Final Township Testing Nitrate Report:

Todd County 2016-2017

May 2019

Minnesota Department of Agriculture

Pesticide and Fertilizer Management Division

ACKNOWLEDGEMENTS

MDA PRIMARY AUTHOR

Nikol Ross

MDA CONTRIBUTORS AND REVIEWERS

Ryan Meyer, Lauren Bammert, Kimberly Kaiser, and Larry Gunderson

FUNDING

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

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

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

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

In 2016, private wells in the Todd County study area (nine 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 797 wells representing an average response rate of 30 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, 5.0 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 248 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 74 wells in 2017. A follow-up sampling was offered to all homeowners with wells that had a detectable nitrate-N result.

A well site visit was conducted to identify wells that were unsuitable for final analysis. The final well dataset is intended to only include private drinking water wells potentially impacted by applied commercial agricultural fertilizer. Therefore, wells with construction issues or nearby potential point sources of nitrogen were removed from the final well dataset. Point sources of nitrogen can include: feedlots, subsurface sewage treatment systems, fertilizer spills, and bulk storage of fertilizer. A total of 37 (4.6 percent) wells were determined to be unsuitable and were removed from the dataset. The final well dataset had a total of 760 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 to 5.9 percent. None of the sampled townships had more than 10 percent of wells at or over the HRL.

INTRODUCTION

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

The goal of nitrate monitoring and assessment is to develop a comprehensive understanding of the severity, magnitude, and long term trends of nitrate in groundwater as measured in public and private wells. The MDA established the Township Testing Program to determine current nitrate concentrations in private wells on a township scale. This program is designed to quickly assess a township in a short time window. Monitoring focuses on areas of the state where groundwater nitrate contamination is more likely to occur. This is based initially on hydrogeologically vulnerable areas where appreciable acres of agricultural crops are grown. Statewide the MDA plans to offer nitrate-N tests to more than 70,000 private well owners in over 300 townships by 2019. As of March 2018, 242 townships in 24 counties have completed the initial sampling.

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

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

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

For further information on the NFMP and Township Testing Program, visit the following webpages:

