Final Township Testing Nitrate Report:

Fillmore County 2017-2018

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Minnesota Department of Agriculture

Pesticide and Fertilizer Management Division

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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 2017, private wells in the Fillmore County study area (24 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 1,477 wells representing an average response rate of 34 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, 16.9 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 over 1,500 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 413 wells in 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 407 (28 percent) wells were determined to be unsuitable and were removed from the dataset. The final well dataset had a total of 1,070 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 0 percent (Beaver, Fountain, and Holt Townships) to 23.3 percent (Preble Township). Four of the 24 townships sampled in Fillmore County have over 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 February 2019, 306 townships from 42 counties have completed the initial sampling.

In 2017, 24 townships in Fillmore 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 department, 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 nitrate-N and pesticide sampling in Fillmore County occurred during the summer and fall of 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 were 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

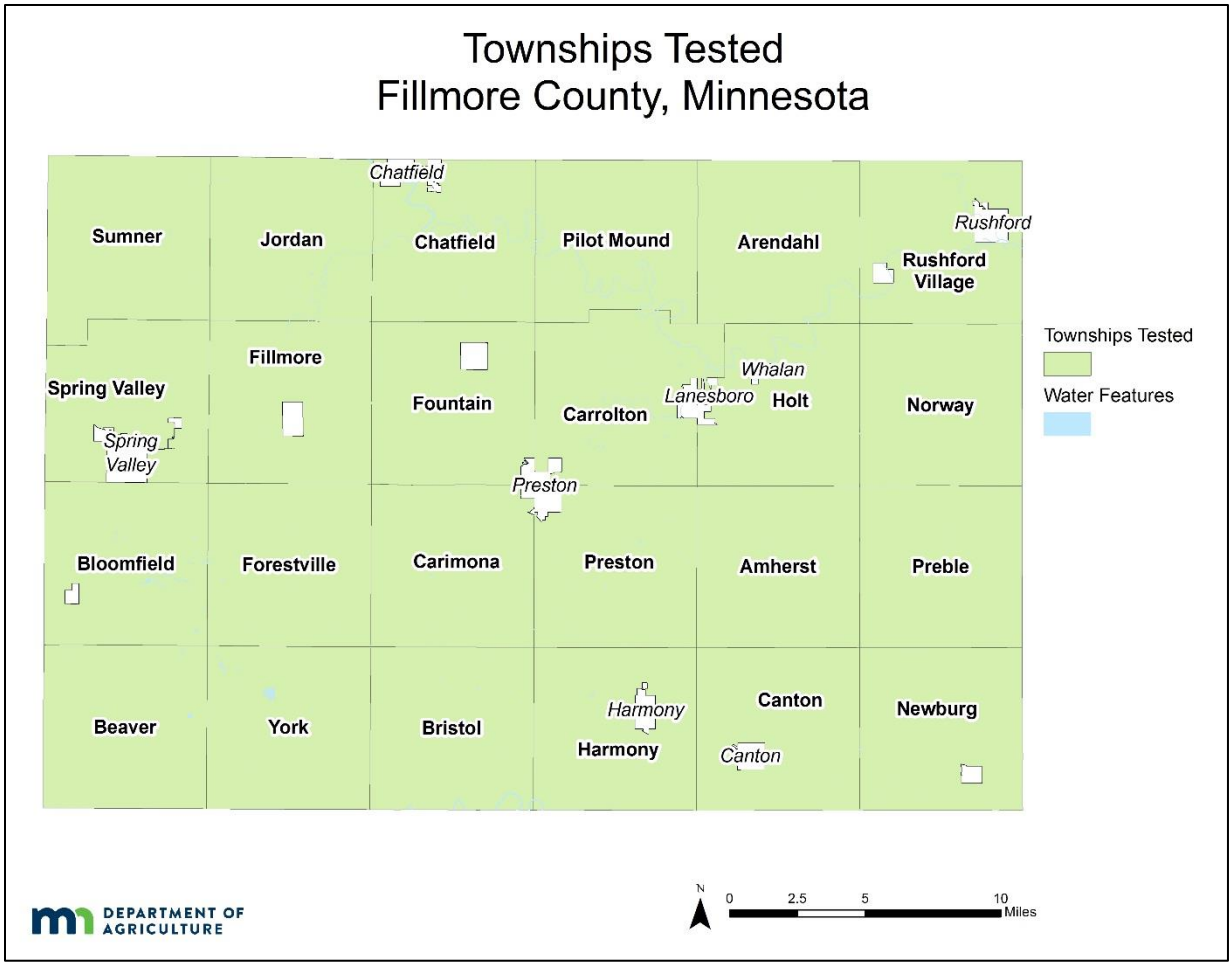

Figure 1. Townships Tested in Fillmore County

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 (Rivett et al., 2008).

In karst environments, macropores and preferential flow pathways in the geology allow for nitrate-contaminated surface leachate to quickly reach aquifers (Bakalowicz, 2005; Witthuhn & Alexander, 1995). The time it takes for contaminated water to leach to aquifers is relatively short in karst systems, and thus there is limited opportunity for denitrification (Katz, 2012). As a result, areas with karst geology and intensive row crop agriculture, like Fillmore County, are particularly vulnerable to groundwater nitrate contamination (Nolan, 2001; Panno et al., 2001). However, geochemical conditions can be highly variable within an aquifer or region and can also change over time (MPCA, 1999).

GEOLOGY AND HYDROGEOLOGY

From approximately 2.5 million years ago to 11,700 years ago, much of the northern Hemisphere, including Minnesota, was intermittently covered by sheets of slowly moving ice known as glaciers (Lusardi & Dengler, 2017). During colder times, the glaciers would grow and move farther south, sometimes covering Minnesota, and during warmer times the glaciers would melt and retreat farther

north away from Minnesota (Lusardi & Dengler, 2017). As these glaciers moved, they moved the earth beneath them and deposited it in other places, destroying the old landscapes and creating new ones in their place (Lusardi & Dengler, 2017). As the glaciers melted, huge amounts of meltwater flowed across the landscape, creating river valleys and depositing clay, silt, sand and gravel deposits known as alluvium.

All of Fillmore County was covered by glaciers during an early glaciation period. This early glaciation probably occurred sometime between 1.7 million years ago and 790,000 years ago, but the precise timing is not known (Hobbs, 1995). Most of the resulting glacial sediment has since eroded away (Hobbs, 1995).

Different parts of the county experienced more recent glaciations to varying extents. The eastern part of Fillmore County was not covered by glaciers during these more recent events but experienced intense erosion by glacial meltwater from nearby areas that had been covered by glaciers (Hobbs, 1995). This is reflected in both the surficial geology of Eastern Fillmore County, where bedrock is widely exposed and deposits of glacial alluvium are common, and in the area's topography, which consists of hills and river valleys (Hobbs, 1995). The western part of the county, which was covered by glaciers as recently as several hundred thousand years ago, has a surficial geology consisting largely of unsorted glacial till and exposed bedrock (Hobbs, 1995). The topography there is generally flatter with more gentle, rolling hills.

Bedrock in Fillmore County consists of layered sedimentary rock deposited over the course of hundreds of millions of years. In the western and southwestern portions of the county, glacial till deposited from more recent glaciations protected younger bedrock from erosion. This younger bedrock consists of the Cedar Valley and Wapsipinicon groups from the Middle Devonian and the Maquoketa, Dubuque, and Stewartville formations of the Upper Ordovician (Mossler, 1995). All of these layers are comprised largely of limestone and dolostone (Mossler, 1995). In many parts of this region this bedrock is exposed at the surface, while in others, particularly the far western portion of the county, bedrock is still covered by a layer of unsorted glacial till.

In the eastern portion of the county, where erosion is more pronounced, bedrock is exposed or covered by only a thin layer of sediment almost everywhere. There are some areas scattered throughout eastern Fillmore County where thicker glacial till is found (Mossler, 1995). Ages of this bedrock vary widely. In the valleys, where erosion was more pronounced, older layers are exposed, with the oldest being the Eau Claire formation of the upper Cambrian (Mossler, 1995). On hills, where erosion is less pronounced, younger layers are exposed, the youngest being from the middle Devonian period (Mossler, 1995). Composition of bedrock in the eastern part of the county also varies, ranging from dolomite to sandstone to shale (Mossler, 1995).

Sandstone aquifers located directly beneath dolostone and limestone layers, as well as aquifers consisting of these dolostone and limestone layers, are particularly susceptible to contamination. This is because limestone and dolostone are susceptible to dissolution, which causes the formation of holes and flow channels in this material, known as karst conduits (Bakalowicz, 2005; Runkel et. al 2003; Witthuhn & Alexander, 1995). These karst conduits allow for contaminated water from the surface to

quickly flow through the limestone and dolostone into the underlying aquifers (Runkel et al., 2003). Deeper sandstone aquifers, such as the Mt. Simon, Franconia, and Wonewoc aquifers, tend to be more resistant to contamination than their shallower counterparts as they are protected by the St. Lawrence and Eau Claire siltstone and shale confining layers (Runkel et al., 2003, Steenberg, 2014). Locations in the western portion of the county where bedrock is covered by glacial till are also less susceptible to contamination as the till acts as a confining layer, slowing the flow of water from the surface to the aquifers below, allowing more time for attenuation of contaminants (MDNR, 1991).

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 Fillmore County as presented in Figure 2.

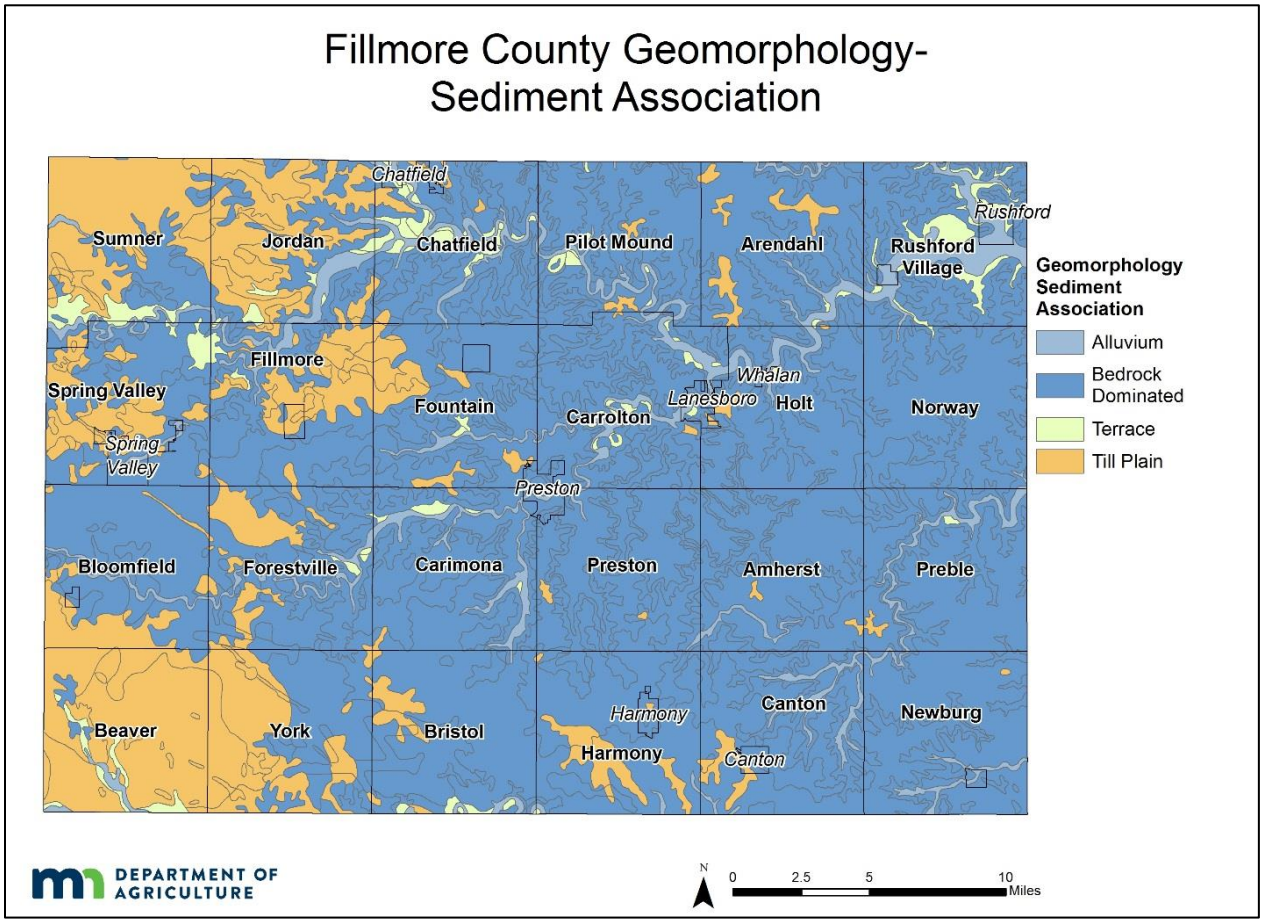

Figure 2. Statewide Geomorphology Layer, Sediment Association in Fillmore County (MDNR, MGS, UMD, 1997)

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 Dodge County. Further details are in Appendix B.

SUBSURFACE SEWAGE TREATMENT SYSTEM

Subsurface Sewage treatment systems (SSTS) can be a potential source for contaminates in groundwater such as nitrate and fecal material (MDH, 2014). A total of 5,144 SSTS were reported in Fillmore County for 2017. Over a recent 14 year period (2002-2017), 1,459 construction permits for new, replacement, or repairs for SSTS were issued. Of all the reported septic systems in Fillmore County, 28 percent are newer than 2002 or have been repaired since 2002 (MPCA, 2018a). 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 Fillmore County study area there are a total of 693 active feedlots. Of these, 328 are permitted to house more than 100 animal units (AU) and 115 are permitted to house more than 300 AU (Appendix B; Figure 7). The vast majority of feedlots in the study area (80.5%) contain dairy and beef cattle.

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 Fillmore County study area has a total of 11 fertilizer storage licenses. (Appendix B; Table 11).

FERTILIZER SPILLS AND INVESTIGATIONS

A total of 14 historic fertilizer spills and investigations occurred in the Fillmore County study area. The majority of these were small spills and investigations and old emergency incidents (Appendix B; Table 12).

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 these 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.

