4.04
Total	167	0.08	15.96	2.18	3.28