www.mda.state.mn.us/nfmp

www.mda.state.mn.us/townshiptesting

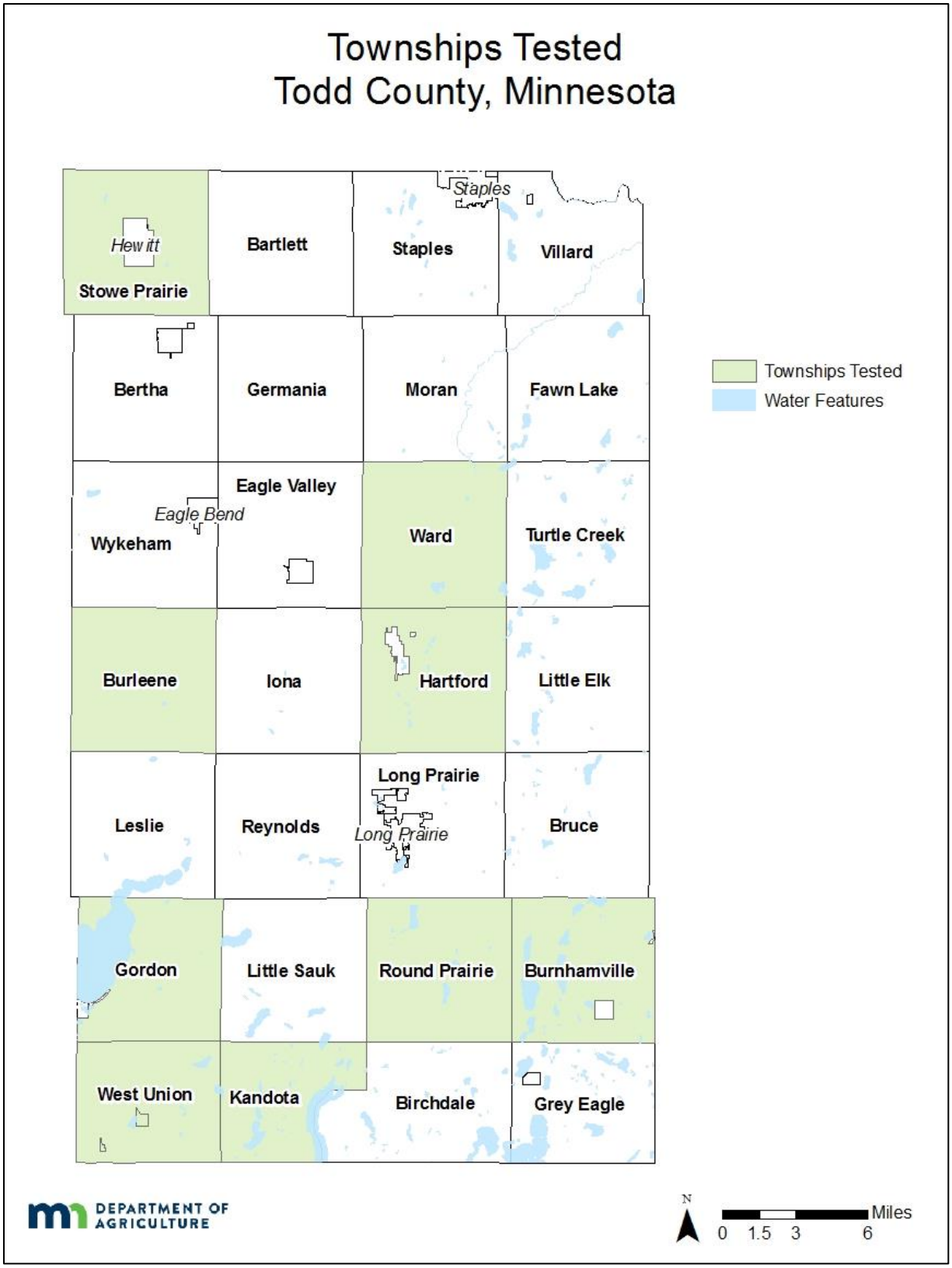


Figure 1. Townships Tested in Todd County

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 (Dubrovsky et al., 2010). In systems with sandy unconfined aquifers, such as parts of Todd County, contaminants such as nitrate can travel quickly to the aquifer, leaving little chance for denitrification or other attenuating processes. As a result certain areas of Todd County, with shallow unconfined sandy aquifers (Peterson, 2010a), and intensive row crop agriculture, are particularly vulnerable to elevated nitrate concentrations. It is important to note that geochemical conditions can be highly variable within an aquifer or region and can also change over-time (MPCA, 1998).

GEOLOGY AND HYDROGEOLOGY

Around 1 to 2 million years ago glaciers from the Laurentide ice sheet covered much of Minnesota. Glacial lobes from the ice sheet advanced and retreated, picking up rocks and sediment, and then depositing them elsewhere (Setterholm, 2007). Most of modern day Todd County is covered by a thick layer of this deposited glacial material, with a maximum thickness of 530 feet. The thickest areas of glacial material are located in west central Todd County, just south of Eagle Bend. There are two small outcrops of bedrock; one near Browerville and the other near the city of Philbrook. These glacial sediments were deposited during the Quaternary period and are often referred to as Quaternary sediments (Setterholm, 2007).

The last glaciation event in Todd County occurred during the Late Wisconsinan time, in which there were three main ice lobes (Setterholm, 2007). Todd County was initially covered by the Wadena lobe. This

glacier deposited a mainly sandy till, known as the Hewitt till. The Wadena lobe also created numerous drumlins in the northern two-thirds of the county. Today peat is often found in the troughs of these drumlins. Next the Superior lobe advanced into Todd County from the east, covering only the eastern third of the county. This lobe created the St. Croix moraine and also deposited till from the Cromwell Formation, which was sandy in this region. Finally the Des Moines lobe advanced from the southwest and covered the southwestern corner. Upon its retreat it commonly left behind thick deposits (20 to 50 feet) of a clay loam till from the New Ulm Formation (Setterholm, 2007; Peterson, 2010a).

Below the Late Wisconsinan glacial deposits are older "Pre-Wisconsinan" glacial deposits. These deposits are rarely seen near the surface in Todd County, but appear in some small surficial outcrops. The Browerville formation is the youngest of the Pre-Wisconsinan tills and can be found in thick deposits of up to 200 feet, but it is not continuous throughout the county. Beneath this are many other older layers of glacial deposits (Setterholm, 2007).

In Todd County almost all (99 percent) groundwater wells withdraw water from unconsolidated Quaternary aquifers. The surficial sand aquifers are a significant source of groundwater, but fewer wells (13 percent of Quaternary wells) overall utilize them compared to the buried sand aquifers. However, a large portion (38.1 percent) of permitted high capacity wells draw from this aquifer (Peterson, 2010b). Most of the surficial sand aquifers are located in relatively narrow bands along the modern day Long Prairie River and Sauk River. There are some areas outside these channels, chiefly in the northeast and east that have surficial sands. While certain areas are up to 100 feet thick, on average these sands are 20 feet thick. Therefore not all areas are viable aquifers (Peterson, 2010a).

More wells (84 percent of Quaternary wells) utilize the buried sand and gravel Quaternary aquifers compared to the surficial sand aquifers (Peterson, 2010b). Layers of buried sand and gravel aquifers occur throughout most of the Todd County. Some of these are hydrologically connected to the surficial aquifers above. A thick portion of buried sand exists just south of Long Prairie. This particular extent became a drainage area for the meltwater (or outwash) of many of the nearby glacial lobes (Peterson, 2010a).

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 Todd County as presented in Figure 2.

Beneath these thick glacial deposits is consolidated bedrock. Most of the bedrock originated from the Precambrian Era. There are some local deposits from the Cretaceous period, but most of these deposits have eroded over time (Setterholm, 2007). Groundwater from bedrock aquifers is utilized in less than 1 percent of wells. These wells are generally found in southeastern Todd County (Peterson, 2010b).