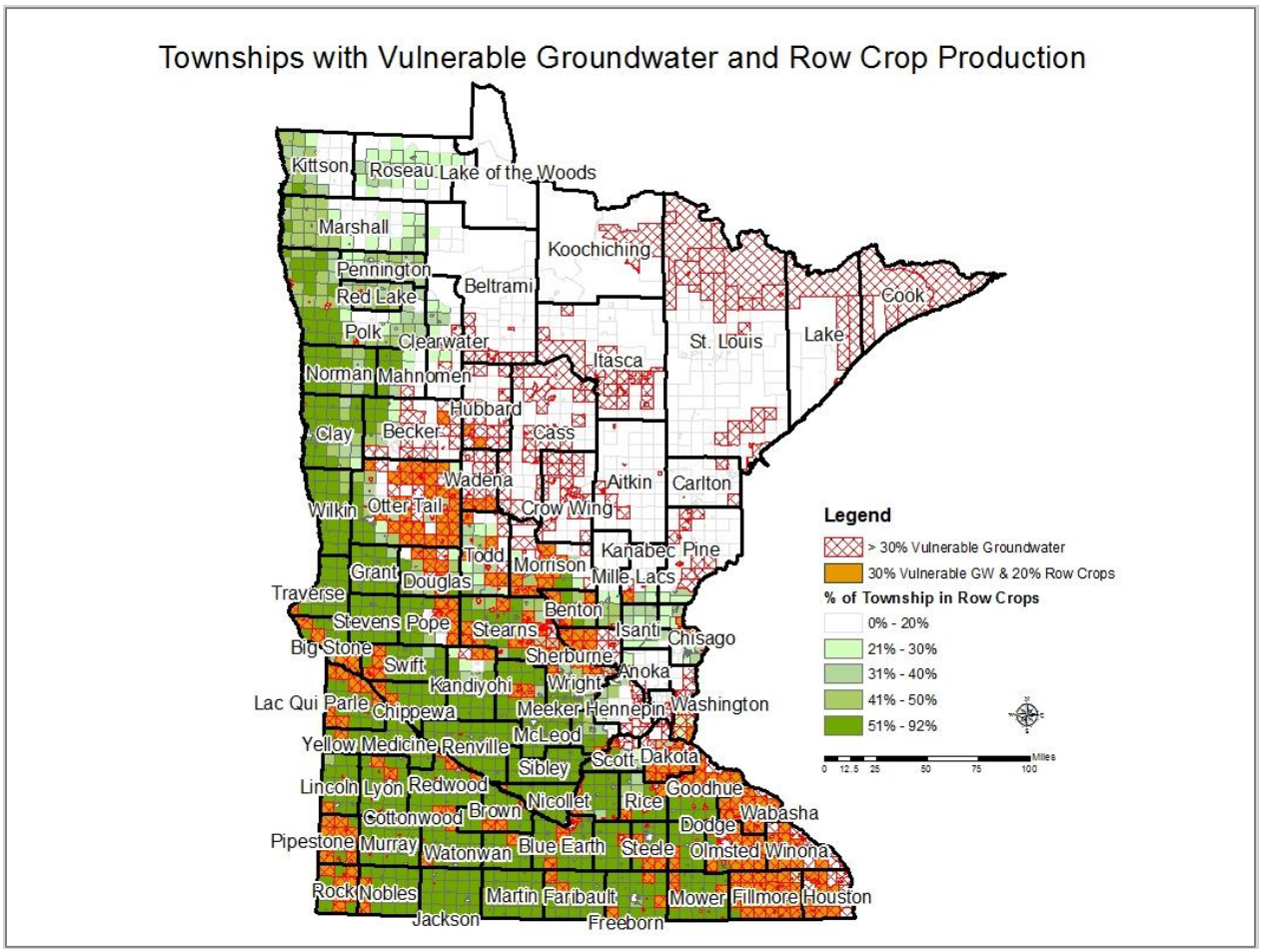

Figure 3. Minnesota Townships with Vulnerable Groundwater and Row Crop Production

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 Fillmore County depicting the aquifer vulnerabilities is shown below in Figure 4. Fillmore County only has regions with high and low aquifer sensitivity, there are no areas classified as having medium sensitivity.

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

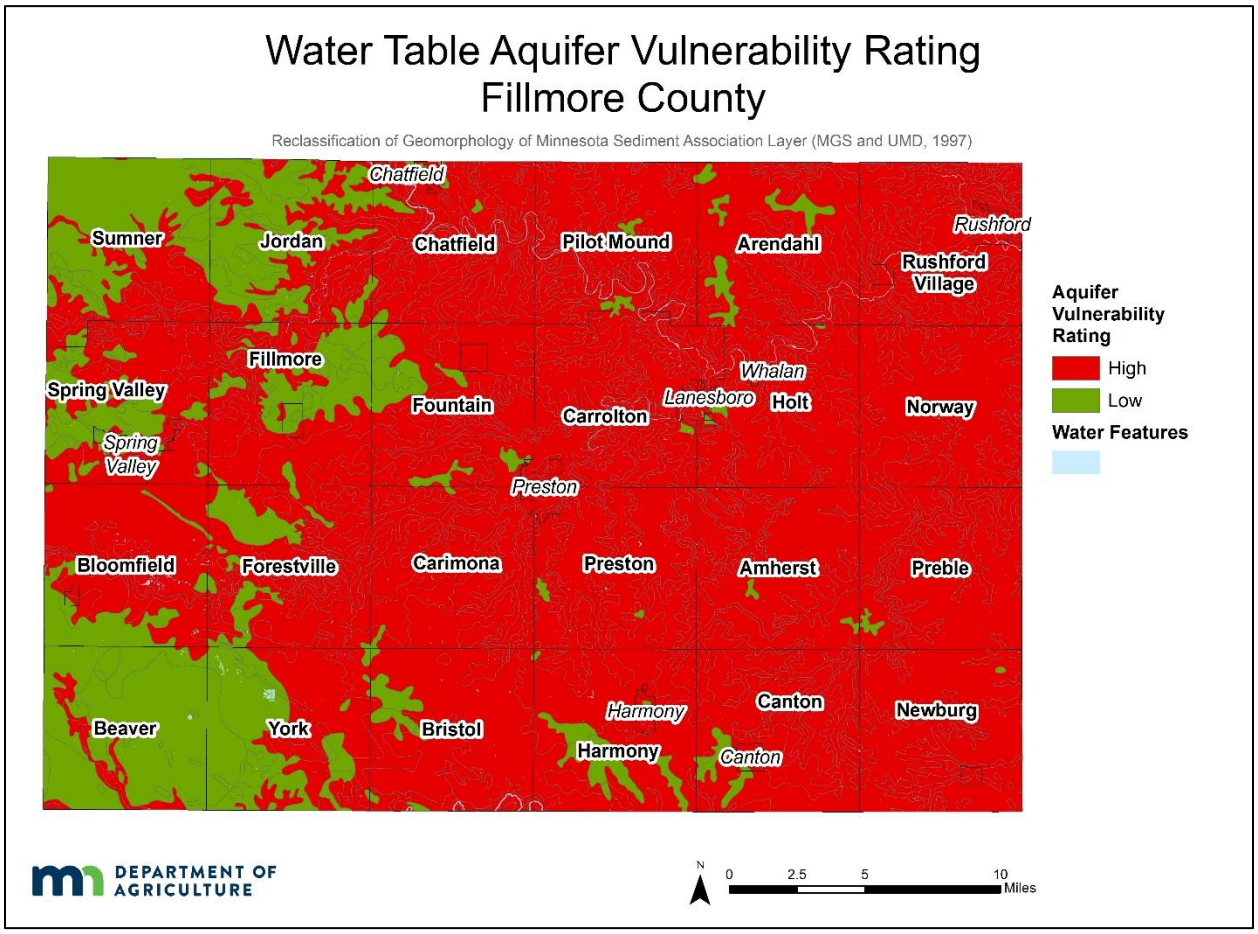

Figure 4. Water Table Aquifer Vulnerability Rating in Fillmore County

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 Fillmore County can be found in Appendix C (Figure 9, Table 14). On average 46 percent of the land cover was row crop agriculture.

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 2017. 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 1,477 homeowners using the mail-in kit (Table 2). These 1,477 samples are considered the "initial well dataset". Overall, 34 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 2018 by MDA staff. A total of 413 follow-up samples were analyzed (Table 2).

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).

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

Township	Kits Sent	Return Rate for Kits	Initial Well Dataset	Well Site Visits & Follow-up Sampling Conducted
Amherst	180	35.0%	63	14
Arendahl	163	36.8%	60	15
Beaver	112	41.1%	46	3
Bloomfield	159	34.0%	54	22
Bristol	192	29.7%	57	6
Canton	252	22.2%	56	20
Carimona	161	33.5%	54	22
Carrolton	179	42.5%	76	29
Chatfield	215	40.5%	87	25
Fillmore	228	28.5%	65	13
Forestville	183	36.6%	67	22
Fountain	142	27.5%	39	11
Harmony	151	27.8%	42	13
Holt	151	33.1%	50	14
Jordan	171	31.0%	53	12
Newburg	207	37.7%	78	25
Norway	173	25.4%	44	9
Pilot Mound	191	31.9%	61	22
Preble	143	30.8%	44	16
Preston	154	35.1%	54	26
Rushford Village	269	47.6%	128	30
Spring Valley	249	34.1%	85	22
Sumner	189	25.4%	48	9
York	186	35.5%	66	13
Total	4,400	33.6%	1,477	413

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 407 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 potentially 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.

Additionally, for Fillmore County two wells were removed because the water sample was drawn from a cistern. Cisterns are buried or above-ground tanks used for the storage of water. In these systems, water is pumped from a well into the cistern, where it is then drawn for use (Hardie, 2018). Cisterns are vulnerable to leaks and contamination due to underground cracking, damaged lids, fill ports, or vents (Alberta Health Services, 2016), thus wells with a water sample drawn from a cistern are 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 be an older well.

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

Site visits were not conducted at locations where the homeowner did not return a signed consent form to the MDA. 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. Again site visits were not conducted at these locations because the homeowner did not return a signed consent form to the MDA.

DUPLICATE / EXTRA KIT

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

SHARED WELL

Several homes in Fillmore County share their domestic drinking water wells. Only one result per well was kept in the final dataset, and any additional samples from the same well were removed.

INITIAL RESULTS

INITIAL WELL DATASET

A total of 1,477 well owners returned water samples for analysis across the 24 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-N for all townships were less than the detection limit (<DL) which is 0.25 mg/L. The maximum values ranged from 11.8 mg/L (Preston Township) to 45.1 mg/L (Pilot Mound Township). Median values range from <0.25 mg/L (Beaver and Jordan Townships) to 6.8 mg/L (Bloomfield Townships). The 90th percentiles range from 3.6 mg/L (Rushford Village) to 19.0 mg/L (Norway Township).

Initial results from the sampling showed that in 19 out of 24 tested townships (Amherst, Arendahl, Bloomfield, Bristol, Canton, Carimona, Chatfield, Fillmore, Forestville, Fountain, Harmony, Holt, Newburg, Norway, Pilot Mound, Preble, Spring Valley, Sumner, and York Townships) ten percent or more of the wells were at or over 10 mg/L nitrate-N. Data from the Township Testing Program (MDA) suggests that private well water in these 19 townships are more heavily impacted by nitrate than other areas of the upper United States. Both the USGS report and MDA Township Testing studies indicate that nitrate concentrations can vary considerably over short distances.

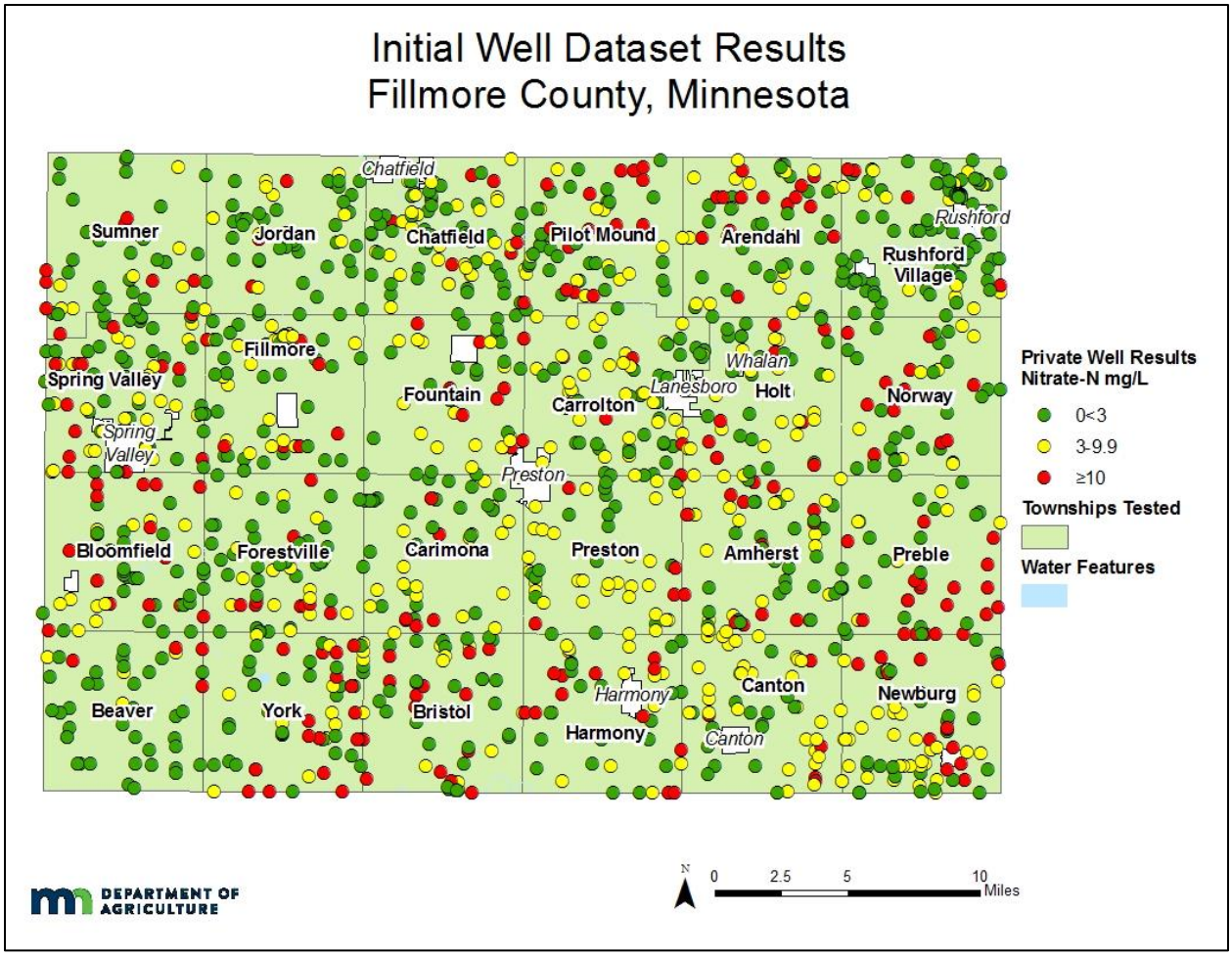

Figure 5. Well locations and Nitrate Results from Initial Dataset in Fillmore County

Table 3. Fillmore 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	3<10	≥5	≥7	≥10	<3	3<10	≥5	≥7	≥10
		Nitrate-N mg/L or PPM																	
Amherst	63	<0.25	18.8	5.4	3.1	9.9	14.6	15.7	18.5	28	20	26	23	15	44.4%	31.7%	41.3%	36.5%	23.8%
Arendahl	60	<0.25	29.6	6.4	3.6	11.0	15.9	19.8	29.0	27	17	26	25	16	45.0%	28.3%	43.3%	41.7%	26.7%
Beaver	46	<0.25	17.0	1.3	<0.25	0.4	3.9	7.2	17.0	39	5	3	2	2	84.8%	10.9%	6.5%	4.3%	4.3%
Bloomfield	54	<0.25	17.4	6.1	6.8	10.6	13.2	15.0	17.3	23	13	31	26	18	42.6%	24.1%	57.4%	48.1%	33.3%
Bristol	57	<0.25	18.9	4.6	1.8	9.1	14.1	14.7	18.7	33	11	22	16	13	57.9%	19.3%	38.6%	28.1%	22.8%
Canton	56	<0.25	29.7	5.6	4.6	7.9	10.5	15.9	29.3	20	30	25	17	6	35.7%	53.6%	44.6%	30.4%	10.7%
Carimona	54	<0.25	25.7	4.6	2.6	6.1	13.7	19.3	25.7	28	19	17	10	7	51.9%	35.2%	31.5%	18.5%	13.0%
Carrolton	76	<0.25	22.1	3.8	3.3	4.8	9.5	12.1	20.8	37	32	16	12	7	48.7%	42.1%	21.1%	15.8%	9.2%
Chatfield	87	<0.25	20.0	3.9	2.4	6.0	10.0	13.1	19.2	47	31	27	17	9	54.0%	35.6%	31.0%	19.5%	10.3%
Fillmore	65	<0.25	25.8	4.3	1.9	7.3	10.9	15.0	24.7	35	22	23	18	8	53.8%	33.8%	35.4%	27.7%	12.3%
Forestville	67	<0.25	16.6	4.1	1.7	7.4	12.6	13.5	16.5	38	18	21	17	11	56.7%	26.9%	31.3%	25.4%	16.4%
Fountain	39	<0.25	16.5	5.6	3.7	9.6	14.3	16.0	16.5	16	15	18	15	8	41.0%	38.5%	46.2%	38.5%	20.5%
Harmony	42	<0.25	22.0	5.9	3.9	11.2	13.7	15.1	22.0	18	12	19	17	12	42.9%	28.6%	45.2%	40.5%	28.6%
Holt	50	<0.25	39.9	6.0	4.0	8.4	14.1	19.1	39.9	21	20	23	17	9	42.0%	40.0%	46.0%	34.0%	18.0%
Jordan	53	<0.25	11.8	2.5	<0.25	5.9	9.0	10.0	11.8	37	13	15	12	3	69.8%	24.5%	28.3%	22.6%	5.7%
Newburg	78	<0.25	23.6	6.1	5.9	9.5	13.2	14.6	22.1	27	35	44	32	16	34.6%	44.9%	56.4%	41.0%	20.5%
Norway	44	<0.25	28.0	6.3	1.9	10.3	19.0	22.4	28.0	24	9	19	16	11	54.5%	20.5%	43.2%	36.4%	25.0%
Pilot Mound	61	<0.25	45.1	5.9	2.9	10.0	12.8	16.3	42.6	31	15	27	23	15	50.8%	24.6%	44.3%	37.7%	24.6%
Preble	44	<0.25	28.4	7.1	4.5	13.3	15.5	19.0	28.4	20	7	22	21	17	45.5%	15.9%	50.0%	47.7%	38.6%
Preston	54	<0.25	12.7	4.6	4.7	7.2	9.4	10.0	12.6	20	30	26	15	4	37.0%	55.6%	48.1%	27.8%	7.4%
Rushford Village	128	<0.25	21.3	1.8	0.5	2.5	3.6	7.5	19.4	102	22	11	7	4	79.7%	17.2%	8.6%	5.5%	3.1%
Spring Valley	85	<0.25	16.8	3.9	1.6	7.1	10.7	12.2	15.7	44	30	34	22	11	51.8%	35.3%	40.0%	25.9%	12.9%
Sumner	48	<0.25	16.0	3.3	0.1	5.4	12.3	12.7	16.0	32	8	12	10	8	66.7%	16.7%	25.0%	20.8%	16.7%
York	66	<0.25	20.6	5.6	3.7	11.4	15.4	16.6	20.1	33	13	33	24	20	50.0%	19.7%	50.0%	36.4%	30.3%
Total	1,477	<0.25	45.1	4.6	2.5	7.7	12.4	15.4	22.1	780	447	540	414	250	52.8%	30.3%	36.6%	28.0%	16.9%

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 1,572 people in Fillmore County's study area have drinking water over the nitrate HRL (Table 4). Nitrate contamination is a significant problem for many wells in Fillmore County.

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

Township	Estimated 2017 Population on Private Wells*	Estimated 2017 Households on Private Wells*	Estimated Population ≥10 mg/L Nitrate-N**
Amherst	386	129	92
Arendahl	336	121	90
Beaver	236	93	10
Bloomfield	341	140	114
Bristol	370	128	84
Canton	734	207	79
Carimona	289	119	37
Carrolton	318	123	29
Chatfield	533	190	55
Fillmore	484	191	60
Forestville	347	146	57
Fountain	319	130	65
Harmony	387	133	111
Holt	259	110	47
Jordan	365	144	21
Newburg	366	156	75
Norway	328	115	82
Pilot Mound	355	140	87
Preble	199	83	77
Preston	367	117	27
Rushford Village	834	316	26
Spring Valley	502	219	65
Sumner	456	169	76
York	350	144	106
Total	9,461	3,563	1,572

*Data collected from the Minnesota State Demographic Center, 2017

**Estimates based off of the 2017 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 359 documented wells (Table 5). Approximately 24 percent of the sampled wells had corresponding well logs. Of those wells with a well log, 100 did not have a designated aquifer. Thus, the data gathered on aquifers represents roughly 18 percent 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 exception of the 'Quaternary undifferentiated' and 'multiple' aquifer categories where geologic age can vary . According to the well log data, the most commonly utilized aquifers for the sampled wells were the Prairie Du Chien group, the Jordan Sandstone, and the Tunnel City group. 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 393 feet.

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

QUATERNARY WATER TABLE

The Quaternary Water Table aquifers are located within the Quaternary glacial deposits. Quaternary Water Table aquifers are defined as having less than ten feet of confining material (clay) between the land surface and the well screen (MPCA, 1999).

SPILLVILLE FORMATION

The Spillville Formation consists of limestone and dolostone, and often contains voids within this material (Mossler, 1995).

GALENA GROUP AND MAQUOKETA FORMATION

The Galena group and Maquoketa aquifers are part of the Upper Carbonate aquifer group (MPCA, 1999). They consist mostly of limestone with thin beds of shale and dolostone interspersed throughout (Mossler, 1995).

PRAIRIE DU CHIEN GROUP

The Prairie du Chien aquifers are within the Oneota Dolomite and Shakopee Formations. Both consist of thin- to thick-bedded dolomite (MPCA, 1999).

JORDAN FORMATION

The Jordan aquifers are within fine to medium grained sandstone. This sandstone range from massive or thick-bedded to thin bedded (MPCA, 1999).

ST. LAWRENCE FORMATION

The St. Lawrence formation consists mainly of siltstone (MPCA, 1999) with horizontal bedding fractures. These bedding fractures make horizontal water flow in this aquifer much faster than vertical water flow (Green et al., 2012).

TUNNEL CITY GROUP (FRANCONIA FORMATION)

The Tunnel City Group, also called the Franconia Formation, consists of mostly of fine-grained sandstone with interbedded shale and dolomitic sandstone (MPCA, 1999). Although it is typically low-permeability, it can be used as an aquifer in some cases (MPCA, 1999).

WONEWOC FORMATION

The Wonewoc sandstone, also called the Ironton & Galesville sandstone, consists of poorly-sorted sandstone in its upper reaches, and becomes better sorted deeper down (Mossler, 1995).

EAU CLAIRE FORMATION

The upper part of the Eau Claire formation consists of fine-grained sandstone and shale. The middle and lower parts consists mainly of siltstone and shale beds (Mossler, 1995). It has low permeability and is thus considered a confining unit in most places (Steenberg, 2014).

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 Undifferentiated	1	140	1	0	0	100.0%	0.0%	0.0%
Quaternary Water Table	1	85	0	1	0	0.0%	100.0%	0.0%
Spillville Formation	3	100	1	2	0	33.3%	66.7%	0.0%
Maquoketa Formation	3	115	1	2	0	33.3%	66.7%	0.0%
Galena Group	25	270	12	7	6	48.0%	28.0%	24.0%
St. Peter Sandstone	17	378	17	0	0	100.0%	0.0%	0.0%
Prairie Du Chien Group	102	443	70	27	5	68.6%	26.5%	4.9%
Jordan Sandstone	63	383	46	14	3	73.0%	22.2%	4.8%
St. Lawrence Formation	4	296	4	0	0	100.0%	0.0%	0.0%
Tunnel City (Franconia Formation)	31	408	30	1	0	96.8%	3.2%	0.0%
Wonewoc Sandstone	5	281	5	0	0	100.0%	0.0%	0.0%
Eau Claire Formation	1	140	1	0	0	100.0%	0.0%	0.0%
Multiple	3	420	3	0	0	100.0%	0.0%	0.0%
Not Available	100	393	77	20	3	77.0%	20.0%	3.0%
Total	359	393	268	74	17	74.7%	20.6%	4.7%

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 majority of wells in each township are located on "rural" property. There were no properties located on lakes and very few (2 percent) in sub-divisions.

Approximately 81 percent of sampled wells are of drilled construction and less than one percent are sand-point wells. Sand point (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. There was only one hand-dug well in Fillmore County. As previously mentioned, hand dug wells are shallow and more sensitive to local surface runoff contamination than deeper drilled wells.

According to the survey, most sampled wells are between 100-299 feet deep (31%) or greater than 300 feet (33%). Shallower wells are less common, with 9 percent of wells being 50-99 feet, 2 percent of wells being 16-49 feet, and 0.3 percent of wells being 0-15 feet deep.

Most of the wells (62.3 percent) had not been tested for nitrate within the last ten years or homeowners were unsure if they had been tested. Only 8 percent reported 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 response summary relates to isolation distances of potential 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 54 percent of the properties.
- Agricultural fields are closer than 300 feet from wells at 48 percent of the properties.
- Twenty-eight percent of the 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 (58 percent) are over 300 feet from an active or inactive feedlot.
- Very few well owners (about 2 percent) across all townships store more than 500 pounds of fertilizer on their property.
- A small minority of wells (4 percent) are less than 50 feet away from septic systems.

FINAL RESULTS

FINAL WELL DATASET

A total of 1,477 well water samples were collected by homeowners across 24 townships. A total of 407 (28 percent) wells were found to be unsuitable and were removed to create the final well dataset. The final analysis was conducted on the remaining 1,070 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-N 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 0.0 to 23.3 percent.

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

Township	Initial Well Dataset	Final Well Dataset	Final Number of Wells ≥10 mg/L Nitrate-N	Final Percentage of Wells ≥10 mg/L Nitrate-N
Amherst	63	42	3	7.1%
Arendahl	60	43	5	11.6%
Beaver	46	42	0	0.0%
Bloomfield	54	31	4	12.9%
Bristol	57	38	3	7.9%
Canton	56	39	1	2.6%
Carimona	54	45	3	6.7%
Carrolton	76	63	1	1.6%
Chatfield	87	65	2	3.1%
Fillmore	65	50	1	2.0%
Forestville	67	49	4	8.2%
Fountain	39	27	0	0.0%
Harmony	42	26	2	7.7%
Holt	50	32	0	0.0%
Jordan	53	45	1	2.2%
Newburg	78	45	2	4.4%
Norway	44	29	3	10.3%
Pilot Mound	61	42	4	9.5%
Preble	44	30	7	23.3%
Preston	54	40	2	5.0%
Rushford Village	128	117	1	0.9%
Spring Valley	85	61	3	4.9%
Sumner	48	36	1	2.8%
York	66	33	1	3.0%
Total	1,477	1,070	54	5.0%

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 4.4 mg/L (Beaver Township) to 29.6 mg/L (Arendahl Township). The 90th percentile ranged from 1.4 mg/L (York Township) to 16.1 mg/L nitrate-N (Norway Township).

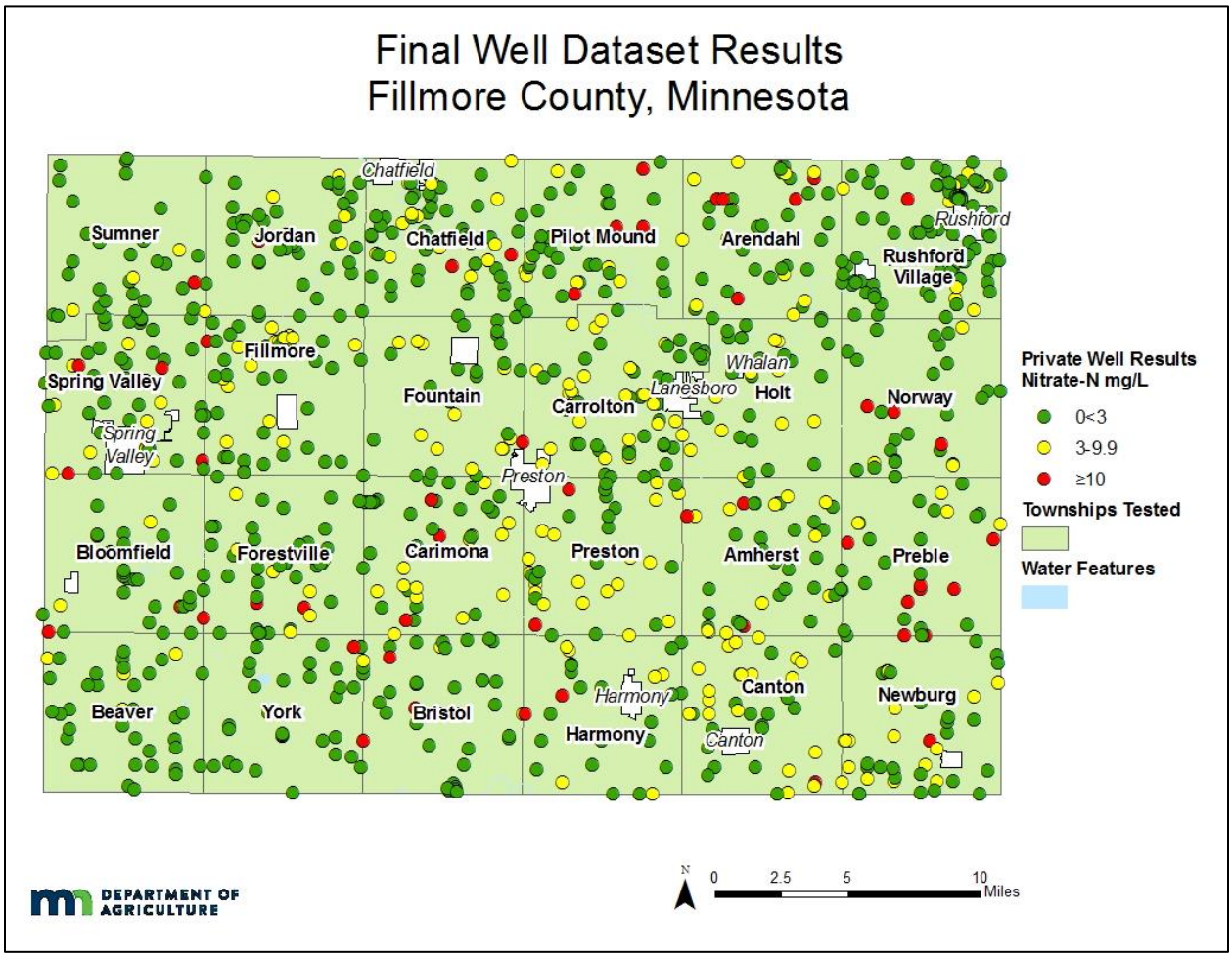

Figure 6. Well Locations and Nitrate Results from Final Well Dataset in Fillmore County

Table 7. Fillmore 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)																	
Amherst	42	<DL	15.6	2.6	1.7	3.2	8.6	13.0	15.6	27	12	6	5	3	64.3%	28.6%	14.3%	11.9%	7.1%
Arendahl	43	<DL	29.6	4.1	2.2	4.7	12.5	18.7	29.6	27	11	9	9	5	62.8%	25.6%	20.9%	20.9%	11.6%
Beaver	42	<DL	4.4	0.5	<DL	0.3	2.5	3.7	4.4	38	4	0	0	0	90.5%	9.5%	0.0%	0.0%	0.0%
Bloomfield	31	<DL	15.1	2.9	<DL	5.7	12.3	14.9	15.1	23	4	8	7	4	74.2%	12.9%	25.8%	22.6%	12.9%
Bristol	38	<DL	14.8	1.7	<DL	1.8	4.5	13.4	14.8	33	2	3	3	3	86.8%	5.3%	7.9%	7.9%	7.9%
Canton	39	<DL	17.4	3.6	2.9	4.6	7.5	8.8	17.4	20	18	8	5	1	51.3%	46.2%	20.5%	12.8%	2.6%
Carimona	45	<DL	23.6	3.0	1.7	4.4	6.3	11.3	23.6	28	14	8	4	3	62.2%	31.1%	17.8%	8.9%	6.7%
Carrolton	63	<DL	10.6	2.4	2.5	4.0	4.9	6.1	10.1	37	25	4	3	1	58.7%	39.7%	6.3%	4.8%	1.6%
Chatfield	65	<DL	17.9	2.3	1.3	3.6	6.2	8.7	16.9	46	17	8	5	2	70.8%	26.2%	12.3%	7.7%	3.1%
Fillmore	50	<DL	11.2	2.1	0.1	4.2	7.0	8.6	11.2	35	14	8	5	1	70.0%	28.0%	16.0%	10.0%	2.0%
Forestville	49	<DL	16.6	2.4	0.9	3.3	7.3	12.8	16.6	36	9	6	5	4	73.5%	18.4%	12.2%	10.2%	8.2%
Fountain	27	<DL	9.9	2.6	1.1	4.3	7.3	8.9	9.9	16	11	6	3	0	59.3%	40.7%	22.2%	11.1%	0.0%
Harmony	26	<DL	22.0	3.0	0.8	3.5	8.4	15.2	22.0	18	6	4	4	2	69.2%	23.1%	15.4%	15.4%	7.7%
Holt	32	<DL	9.9	2.2	1.0	3.2	6.2	6.9	9.9	21	11	5	1	0	65.6%	34.4%	15.6%	3.1%	0.0%
Jordan	45	<DL	11.8	1.5	<DL	0.6	7.4	8.3	11.8	37	7	7	5	1	82.2%	15.6%	15.6%	11.1%	2.2%
Newburg	45	<DL	18.2	3.1	1.7	5.2	7.7	10.5	18.2	27	16	12	5	2	60.0%	35.6%	26.7%	11.1%	4.4%
Norway	29	<DL	28.0	3.4	<DL	2.2	16.1	23.6	28.0	23	3	5	4	3	79.3%	10.3%	17.2%	13.8%	10.3%
Pilot Mound	42	<DL	13.9	2.9	0.9	4.3	10.3	12.7	13.9	30	8	9	7	4	71.4%	19.0%	21.4%	16.7%	9.5%
Preble	30	<DL	20.1	4.5	2.2	7.5	14.0	15.0	20.1	19	4	9	8	7	63.3%	13.3%	30.0%	26.7%	23.3%
Preston	40	<DL	12.7	3.7	3.2	6.2	7.9	10.0	12.7	20	18	12	8	2	50.0%	45.0%	30.0%	20.0%	5.0%
Rushford Village	117	<DL	18.9	1.3	<DL	2.2	3.3	3.5	12.5	99	17	3	2	1	84.6%	14.5%	2.6%	1.7%	0.9%
Spring Valley	61	<DL	12.1	1.9	<DL	3.9	6.5	9.8	11.9	44	14	10	5	3	72.1%	23.0%	16.4%	8.2%	4.9%
Sumner	36	<DL	12.6	1.0	<DL	1.0	3.2	4.2	12.6	32	3	1	1	1	88.9%	8.3%	2.8%	2.8%	2.8%
York	33	<DL	11.0	0.8	<DL	<DL	1.4	8.2	11.0	31	1	2	2	1	93.9%	3.0%	6.1%	6.1%	3.0%
Total	1,070	<DL	29.6	2.4	0.5	3.3	7.0	10.1	17.8	767	249	153	106	54	71.7%	23.3%	14.3%	9.9%	5.0%

<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, Fillmore County

Township	Final Well Dataset	Percent in Row Crop Production 2013*	Percent in Vulnerable Geology	Percent ≥7 mg/L	Percent ≥10 mg/L
				Nitrate-N mg/L or parts per million (ppm)	
Amherst	42	41.9%	99.0%	11.9%	7.1%
Arendahl	43	37.2%	91.5%	20.9%	11.6%
Beaver	42	73.7%	10.9%	0.0%	0.0%
Bloomfield	31	72.4%	80.6%	22.6%	12.9%
Bristol	38	59.6%	92.4%	7.9%	7.9%
Canton	39	50.7%	95.1%	12.8%	2.6%
Carimona	45	38.0%	99.3%	8.9%	6.7%
Carrolton	63	23.7%	99.5%	4.8%	1.6%
Chatfield	65	30.3%	96.0%	7.7%	3.1%
Fillmore	50	52.0%	69.0%	10.0%	2.0%
Forestville	49	39.6%	81.2%	10.2%	8.2%
Fountain	27	53.3%	84.4%	11.1%	0.0%
Harmony	26	65.5%	86.8%	15.4%	7.7%
Holt	32	24.9%	98.5%	3.1%	0.0%
Jordan	45	36.0%	43.6%	11.1%	2.2%
Newburg	45	55.9%	99.8%	11.1%	4.4%
Norway	29	36.5%	100.0%	13.8%	10.3%
Pilot Mound	42	31.9%	97.6%	16.7%	9.5%
Preble	30	30.7%	99.0%	26.7%	23.3%
Preston	40	35.9%	99.1%	20.0%	5.0%
Rushford Village	117	15.5%	100.0%	1.7%	0.9%
Spring Valley	61	52.8%	67.8%	8.2%	4.9%
Sumner	36	65.2%	37.1%	2.8%	2.8%
York	33	72.6%	49.4%	6.1%	3.0%
Total	1,070	45.7%	82.4%	9.9%	5.0%

*Data retrieved from USDA NASS Cropland Data Layer, 2013

WELL AND WATER CHARACTERISTICS FOR FINAL WELL DATASET

WELL CONSTRUCTION

Unique identification numbers from well logs were compiled for the wells in the Fillmore 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/). The 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 (90 percent), and only 6 (0.6 percent) were sand point wells
- The median depth of wells was 410 feet, and the shallowest was 80 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 413 wells, of these 289 follow-up wells are included in the final well dataset. Field measurements of the well water parameters were recorded on Private Well Field Log & Well Survey Form (Appendix J).Starting in 2018, an electronic version of this form was used, and it incorporated all the same information as the paper form. 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 are described below and a more comprehensive view is available in Appendix K (Tables 38-41).

- The temperatures ranged from 8.1°C to 20.6°C
- The median specific conductivity was 601 µS/cm, and was as high as 1371 µS/cm
- The water from the wells had a median pH of 7.32
- The dissolved oxygen readings ranged from 0.1 mg/L to 15.86 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 (N2). 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 commercial row crop production in selected townships in Fillmore County. In order to prioritize testing, the MDA looked at townships with significant row crop production and vulnerable geology. Approximately 46 percent of the land cover in the Fillmore County study area is row crop agriculture.

Twenty-four townships were sampled, covering about 520,000 acres. The initial (homeowner collected) nitrate sampling resulted in 1,477 samples. The 1,477 households that participated represent, approximately, a 34 percent return rate of homeowner offered sampling kits. 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 413 wells.

The MDA conducted a nitrogen source assessment and identified wells near potential point sources and wells with poor construction. A total of 407 (28 percent) wells were found to be unsuitable and were removed from the initial well dataset of 1,477 wells. The remaining 1,070 wells were believed to be impacted by nitrogen fertilizer and were included in the final well dataset.

In the final well dataset 90 percent of wells are drilled; less than 1 percent were sand points. The median depth of the wells was 410 feet and the depths ranged from 80 to 670 feet deep.

For the final well dataset, in four of the 24 townships tested in Fillmore County, more than 10 percent of the wells were 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 0 percent (Beaver Township) to 23.3 percent (Preble Township).

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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** _____

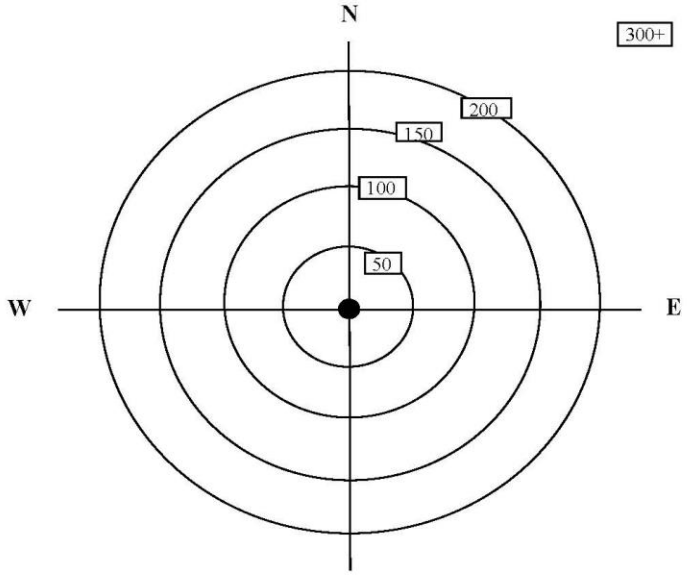
MDA -Private Well Field Log & Well Survey Form

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 (Individual Subsurface Treatment Systems, 2016; Midsized Subsurface Treatment Systems, 2016). 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. An 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 and MPCA, 2013a).

In 2017, Fillmore County reported a total of 5,144 SSTS, and 2.3 percent were inspected for compliance. Compliance inspections are conducted in Fillmore County during property transfers, when building permits are applied for, upon completion of new or replacement SSTS, before the addition of a bedroom or bathroom, when the use of the property is changing, or whenever the County deems appropriate. Holding tanks are only allowed under limited circumstances. If an SSTS is found to non-compliant or failing, it must be replaced within 12 months. If it is found to be an imminent public health threat, it must be brought up to code within 10 months. To accommodate the large Amish population of the county, houses without toilets are allowed to have special grey-water septic systems that are subject to less rigorous requirements than normal septic systems (Fillmore County, 2013).

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, 2017b). 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 (MPCA, 2017b).

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

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, 2017b). 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, 2017a). 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, 2017b). A map and table of the feedlots located in the Fillmore County study area can be found below (Figure 7; Table 10).

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

Township	Total Feedlots	Active Feedlots	Inactive Feedlots	Average AU Permitted** Per Feedlot	Total Permitted** AU	Total Square Miles	Permitted** AU per Square Mile
Amherst	73	37	36	106	3,940	36	110
Arendahl	51	33	18	92	3,036	36	85
Beaver	22	11	11	200	2,201	36	61
Bloomfield	46	19	27	102	1,947	36	55
Bristol	97	43	54	166	7,143	36	198
Canton	64	34	30	190	6,457	35	184
Carimona	80	44	36	348	15,300	36	430
Carrolton	81	39	42	214	8,346	38	220
Chatfield	71	33	38	121	3,980	34	117
Fillmore	84	39	45	207	8,078	35	231
Forestville	78	37	41	139	5,133	36	142
Fountain	59	23	36	243	5,578	35	161
Harmony	68	18	50	268	4,825	35	138
Holt	49	25	24	183	4,576	33	141
Jordan	74	25	49	158	3,950	36	110
Newburg	81	24	57	170	4,091	35	116
Norway	71	39	32	193	7,541	36	211
Pilot Mound	65	31	34	159	4,933	34	144
Preble	64	16	48	159	2,541	36	71
Preston	73	34	39	201	6,845	35	198
Rushford Village	46	21	25	81	1,702	34	50
Spring Valley	61	22	39	128	2,827	32	89
Sumner	68	20	48	131	2,618	37	70
York	66	26	40	128	3,332	36	92
Total	1,592	693	899	*174	120,918	846	*143

*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 143 AU per square mile (0.22 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 Fillmore County study area, livestock densities average 0.49 AU per acre of row crops (MPCA, 2017b; USDA NASS, 2013).

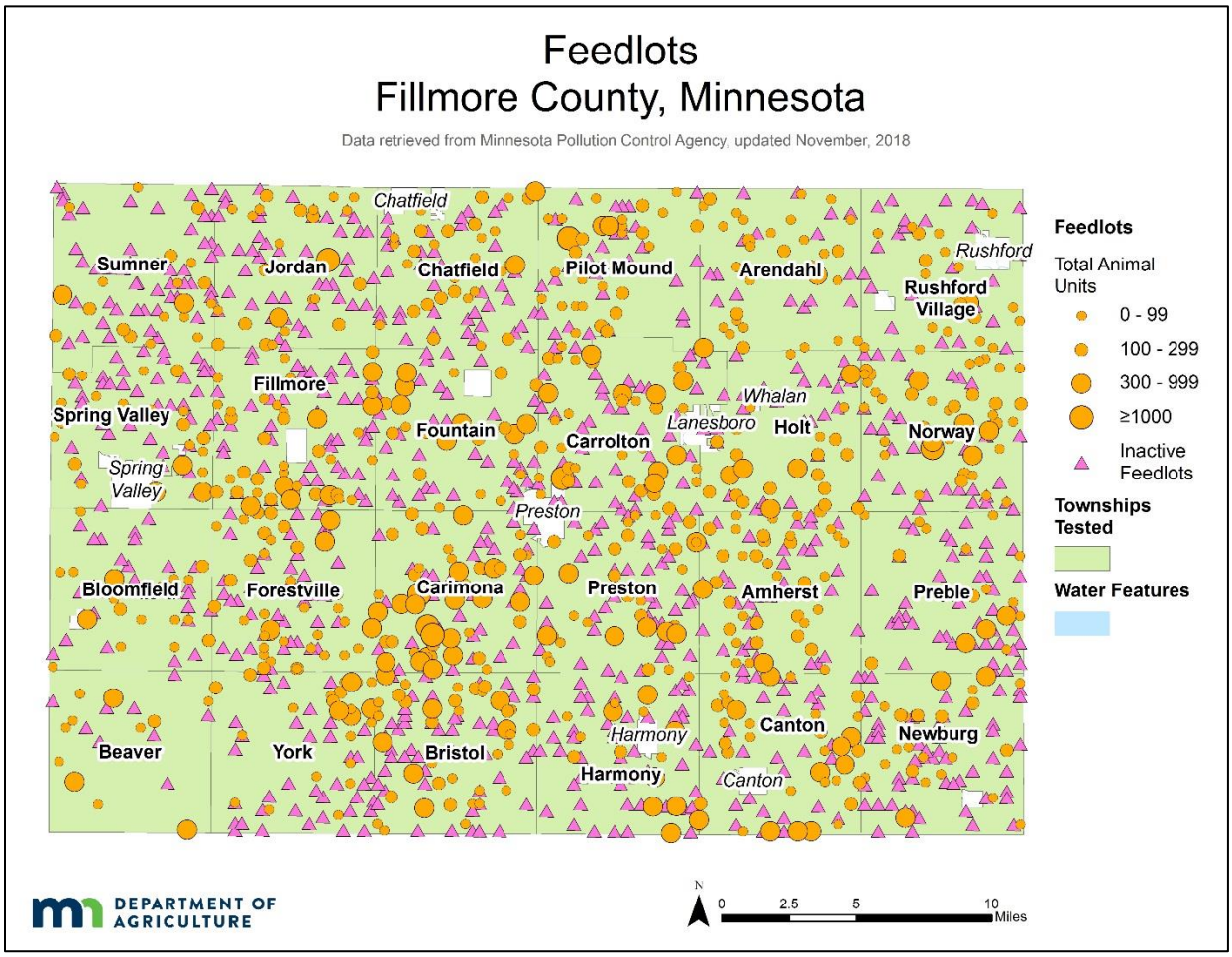


Figure 7. Feedlot Locations in Fillmore County (MPCA, 2018)

FERTILIZER STORAGE LOCATION

The 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, Fillmore County

Township	Bulk Fertilizer Storage	Anhydrous Ammonia	Chemigation Sites	Abandoned Sites	Total
Amherst	0	0	0	0	0
Arendahl	0	0	0	0	0
Beaver	0	0	0	0	0
Bloomfield	1	1	0	0	2
Bristol	0	0	0	0	0
Canton	0	0	0	0	0
Carimona	0	0	0	0	0
Carrolton	1	0	0	0	1
Chatfield	0	0	0	0	0
Fillmore	1	1	0	0	2
Forestville	0	0	0	0	0
Fountain	1	1	0	0	2
Harmony	0	0	0	0	0
Holt	0	0	0	0	0
Jordan	0	0	0	0	0
Newburg	1	0	0	0	1
Norway	0	0	0	0	0
Pilot Mound	0	0	0	0	0
Preble	0	0	0	0	0
Preston	0	0	0	0	0
Rushford Village	0	0	0	0	0
Spring Valley	0	0	0	0	0
Sumner	3	0	0	0	3
York	0	0	0	0	0
Total	8	3	0	0	11

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 Fillmore 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, 2018).

The MDA tracks several types of incidents. Incident investigations are typically for larger spills. There are five 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. Old emergency incidents were closed prior to March 1st, 2004 (MDA, 2018), 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. Small spills and investigations are typically smaller emergency spills such as a truck spilling chemicals. There are six 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, 2018). 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.

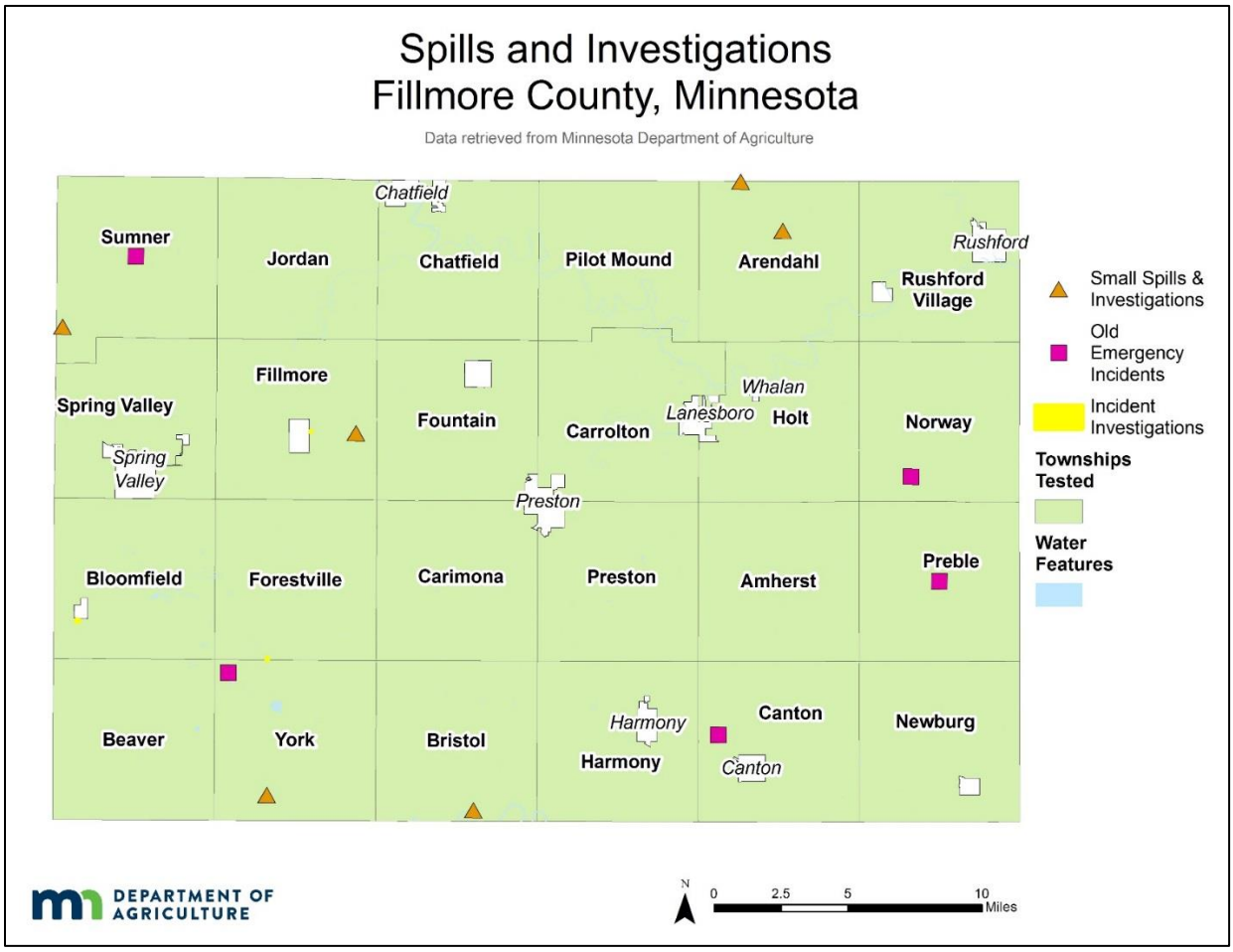


Figure 8. Fertilizer Spills and Investigations in Fillmore County (MDA, 2018)

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

Contaminant	Incident Investigations	Contingency Areas	Small Spills and Investigations	Old Emergency Incidents	Total
Fertilizer	0	0	2	3	5
Pesticides & Fertilizer	3	0	1	2	6
Anhydrous Ammonia	0	0	3	0	3
Total	3	0	6	5	14

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

Township	Incidents and Spills
Amherst	0
Arendahl	2
Beaver	0
Bloomfield	1
Bristol	1
Canton	1
Carimona	0
Carrolton	0
Chatfield	0
Fillmore	2
Forestville	1
Fountain	0
Harmony	0
Holt	0
Jordan	0
Newburg	0
Norway	1
Pilot Mound	0
Preble	1
Preston	0
Rushford Village	0
Spring Valley	0
Sumner	2
York	2
Total	14

APPENDIX C

LAND AND WATER USE

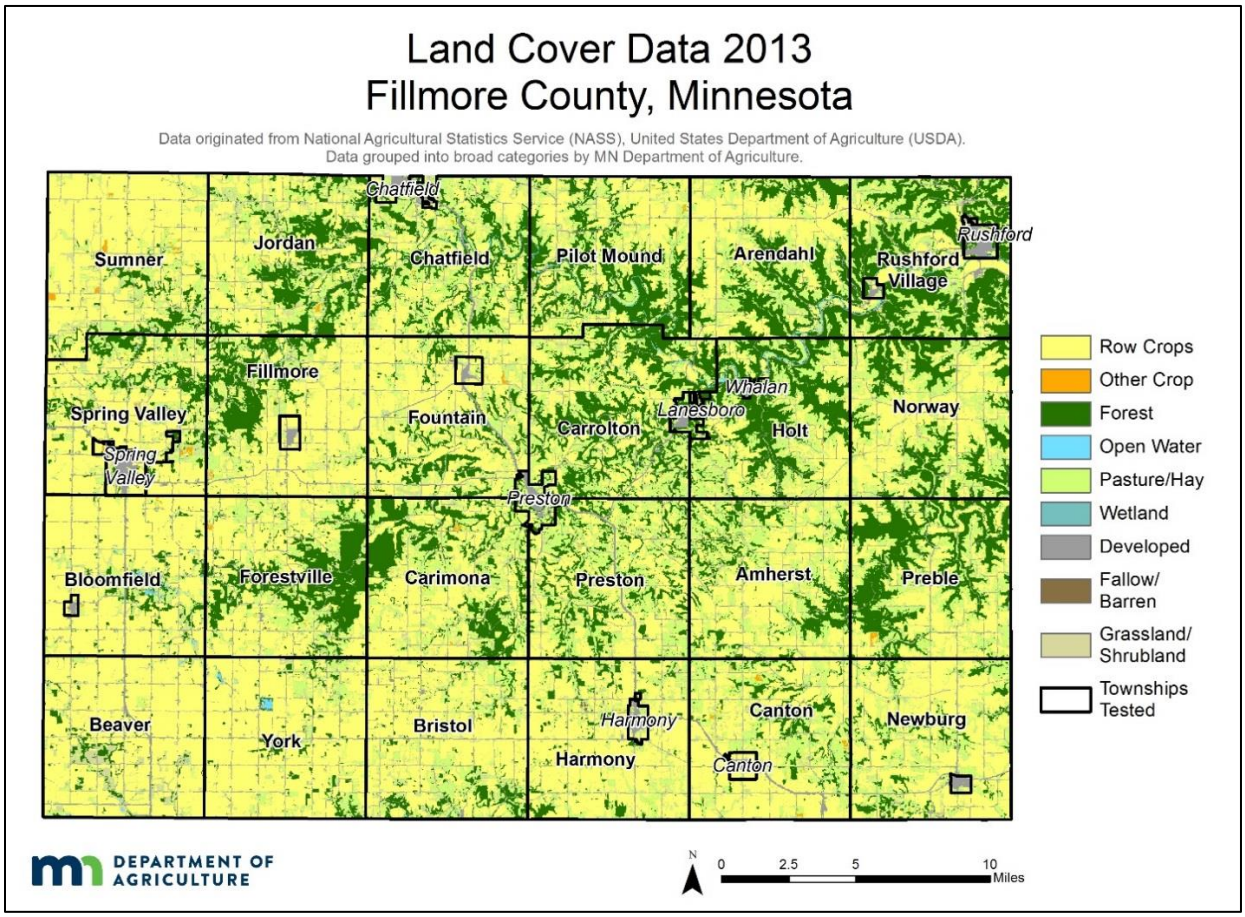


Figure 9. Land Cover in Fillmore County (USDA NASS Cropland Data Layer, 2013)

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

Township	Total Acres	Row Crop	Other Crops	Forest	Open Water	Pasture/ Hay	Wetland	Developed	Fallow/ Barren	Grassland/ Shrubland
Amherst	22,899	42%	0%	17%	0%	31%	0%	4%	0%	6%
Arendahl	22,884	37%	0%	29%	0%	25%	0%	4%	0%	5%
Beaver	23,127	74%	0%	4%	0%	5%	0%	6%	0%	10%
Bloomfield	22,843	72%	0%	6%	0%	9%	0%	6%	0%	7%
Bristol	23,038	60%	0%	9%	0%	18%	0%	4%	0%	9%
Canton	22,416	51%	1%	10%	0%	26%	0%	5%	0%	8%
Carimona	22,787	38%	0%	25%	0%	25%	0%	3%	0%	8%
Carrolton	24,354	24%	0%	36%	0%	29%	0%	4%	0%	6%
Chatfield	21,828	30%	0%	24%	0%	31%	1%	5%	0%	9%
Fillmore	22,356	52%	0%	18%	0%	16%	0%	4%	0%	9%
Forestville	23,086	40%	0%	28%	0%	20%	0%	3%	0%	9%
Fountain	22,161	53%	0%	15%	0%	19%	0%	5%	0%	8%
Harmony	22,296	66%	0%	7%	0%	15%	0%	4%	0%	8%
Holt	20,798	25%	0%	37%	1%	29%	0%	4%	0%	5%
Jordan	22,997	36%	1%	25%	0%	24%	0%	3%	0%	11%
Newburg	22,645	56%	0%	9%	0%	24%	0%	5%	0%	7%
Norway	22,848	36%	0%	27%	0%	28%	0%	4%	0%	5%
Pilot Mound	21,987	32%	0%	31%	1%	26%	0%	3%	0%	6%
Preble	22,848	31%	0%	34%	0%	27%	0%	3%	0%	5%
Preston	22,111	36%	0%	20%	0%	32%	0%	4%	0%	8%
Rushford Village	21,586	16%	0%	49%	1%	25%	0%	4%	0%	5%
Spring Valley	20,362	53%	1%	15%	0%	17%	0%	5%	0%	10%
Sumner	23,985	65%	1%	7%	0%	14%	0%	4%	0%	10%
York	23,111	73%	0%	5%	0%	10%	0%	5%	0%	6%
Average	*541,350	46%	0%	20%	0%	22%	0%	4%	0%	8%

*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, 2018a). There are a total of 51 active groundwater well permits in the study area, three of which are used for irrigating major crops (Figure 10). About 470 acres of cropland are permitted for groundwater irrigation in this area. Most permitted wells withdraw groundwater from Paleozoic and unclassified aquifers (Table 16 MDNR, 2018b).

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

Township	Major Crop Groundwater Well Use Permits	Average Depth (feet)	Irrigated Acres
Amherst	0	-	0
Arendahl	0	-	0
Beaver	0	-	0
Bloomfield	2	417	453
Bristol	0	-	0
Canton	0	-	0
Carimona	0	-	0
Carrolton	0	-	0
Chatfield	0	-	0
Fillmore	0	-	0
Forestville	0	-	0
Fountain	0	-	0
Harmony	0	-	0
Holt	0	-	0
Jordan	0	-	0
Newburg	0	-	0
Norway	0	-	0
Pilot Mound	0	-	0
Preble	0	-	0
Preston	0	-	0
Rushford Village	1	360	17
Spring Valley	0	-	0
Sumner	0	-	0
York	0	-	0
Total	3	398*	470

*Represents an average

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

Water Use Well Permits	Total	Average Depth (feet)	Quaternary	Paleozoic	Not Classified
Agricultural Irrigation	3	398	0	2	1
Non-Crop Irrigation	4	276	1	2	1
Water Supply	4	300	0	3	1
Industrial Processing	1	0	0	0	1
Special Categories	39	270	0	18	21
Total	51	274*	1	25	25

* Represents an average

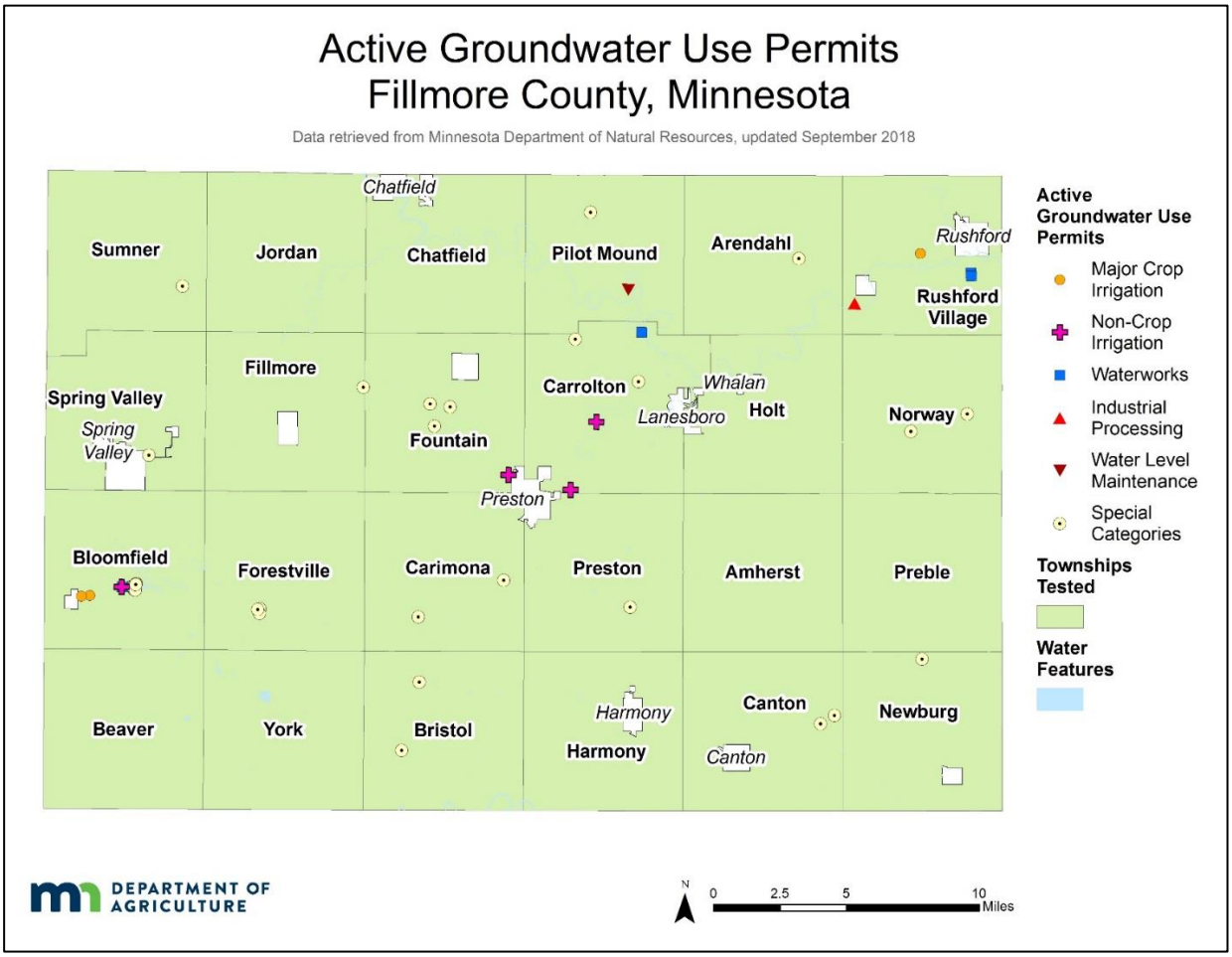


Figure 10. Active Groundwater Use Permits in Fillmore County (MDNR, 2018b)

APPENDIX D

Nitrate Brochure

The Minnesota Department of Agriculture and the Fillmore County Environmental Services 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, Fillmore 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 or Extra Kit	Shared Well	Total
Amherst	7	0	0	0	0	12	1	1	0	21
Arendahl	3	1	0	0	0	13	0	0	0	17
Beaver	0	0	0	0	0	3	0	0	1	4
Bloomfield	4	9	0	0	4	5	1	0	0	23
Bristol	6	2	0	0	0	11	0	0	0	19
Canton	4	4	0	0	2	7	0	0	0	17
Carimona	2	2	0	0	0	5	0	0	0	9
Carrolton	4	1	0	0	0	7	0	0	1	13
Chatfield	6	1	0	1	1	11	0	0	2	22
Fillmore	1	3	0	0	0	10	1	0	0	15
Forestville	3	3	0	1	1	7	1	2	0	18
Fountain	0	2	0	0	1	9	0	0	0	12
Harmony	4	1	0	0	0	10	0	0	1	16
Holt	5	2	0	0	1	10	0	0	0	18
Jordan	2	0	0	0	0	4	1	1	0	8
Newburg	8	4	0	3	0	18	0	0	0	33
Norway	2	2	0	0	0	11	0	0	0	15
Pilot Mound	4	2	0	1	0	11	0	0	1	19
Preble	4	1	0	0	0	8	0	0	1	14
Preston	6	3	0	0	0	4	1	0	0	14
Rushford Village	1	3	0	0	0	4	0	0	3	11
Spring Valley	9	1	0	1	3	10	0	0	0	24
Sumner	2	1	0	1	2	5	1	0	0	12
York	7	4	0	0	1	18	1	2	0	33
Total	94	52	0	8	16	213	8	6	10	407

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

Township	Site Visit	No Site Visit	Total
Amherst	4	17	21
Arendahl	1	16	17
Beaver	0	4	4
Bloomfield	14	9	23
Bristol	2	17	19
Canton	7	10	17
Carimona	4	5	9
Carrolton	5	8	13
Chatfield	7	15	22
Fillmore	3	12	15
Forestville	8	10	18
Fountain	3	9	12
Harmony	4	12	16
Holt	4	14	18
Jordan	2	6	8
Newburg	10	23	33
Norway	4	11	15
Pilot Mound	6	13	19
Preble	3	11	14
Preston	7	7	14
Rushford Village	6	5	11
Spring Valley	8	16	24
Sumner	5	7	12
York	7	26	33
Total	124	283	407

APPENDIX F

MINNESOTA WELL INDEX

The MWI was used to gather information about the 24 townships in Fillmore 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 1,340 documented (have a verified location in the MWI) wells:

- About 1% are completed in the Quaternary aquifers: the Quaternary water table aquifer (QWTA), the Quaternary buried artesian aquifer, and the Quaternary undifferentiated aquifer.
- The most utilized aquifers in the study area are the St. Peter sandstone, the Prairie Du Chien group, the Jordan sandstone, and the Tunnel City group. Seventy-five percent of documented wells finish in these aquifers.
- The deepest commonly used aquifers (the Tunnel City and Wonewoc) are used most heavily in townships in the northeastern portion of the township (Rushford Village, Norway, Arendahl, Preble, and Holt).
- The shallowest aquifers (the Wapsipinicon/Spillville, Maquoketa, and Galena) are most commonly used in southwestern townships, where bedrock is predominantly covered by glacial till.
- For 10 percent of wells the aquifer was undocumented.

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

Township	Quaternary Water Table	Quaternary Buried Artesian	Quaternary Undifferentiated	Cedar Valley	Wapsipinicon/ Spillville	Maquoketa Group	Galena Group	St. Peter Sandstone	Prairie Du Chien Group	Jordan Sandstone	St. Lawrence	Tunnel City	Wonewoc Sandstone	Eau Claire	Mt. Simon Sandstone	Indeterminate	Multiple Aquifers	Not Available	Total
	Number of wells drawing water from an aquifer																		
Amherst	0	0	0	0	0	0	1	1	13	19	3	8	0	0	0	0	1	4	50
Arendahl	2	0	0	0	0	0	0	0	1	7	1	22	1	0	0	0	0	6	40
Beaver	0	0	2	3	14	4	9	1	0	0	0	0	0	0	0	1	2	2	38
Bloomfield	0	0	0	0	14	3	10	6	11	0	0	0	0	0	0	0	2	0	46
Bristol	0	0	0	0	0	1	5	7	35	0	0	0	0	0	0	0	1	7	56
Canton	0	0	0	0	0	0	1	3	38	9	1	1	0	0	0	0	1	6	60
Carimona	0	0	0	0	0	0	1	4	32	22	0	0	0	0	0	0	0	4	63
Carrolton	0	0	0	0	0	0	1	0	3	26	0	11	0	0	0	0	4	9	54
Chatfield	0	0	0	0	0	0	0	0	50	51	1	1	0	0	0	0	1	8	112
Fillmore	0	0	0	0	0	0	4	12	50	1	0	0	0	0	0	0	0	3	70
Forestville	0	0	0	0	0	1	4	17	44	0	0	0	0	0	0	0	1	3	70
Fountain	0	0	0	0	0	0	1	4	42	10	0	3	0	0	0	0	0	6	66
Harmony	0	0	0	0	0	0	3	2	34	2	0	0	0	0	0	0	0	1	42
Holt	2	0	0	0	0	0	0	0	1	8	2	19	0	0	0	0	0	6	38
Jordan	0	0	1	0	0	0	2	5	55	2	0	0	0	0	0	0	2	10	77
Newburg	0	0	0	0	0	0	0	0	10	20	0	5	0	0	0	0	6	7	48
Norway	0	0	0	0	0	0	0	0	1	6	1	19	8	0	0	0	2	4	41
Pilot Mound	1	0	0	0	0	0	0	0	7	40	2	6	0	0	0	0	0	8	64
Preble	0	0	0	0	0	0	0	0	3	4	0	13	1	0	0	0	1	3	25
Preston	0	0	0	0	0	0	0	0	20	26	3	1	0	0	0	0	0	5	55
Rushford Village	2	1	0	0	0	0	0	0	0	1	1	31	23	2	2	0	1	12	76
Spring Valley	0	0	0	0	0	4	6	22	15	0	0	0	0	0	0	0	2	6	55
Sumner	0	0	0	0	0	1	4	26	13	0	0	0	0	0	0	0	0	4	48
York	0	0	0	0	4	3	5	10	14	0	0	0	0	0	0	0	5	5	46
Total	7	1	3	3	32	17	57	120	492	254	15	140	33	2	2	1	32	129	1,340
Average Well Depth (ft)	99	145	140	72	132	172	242	404	429	400	413	433	330	315	505	225	304	380	392

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	River Home	Sub-Division	Other	Not Available
Amherst	63	88.9%	0.0%	0.0%	1.6%	9.5%
Arendahl	60	88.3%	1.7%	0.0%	1.7%	8.3%
Beaver	46	91.3%	2.2%	0.0%	0.0%	6.5%
Bloomfield	54	87.0%	3.7%	0.0%	0.0%	9.3%
Bristol	57	86.0%	0.0%	0.0%	3.5%	10.5%
Canton	56	92.9%	0.0%	0.0%	3.6%	3.6%
Carimona	54	92.6%	1.9%	0.0%	1.9%	3.7%
Carrolton	76	85.5%	2.6%	3.9%	2.6%	5.3%
Chatfield	87	87.4%	1.1%	1.1%	0.0%	10.3%
Fillmore	65	84.6%	0.0%	0.0%	4.6%	10.8%
Forestville	67	79.1%	6.0%	0.0%	6.0%	9.0%
Fountain	39	87.2%	0.0%	0.0%	0.0%	12.8%
Harmony	42	85.7%	0.0%	0.0%	2.4%	11.9%
Holt	50	90.0%	2.0%	0.0%	0.0%	8.0%
Jordan	53	90.6%	0.0%	0.0%	5.7%	3.8%
Newburg	78	94.9%	0.0%	0.0%	1.3%	3.8%
Norway	44	88.6%	0.0%	0.0%	2.3%	9.1%
Pilot Mound	61	83.6%	3.3%	0.0%	3.3%	9.8%
Preble	44	81.8%	0.0%	0.0%	4.5%	13.6%
Preston	54	77.8%	0.0%	0.0%	1.9%	20.4%
Rushford Village	128	67.2%	0.0%	18.0%	2.3%	12.5%
Spring Valley	85	92.9%	1.2%	2.4%	1.2%	2.4%
Sumner	48	91.7%	0.0%	0.0%	4.2%	4.2%
York	66	83.3%	0.0%	0.0%	3.0%	13.6%
Total	1,477	85.8%	1.1%	2.0%	2.4%	8.8%

Table 21. Well Construction Type

Township	Total	Drilled	Sand Point	Hand Dug	Not Available
Amherst	63	79.4%	0.0%	0.0%	20.6%
Arendahl	60	83.3%	0.0%	0.0%	16.7%
Beaver	46	73.9%	0.0%	0.0%	26.1%
Bloomfield	54	63.0%	3.7%	0.0%	33.3%
Bristol	57	89.5%	0.0%	0.0%	10.5%
Canton	56	80.4%	1.8%	0.0%	17.9%
Carimona	54	85.2%	0.0%	0.0%	14.8%
Carrolton	76	88.2%	0.0%	0.0%	11.8%
Chatfield	87	88.5%	1.1%	0.0%	10.3%
Fillmore	65	84.6%	0.0%	0.0%	15.4%
Forestville	67	86.6%	0.0%	1.5%	11.9%
Fountain	39	92.3%	0.0%	0.0%	7.7%
Harmony	42	81.0%	0.0%	0.0%	19.0%
Holt	50	84.0%	4.0%	0.0%	12.0%
Jordan	53	86.8%	0.0%	0.0%	13.2%
Newburg	78	79.5%	1.3%	0.0%	19.2%
Norway	44	84.1%	0.0%	0.0%	15.9%
Pilot Mound	61	78.7%	0.0%	0.0%	21.3%
Preble	44	79.5%	0.0%	0.0%	20.5%
Preston	54	75.9%	0.0%	0.0%	24.1%
Rushford Village	128	78.1%	3.1%	0.0%	18.8%
Spring Valley	85	78.8%	0.0%	0.0%	21.2%
Sumner	48	77.1%	0.0%	0.0%	22.9%
York	66	77.3%	1.5%	0.0%	21.2%
Total	1,477	81.4%	0.8%	0.1%	17.7%

Table 22. Age of Well

Township	Total	1994 to Present	1985 to 1993	1975 to 1984	Before 1975	Not Available
Amherst	35	23.8%	3.2%	3.2%	25.4%	44.4%
Arendahl	60	26.7%	5.0%	8.3%	35.0%	25.0%
Beaver	46	21.7%	8.7%	2.2%	32.6%	34.8%
Bloomfield	54	16.7%	3.7%	7.4%	40.7%	31.5%
Bristol	57	22.8%	3.5%	10.5%	21.1%	42.1%
Canton	56	14.3%	5.4%	14.3%	32.1%	33.9%
Carimona	54	24.1%	7.4%	14.8%	31.5%	22.2%
Carrolton	76	28.9%	3.9%	9.2%	42.1%	15.8%
Chatfield	87	26.4%	4.6%	13.8%	33.3%	21.8%
Fillmore	65	27.7%	4.6%	12.3%	24.6%	30.8%
Forestville	67	20.9%	6.0%	9.0%	41.8%	22.4%
Fountain	39	20.5%	12.8%	12.8%	30.8%	23.1%
Harmony	42	14.3%	9.5%	7.1%	35.7%	33.3%
Holt	50	28.0%	6.0%	10.0%	34.0%	22.0%
Jordan	53	28.3%	0.0%	18.9%	32.1%	20.8%
Newburg	78	21.8%	2.6%	5.1%	30.8%	39.7%
Norway	44	20.5%	4.5%	9.1%	40.9%	25.0%
Pilot Mound	61	23.0%	4.9%	8.2%	26.2%	37.7%
Preble	44	22.7%	9.1%	2.3%	36.4%	29.5%
Preston	54	20.4%	9.3%	11.1%	27.8%	31.5%
Rushford Village	128	33.6%	7.0%	14.8%	17.2%	27.3%
Spring Valley	85	18.8%	10.6%	8.2%	40.0%	22.4%
Sumner	48	22.9%	8.3%	2.1%	41.7%	25.0%
York	66	12.1%	4.5%	9.1%	28.8%	45.5%
Total	1,477	23.2%	5.9%	9.7%	31.9%	29.3%

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
Amherst	63	0.0%	0.0%	4.8%	30.2%	31.7%	33.3%
Arendahl	60	0.0%	3.3%	5.0%	30.0%	38.3%	23.3%
Beaver	46	0.0%	13.0%	17.4%	23.9%	10.9%	34.8%
Bloomfield	54	0.0%	5.6%	25.9%	18.5%	20.4%	29.6%
Bristol	57	0.0%	0.0%	14.0%	24.6%	45.6%	15.8%
Canton	56	3.6%	3.6%	5.4%	33.9%	33.9%	19.6%
Carimona	54	0.0%	0.0%	9.3%	22.2%	46.3%	22.2%
Carrolton	76	0.0%	3.9%	10.5%	26.3%	36.8%	22.4%
Chatfield	87	1.1%	1.1%	6.9%	28.7%	43.7%	18.4%
Fillmore	65	0.0%	3.1%	4.6%	36.9%	30.8%	24.6%
Forestville	67	0.0%	0.0%	13.4%	28.4%	40.3%	17.9%
Fountain	39	0.0%	2.6%	5.1%	28.2%	46.2%	17.9%
Harmony	42	0.0%	4.8%	2.4%	47.6%	31.0%	14.3%
Holt	50	0.0%	2.0%	6.0%	26.0%	40.0%	26.0%
Jordan	53	0.0%	0.0%	5.7%	30.2%	43.4%	20.8%
Newburg	78	0.0%	2.6%	3.8%	35.9%	20.5%	37.2%
Norway	44	0.0%	0.0%	2.3%	29.5%	45.5%	22.7%
Pilot Mound	61	0.0%	1.6%	4.9%	39.3%	31.1%	23.0%
Preble	44	0.0%	2.3%	6.8%	43.2%	27.3%	20.5%
Preston	54	0.0%	0.0%	3.7%	22.2%	50.0%	24.1%
Rushford Village	128	0.8%	2.3%	4.7%	46.9%	14.8%	30.5%
Spring Valley	85	0.0%	0.0%	15.3%	25.9%	31.8%	27.1%
Sumner	48	0.0%	2.1%	14.6%	31.3%	20.8%	31.3%
York	66	0.0%	0.0%	19.7%	22.7%	31.8%	25.8%
Total	1,477	0.3%	2.1%	8.8%	31.1%	33.0%	24.8%

Table 24. Unique Well ID Known

Township	Total	No, Unique Well ID not known	Yes, Unique Well ID known	Not Available
Amherst	63	73.0%	12.7%	14.3%
Arendahl	60	65.0%	15.0%	20.0%
Beaver	46	65.2%	17.4%	17.4%
Bloomfield	54	88.9%	3.7%	7.4%
Bristol	57	75.4%	12.3%	12.3%
Canton	56	78.6%	10.7%	10.7%
Carimona	54	70.4%	14.8%	14.8%
Carrolton	76	68.4%	22.4%	9.2%
Chatfield	87	63.2%	23.0%	13.8%
Fillmore	65	73.8%	10.8%	15.4%
Forestville	67	80.6%	13.4%	6.0%
Fountain	39	69.2%	15.4%	15.4%
Harmony	42	81.0%	9.5%	9.5%
Holt	50	74.0%	12.0%	14.0%
Jordan	53	66.0%	22.6%	11.3%
Newburg	78	85.9%	10.3%	3.8%
Norway	44	75.0%	15.9%	9.1%
Pilot Mound	61	72.1%	21.3%	6.6%
Preble	44	79.5%	18.2%	2.3%
Preston	54	59.3%	18.5%	22.2%
Rushford Village	128	63.3%	21.9%	14.8%
Spring Valley	85	74.1%	14.1%	11.8%
Sumner	48	70.8%	25.0%	4.2%
York	66	77.3%	18.2%	4.5%
Total	1,477	72.4%	16.2%	11.4%

Table 25. Livestock Located on Property

Township	Total	No Livestock	Yes Livestock	Not Available
Amherst	63	47.6%	42.9%	9.5%
Arendahl	60	63.3%	30.0%	6.7%
Beaver	46	78.3%	17.4%	4.3%
Bloomfield	54	74.1%	14.8%	11.1%
Bristol	57	56.1%	42.1%	1.8%
Canton	56	58.9%	37.5%	3.6%
Carimona	54	61.1%	38.9%	0.0%
Carrolton	76	60.5%	34.2%	5.3%
Chatfield	87	71.3%	23.0%	5.7%
Fillmore	65	69.2%	26.2%	4.6%
Forestville	67	59.7%	38.8%	1.5%
Fountain	39	46.2%	46.2%	7.7%
Harmony	42	73.8%	19.0%	7.1%
Holt	50	62.0%	30.0%	8.0%
Jordan	53	73.6%	20.8%	5.7%
Newburg	78	74.4%	25.6%	0.0%
Norway	44	59.1%	40.9%	0.0%
Pilot Mound	61	68.9%	29.5%	1.6%
Preble	44	61.4%	34.1%	4.5%
Preston	54	51.9%	44.4%	3.7%
Rushford Village	128	81.3%	13.3%	5.5%
Spring Valley	85	84.7%	11.8%	3.5%
Sumner	48	83.3%	12.5%	4.2%
York	66	63.6%	31.8%	4.5%
Total	1,477	67.2%	28.2%	4.5%

Table 26. Fertilizer Stored on Property

Township	Total	No Fertilizer Stored	Yes Fertilizer Stored	Not Available
Amherst	63	84.1%	1.6%	14.3%
Arendahl	60	93.3%	1.7%	5.0%
Beaver	46	89.1%	4.3%	6.5%
Bloomfield	54	87.0%	0.0%	13.0%
Bristol	57	96.5%	0.0%	3.5%
Canton	56	96.4%	1.8%	1.8%
Carimona	54	98.1%	1.9%	0.0%
Carrolton	76	94.7%	0.0%	5.3%
Chatfield	87	95.4%	1.1%	3.4%
Fillmore	65	92.3%	3.1%	4.6%
Forestville	67	98.5%	0.0%	1.5%
Fountain	39	94.9%	2.6%	2.6%
Harmony	42	95.2%	2.4%	2.4%
Holt	50	90.0%	2.0%	8.0%
Jordan	53	92.5%	1.9%	5.7%
Newburg	78	98.7%	1.3%	0.0%
Norway	44	97.7%	0.0%	2.3%
Pilot Mound	61	95.1%	0.0%	4.9%
Preble	44	95.5%	0.0%	4.5%
Preston	54	88.9%	5.6%	5.6%
Rushford Village	128	92.2%	0.8%	7.0%
Spring Valley	85	89.4%	4.7%	5.9%
Sumner	48	85.4%	8.3%	6.3%
York	66	86.4%	9.1%	4.5%
Total	1,477	92.8%	2.2%	5.0%

Table 27. Farming on Property

Township	Total	No Farming	Yes Farming	Not available
Amherst	63	30.2%	58.7%	11.1%
Arendahl	60	36.7%	60.0%	3.3%
Beaver	46	21.7%	73.9%	4.3%
Bloomfield	54	33.3%	51.9%	14.8%
Bristol	57	26.3%	71.9%	1.8%
Canton	56	50.0%	48.2%	1.8%
Carimona	54	38.9%	59.3%	1.9%
Carrolton	76	39.5%	56.6%	3.9%
Chatfield	87	50.6%	44.8%	4.6%
Fillmore	65	49.2%	46.2%	4.6%
Forestville	67	41.8%	56.7%	1.5%
Fountain	39	23.1%	74.4%	2.6%
Harmony	42	38.1%	61.9%	0.0%
Holt	50	44.0%	48.0%	8.0%
Jordan	53	45.3%	50.9%	3.8%
Newburg	78	48.7%	50.0%	1.3%
Norway	44	36.4%	61.4%	2.3%
Pilot Mound	61	42.6%	55.7%	1.6%
Preble	44	29.5%	65.9%	4.5%
Preston	54	31.5%	64.8%	3.7%
Rushford Village	128	60.2%	32.8%	7.0%
Spring Valley	85	51.8%	43.5%	4.7%
Sumner	48	41.7%	54.2%	4.2%
York	66	34.8%	62.1%	3.0%
Total	1,477	41.4%	54.2%	4.3%

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	≥300 Feet to Feedlot	Not Available
Amherst	63	4.8%	7.9%	20.6%	50.8%	15.9%
Arendahl	60	6.7%	1.7%	16.7%	66.7%	8.3%
Beaver	46	2.2%	8.7%	17.4%	47.8%	23.9%
Bloomfield	54	11.1%	3.7%	9.3%	48.1%	27.8%
Bristol	57	10.5%	5.3%	17.5%	47.4%	19.3%
Canton	56	5.4%	3.6%	12.5%	58.9%	19.6%
Carimona	54	0.0%	5.6%	24.1%	63.0%	7.4%
Carrolton	76	10.5%	5.3%	9.2%	63.2%	11.8%
Chatfield	87	3.4%	8.0%	14.9%	60.9%	12.6%
Fillmore	65	4.6%	4.6%	23.1%	44.6%	23.1%
Forestville	67	4.5%	3.0%	23.9%	58.2%	10.4%
Fountain	39	2.6%	7.7%	20.5%	61.5%	7.7%
Harmony	42	19.0%	4.8%	9.5%	54.8%	11.9%
Holt	50	4.0%	6.0%	4.0%	64.0%	22.0%
Jordan	53	0.0%	5.7%	9.4%	79.2%	5.7%
Newburg	78	9.0%	3.8%	9.0%	50.0%	28.2%
Norway	44	2.3%	6.8%	29.5%	45.5%	15.9%
Pilot Mound	61	1.6%	3.3%	18.0%	67.2%	9.8%
Preble	44	11.4%	11.4%	6.8%	52.3%	18.2%
Preston	54	1.9%	9.3%	16.7%	51.9%	20.4%
Rushford Village	128	3.9%	2.3%	9.4%	64.8%	19.5%
Spring Valley	85	7.1%	0.0%	11.8%	62.4%	18.8%
Sumner	48	10.4%	8.3%	4.2%	54.2%	22.9%
York	66	4.5%	6.1%	13.6%	54.5%	21.2%
Total	1,477	5.8%	5.1%	14.4%	57.8%	17.0%

Table 29. Distance to Septic System

Township	Total	0-49 Feet to Septic	50-99 Feet to Septic	100-299 Feet to Septic	≥300 Feet to Septic	Not Available
Amherst	63	1.6%	7.9%	54.0%	23.8%	12.7%
Arendahl	60	5.0%	16.7%	55.0%	16.7%	6.7%
Beaver	46	2.2%	15.2%	47.8%	21.7%	13.0%
Bloomfield	54	1.9%	22.2%	44.4%	13.0%	18.5%
Bristol	57	3.5%	21.1%	42.1%	19.3%	14.0%
Canton	56	3.6%	12.5%	41.1%	26.8%	16.1%
Carimona	54	1.9%	29.6%	31.5%	31.5%	5.6%
Carrolton	76	2.6%	23.7%	46.1%	21.1%	6.6%
Chatfield	87	3.4%	25.3%	43.7%	16.1%	11.5%
Fillmore	65	0.0%	21.5%	41.5%	24.6%	12.3%
Forestville	67	9.0%	16.4%	49.3%	20.9%	4.5%
Fountain	39	2.6%	28.2%	43.6%	17.9%	7.7%
Harmony	42	4.8%	26.2%	42.9%	19.0%	7.1%
Holt	50	4.0%	24.0%	32.0%	26.0%	14.0%
Jordan	53	1.9%	24.5%	50.9%	17.0%	5.7%
Newburg	78	1.3%	19.2%	42.3%	28.2%	9.0%
Norway	44	2.3%	22.7%	47.7%	9.1%	18.2%
Pilot Mound	61	0.0%	16.4%	50.8%	27.9%	4.9%
Preble	44	2.3%	20.5%	43.2%	25.0%	9.1%
Preston	54	7.4%	14.8%	38.9%	24.1%	14.8%
Rushford Village	128	4.7%	14.8%	49.2%	18.0%	13.3%
Spring Valley	85	5.9%	18.8%	40.0%	25.9%	9.4%
Sumner	48	12.5%	31.3%	35.4%	12.5%	8.3%
York	66	3.0%	28.8%	30.3%	27.3%	10.6%
Total	1,477	3.7%	20.4%	43.8%	21.5%	10.6%

Table 30. Distance to an Agricultural Field

Township	Total	0-49 Feet to Field	50-99 Feet to Field	100-299 Feet to Field	≥300 Feet to Field	Not Available
Amherst	63	6.3%	15.9%	30.2%	36.5%	11.1%
Arendahl	60	5.0%	13.3%	28.3%	45.0%	8.3%
Beaver	46	6.5%	6.5%	47.8%	32.6%	6.5%
Bloomfield	54	5.6%	9.3%	29.6%	40.7%	14.8%
Bristol	57	10.5%	12.3%	31.6%	33.3%	12.3%
Canton	56	0.0%	8.9%	32.1%	42.9%	16.1%
Carimona	54	11.1%	14.8%	29.6%	38.9%	5.6%
Carrolton	76	3.9%	9.2%	30.3%	48.7%	7.9%
Chatfield	87	4.6%	8.0%	39.1%	40.2%	8.0%
Fillmore	65	6.2%	6.2%	20.0%	53.8%	13.8%
Forestville	67	7.5%	11.9%	22.4%	47.8%	10.4%
Fountain	39	7.7%	23.1%	20.5%	38.5%	10.3%
Harmony	42	9.5%	16.7%	28.6%	40.5%	4.8%
Holt	50	10.0%	20.0%	12.0%	46.0%	12.0%
Jordan	53	7.5%	9.4%	24.5%	50.9%	7.5%
Newburg	78	6.4%	11.5%	30.8%	38.5%	12.8%
Norway	44	6.8%	20.5%	38.6%	18.2%	15.9%
Pilot Mound	61	8.2%	6.6%	29.5%	49.2%	6.6%
Preble	44	9.1%	13.6%	43.2%	25.0%	9.1%
Preston	54	9.3%	9.3%	33.3%	37.0%	11.1%
Rushford Village	128	3.9%	5.5%	21.1%	57.0%	12.5%
Spring Valley	85	9.4%	7.1%	29.4%	44.7%	9.4%
Sumner	48	8.3%	20.8%	27.1%	35.4%	8.3%
York	66	13.6%	10.6%	31.8%	31.8%	12.1%
Total	1,477	7.1%	11.2%	29.2%	42.0%	10.4%

Table 31. Drinking Water Well

Township	Total	Not Drinking Water	Yes, Drinking Water	Not Available
Amherst	63	9.5%	84.1%	6.3%
Arendahl	60	1.7%	93.3%	5.0%
Beaver	46	4.3%	93.5%	2.2%
Bloomfield	54	3.7%	87.0%	9.3%
Bristol	57	8.8%	87.7%	3.5%
Canton	56	1.8%	94.6%	3.6%
Carimona	54	1.9%	98.1%	0.0%
Carrolton	76	5.3%	92.1%	2.6%
Chatfield	87	5.7%	93.1%	1.1%
Fillmore	65	3.1%	92.3%	4.6%
Forestville	67	0.0%	97.0%	3.0%
Fountain	39	2.6%	97.4%	0.0%
Harmony	42	2.4%	97.6%	0.0%
Holt	50	0.0%	98.0%	2.0%
Jordan	53	0.0%	96.2%	3.8%
Newburg	78	2.6%	92.3%	5.1%
Norway	44	4.5%	93.2%	2.3%
Pilot Mound	61	1.6%	98.4%	0.0%
Preble	44	9.1%	90.9%	0.0%
Preston	54	7.4%	87.0%	5.6%
Rushford Village	128	0.8%	93.0%	6.3%
Spring Valley	85	4.7%	94.1%	1.2%
Sumner	48	0.0%	97.9%	2.1%
York	66	9.1%	86.4%	4.5%
Total	1,477	3.7%	93.0%	3.3%

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

Township	Total	None	Distillation	Filtering System	Reverse Osmosis	Iron Filter	Other	Not Available
Amherst	63	50.8%	1.6%	31.7%	4.8%	0.0%	0.0%	11.1%
Arendahl	60	71.7%	3.3%	13.3%	3.3%	0.0%	0.0%	8.3%
Beaver	46	65.2%	0.0%	19.6%	2.2%	0.0%	2.2%	10.9%
Bloomfield	54	59.3%	0.0%	22.2%	7.4%	0.0%	1.9%	9.3%
Bristol	57	61.4%	3.5%	19.3%	5.3%	0.0%	1.8%	8.8%
Canton	56	75.0%	0.0%	14.3%	3.6%	0.0%	0.0%	7.1%
Carimona	54	68.5%	0.0%	18.5%	3.7%	0.0%	5.6%	3.7%
Carrolton	76	72.4%	0.0%	17.1%	3.9%	0.0%	1.3%	5.3%
Chatfield	87	60.9%	0.0%	16.1%	16.1%	1.1%	1.1%	4.6%
Fillmore	65	49.2%	3.1%	30.8%	6.2%	0.0%	1.5%	9.2%
Forestville	67	64.2%	4.5%	17.9%	3.0%	0.0%	7.5%	3.0%
Fountain	39	76.9%	0.0%	12.8%	2.6%	0.0%	2.6%	5.1%
Harmony	42	66.7%	2.4%	23.8%	7.1%	0.0%	0.0%	0.0%
Holt	50	64.0%	0.0%	20.0%	4.0%	0.0%	4.0%	8.0%
Jordan	53	73.6%	0.0%	17.0%	1.9%	0.0%	0.0%	7.5%
Newburg	78	75.6%	1.3%	12.8%	3.8%	0.0%	3.8%	2.6%
Norway	44	75.0%	0.0%	15.9%	4.5%	0.0%	0.0%	4.5%
Pilot Mound	61	73.8%	0.0%	9.8%	4.9%	0.0%	1.6%	9.8%
Preble	44	75.0%	0.0%	15.9%	6.8%	0.0%	2.3%	0.0%
Preston	54	68.5%	3.7%	16.7%	1.9%	0.0%	0.0%	9.3%
Rushford Village	128	64.8%	0.0%	20.3%	3.1%	0.0%	1.6%	10.2%
Spring Valley	85	63.5%	1.2%	20.0%	5.9%	0.0%	3.5%	5.9%
Sumner	48	64.6%	2.1%	22.9%	2.1%	0.0%	2.1%	6.3%
York	66	66.7%	0.0%	22.7%	3.0%	0.0%	0.0%	7.6%
Total	1,477	66.5%	1.1%	18.9%	4.8%	0.1%	1.9%	6.8%

Table 33. Well 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
Amherst	63	6.3%	11.1%	20.6%	15.9%	15.9%	27.0%	3.2%
Arendahl	60	5.0%	11.7%	15.0%	25.0%	8.3%	31.7%	3.3%
Beaver	46	0.0%	6.5%	21.7%	21.7%	17.4%	30.4%	2.2%
Bloomfield	54	7.4%	20.4%	18.5%	22.2%	3.7%	20.4%	7.4%
Bristol	57	10.5%	8.8%	22.8%	17.5%	12.3%	26.3%	1.8%
Canton	56	7.1%	12.5%	21.4%	12.5%	16.1%	28.6%	1.8%
Carimona	54	11.1%	7.4%	20.4%	18.5%	11.1%	29.6%	1.9%
Carrolton	76	5.3%	14.5%	18.4%	21.1%	11.8%	26.3%	2.6%
Chatfield	87	6.9%	10.3%	14.9%	25.3%	14.9%	24.1%	3.4%
Fillmore	65	10.8%	12.3%	26.2%	15.4%	7.7%	24.6%	3.1%
Forestville	67	13.4%	7.5%	17.9%	29.9%	9.0%	20.9%	1.5%
Fountain	39	7.7%	2.6%	12.8%	30.8%	10.3%	35.9%	0.0%
Harmony	42	9.5%	7.1%	16.7%	21.4%	14.3%	31.0%	0.0%
Holt	50	12.0%	8.0%	14.0%	20.0%	20.0%	24.0%	2.0%
Jordan	53	5.7%	7.5%	13.2%	30.2%	20.8%	18.9%	3.8%
Newburg	78	6.4%	3.8%	15.4%	21.8%	19.2%	33.3%	0.0%
Norway	44	4.5%	4.5%	22.7%	29.5%	11.4%	22.7%	4.5%
Pilot Mound	61	16.4%	8.2%	9.8%	18.0%	18.0%	27.9%	1.6%
Preble	44	9.1%	9.1%	22.7%	34.1%	6.8%	15.9%	2.3%
Preston	54	9.3%	11.1%	13.0%	27.8%	9.3%	25.9%	3.7%
Rushford Village	128	3.1%	11.7%	17.2%	15.6%	15.6%	31.3%	5.5%
Spring Valley	85	8.2%	10.6%	16.5%	21.2%	11.8%	30.6%	1.2%
Sumner	48	14.6%	8.3%	18.8%	25.0%	12.5%	18.8%	2.1%
York	66	6.1%	9.1%	10.6%	19.7%	18.2%	33.3%	3.0%
Total	1,477	7.9%	9.7%	17.4%	21.9%	13.4%	27.0%	2.7%

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
Amherst	63	6.3%	6.3%	3.2%	84.1%
Arendahl	60	10.0%	8.3%	8.3%	73.3%
Beaver	46	2.2%	0.0%	0.0%	97.8%
Bloomfield	54	9.3%	9.3%	5.6%	75.9%
Bristol	57	5.3%	3.5%	1.8%	89.5%
Canton	56	3.6%	3.6%	1.8%	91.1%
Carimona	54	13.0%	3.7%	0.0%	83.3%
Carrolton	76	17.1%	3.9%	0.0%	78.9%
Chatfield	87	10.3%	6.9%	1.1%	81.6%
Fillmore	65	7.7%	13.8%	1.5%	76.9%
Forestville	67	17.9%	3.0%	4.5%	74.6%
Fountain	39	12.8%	2.6%	5.1%	79.5%
Harmony	42	11.9%	14.3%	0.0%	73.8%
Holt	50	10.0%	6.0%	0.0%	84.0%
Jordan	53	20.8%	3.8%	1.9%	73.6%
Newburg	78	2.6%	5.1%	1.3%	91.0%
Norway	44	6.8%	11.4%	4.5%	77.3%
Pilot Mound	61	14.8%	9.8%	3.3%	72.1%
Preble	44	18.2%	9.1%	9.1%	63.6%
Preston	54	9.3%	3.7%	1.9%	85.2%
Rushford Village	128	10.2%	1.6%	0.8%	87.5%
Spring Valley	85	11.8%	4.7%	1.2%	82.4%
Sumner	48	8.3%	8.3%	4.2%	79.2%
York	66	7.6%	3.0%	0.0%	89.4%
Total	1,477	10.3%	5.8%	2.3%	81.7%

APPENDIX I

Table 35. Well Construction Type for Final Well Dataset

Township	Total Wells	Drilled	Sand Point	Not Available
Amherst	42	39	0	3
Arendahl	43	38	0	5
Beaver	42	36	0	6
Bloomfield	31	26	1	4
Bristol	38	36	0	2
Canton	39	34	1	4
Carimona	45	43	0	2
Carrolton	63	60	0	3
Chatfield	65	61	0	4
Fillmore	50	45	0	5
Forestville	49	44	0	5
Fountain	27	27	0	0
Harmony	26	22	0	4
Holt	32	28	0	4
Jordan	45	42	0	3
Newburg	45	38	1	6
Norway	29	27	0	2
Pilot Mound	42	37	0	5
Preble	30	27	0	3
Preston	40	36	0	4
Rushford Village	117	97	3	17
Spring Valley	61	54	0	7
Sumner	36	31	0	5
York	33	32	0	1
Total	1,070	960	6	104

Data compiled from well logs and homeowner responses.

Table 36. Well Depth for Final Well Dataset

Township	Total Wells	Minimum	Maximum	Median	Mean
Amherst	9	270	526	484	458
Arendahl	12	157	600	335	386
Beaver	8	140	500	316	289
Bloomfield	4	225	596	288	349
Bristol	12	261	660	523	517
Canton	7	326	604	460	456
Carimona	16	123	670	449	445
Carrolton	20	100	600	405	382
Chatfield	25	127	610	392	388
Fillmore	14	124	500	348	343
Forestville	13	150	600	460	420
Fountain	8	260	540	420	421
Harmony	5	455	565	532	514
Holt	7	425	640	512	528
Jordan	14	226	520	392	374
Newburg	12	340	452	415	405
Norway	9	330	635	520	503
Pilot Mound	15	112	547	369	330
Preble	12	80	480	318	302
Preston	12	240	576	490	462
Rushford Village	35	85	640	160	245
Spring Valley	15	325	562	470	450
Sumner	10	310	545	450	444
York	13	300	616	520	502
Total	307	80	670	410	395

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

Table 37. Year of Well Construction for Final Well Dataset

Township	Total Wells	Minimum	Maximum	Median	Mean
Amherst	9	1969	2014	2006	2001
Arendahl	12	1974	2017	2003	2000
Beaver	8	1909	2014	2002	1991
Bloomfield	6	1900	2014	1999	1983
Bristol	12	1969	2010	2000	1994
Canton	7	1976	2012	2002	1998
Carimona	17	1950	2008	1999	1990
Carrolton	20	1911	2015	2002	1997
Chatfield	25	1936	2008	1998	1991
Fillmore	14	1958	2016	2008	2002
Forestville	13	1960	2011	2005	2000
Fountain	8	1960	2011	1999	1991
Harmony	7	1955	2010	2001	1992
Holt	7	1996	2007	2004	2003
Jordan	14	1976	2016	2000	1998
Newburg	12	1997	2011	2007	2005
Norway	9	1960	2013	2006	2000
Pilot Mound	15	1961	2015	2000	1995
Preble	11	1940	2008	2004	1991
Preston	12	1976	2011	2002	1999
Rushford Village	35	1978	2017	2000	2000
Spring Valley	16	1945	2016	2002	1998
Sumner	11	1949	2016	2002	1997
York	13	1970	2016	2004	1999
Total	313	1900	2017	2002	1997

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	Minimum	Maximum	Median	Mean
Amherst	9	9.83	11.65	10.50	10.74
Arendahl	14	9.43	12.08	10.31	10.36
Beaver	3	10.07	11.31	10.97	10.78
Bloomfield	8	8.13	14.95	9.97	10.52
Bristol	4	10.20	13.24	10.64	11.18
Canton	13	10.07	20.56	10.72	11.69
Carimona	17	9.61	11.55	10.34	10.52
Carrolton	22	10.17	12.80	10.93	11.04
Chatfield	18	9.64	14.57	10.66	10.99
Fillmore	9	9.73	11.89	10.63	10.56
Forestville	13	9.63	12.20	10.64	10.70
Fountain	8	10.02	11.77	10.28	10.64
Harmony	9	9.97	14.72	10.70	11.20
Holt	10	10.02	12.76	10.50	10.73
Jordan	10	9.60	11.55	10.15	10.40
Newburg	15	10.04	13.82	10.77	11.20
Norway	5	10.36	11.31	10.72	10.81
Pilot Mound	15	9.52	11.98	10.58	10.82
Preble	11	9.74	12.19	10.50	10.81
Preston	19	9.15	13.64	10.84	10.96
Rushford Village	23	10.12	13.10	10.94	11.06
Spring Valley	13	9.80	12.80	10.86	10.86
Sumner	4	10.18	11.45	10.62	10.72
York	6	10.50	14.04	11.54	12.04
Total	278	8.13	20.56	10.70	10.89

Table 39. pH of Well Water for Final Well Dataset

Township	Samples	Minimum	Maximum	Median	Mean
Amherst	9	6.95	7.47	7.22	7.22
Arendahl	14	7.00	7.62	7.37	7.32
Beaver	3	7.12	7.37	7.26	7.25
Bloomfield	8	7.32	7.69	7.43	7.46
Bristol	4	7.19	7.23	7.22	7.22
Canton	13	7.28	7.77	7.39	7.42
Carimona	17	6.78	7.87	7.34	7.33
Carrolton	22	6.94	7.48	7.29	7.28
Chatfield	18	7.06	7.81	7.42	7.38
Fillmore	9	6.89	7.50	7.31	7.30
Forestville	13	7.00	7.83	7.40	7.40
Fountain	8	7.03	7.59	7.27	7.25
Harmony	9	6.99	7.45	7.17	7.21
Holt	10	7.14	7.72	7.32	7.36
Jordan	10	7.07	7.58	7.29	7.34
Newburg	15	6.95	7.55	7.26	7.24
Norway	5	6.98	7.54	7.25	7.26
Pilot Mound	15	7.07	7.62	7.33	7.33
Preble	11	7.17	7.48	7.25	7.28
Preston	19	7.03	7.46	7.23	7.23
Rushford Village	23	7.32	7.64	7.43	7.43
Spring Valley	13	7.06	7.44	7.33	7.29
Sumner	4	7.26	7.60	7.36	7.39
York	6	6.92	7.54	7.28	7.26
Total	278	6.78	7.87	7.32	7.32

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

Township	Samples	Minimum	Maximum	Median	Mean
Amherst	9	495	833	693	690
Arendahl	14	489	1,184	632	707
Beaver	3	514	656	572	581
Bloomfield	8	515	795	636	639
Bristol	4	527	622	611	593
Canton	13	517	731	576	586
Carimona	17	471	1,371	558	635
Carrolton	22	445	816	590	607
Chatfield	18	450	1,034	576	629
Fillmore	9	525	1,070	597	685
Forestville	13	525	1,164	671	704
Fountain	8	527	722	612	618
Harmony	9	500	997	664	683
Holt	10	548	764	598	625
Jordan	10	477	854	709	684
Newburg	15	453	957	591	591
Norway	5	501	1,045	685	700
Pilot Mound	15	455	763	581	599
Preble	11	430	900	639	631
Preston	19	488	759	619	621
Rushford Village	23	442	601	524	530
Spring Valley	13	519	964	636	663
Sumner	4	469	842	708	682
York	6	470	958	662	675
Total	278	430	1,371	601	632

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

Township	Samples	Minimum	Maximum	Median	Mean
Amherst	9	2.7	7.6	5.0	5.0
Arendahl	14	2.2	12.2	7.6	7.2
Beaver	3	0.2	8.3	0.6	3.0
Bloomfield	8	0.9	11.4	4.8	5.3
Bristol	4	7.2	9.4	8.7	8.5
Canton	13	1.1	6.4	4.4	4.1
Carimona	17	0.9	12.2	7.3	7.4
Carrolton	22	3.1	10.6	7.9	7.6
Chatfield	18	0.1	9.0	5.2	4.9
Fillmore	9	1.1	7.6	4.8	4.6
Forestville	13	0.4	12.2	8.1	7.8
Fountain	8	0.7	10.8	4.2	4.9
Harmony	9	1.3	6.1	4.9	4.1
Holt	10	4.3	9.4	7.2	7.4
Jordan	10	0.2	9.4	6.6	6.3
Newburg	15	0.6	10.3	5.3	5.7
Norway	5	7.2	13.3	8.0	9.1
Pilot Mound	15	2.4	15.9	9.4	9.3
Preble	11	2.4	9.7	7.3	6.7
Preston	19	0.9	12.1	7.2	6.9
Rushford Village	23	2.4	14.3	7.2	7.2
Spring Valley	13	0.4	8.8	5.1	5.0
Sumner	4	0.1	9.4	1.1	2.9
York	6	0.2	6.9	5.0	4.4
Total	278	0.1	15.9	6.5	6.4