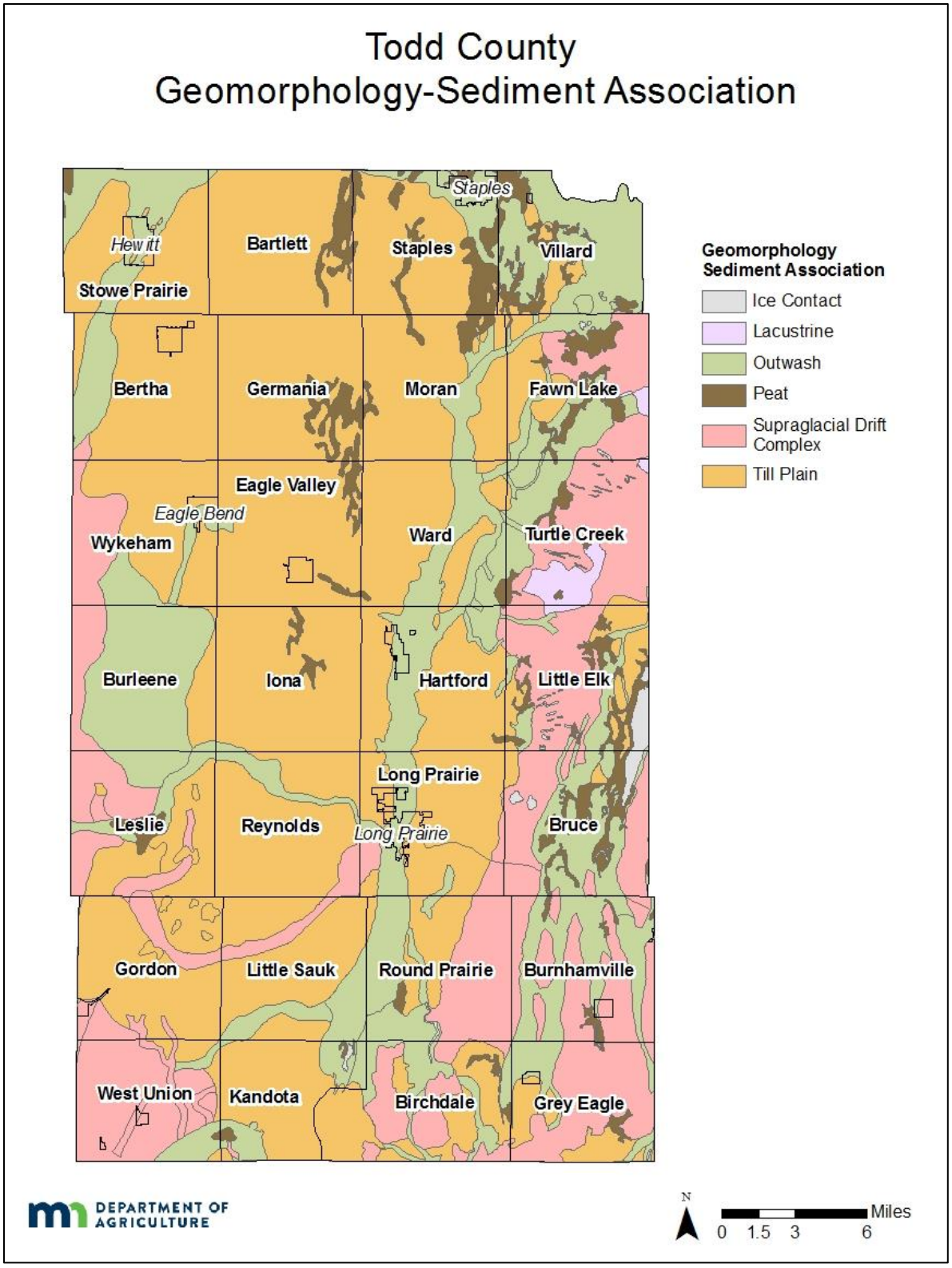


Figure 2. Statewide Geomorphology Layer, Sediment Association in Todd County (MDNR, MGS, and UMD, 1997)

NITROGEN POINT SOURCES

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

SUBSURFACE SEWAGE TREATMENT SYSTEM

Subsurface sewage treatment systems (SSTS) can be a potential source for contaminants in groundwater such as nitrate and fecal material (MDH, 2014). A total of 5,734 SSTS were reported in Todd County for 2016. Over a recent 15 year period (2002-2016), 2,948 construction permits for new, replacement, or repairs for SSTS were issued. Of all the reported septic systems in Todd County, 51 percent are newer than 2002 or have been repaired since 2002 (MPCA, 2017a). When new SSTS's are installed they are required to be in compliance with the rules at the time of installation. Newer systems meet modern SSTS regulations and must comply with the current well code; which requires a 50 foot horizontal separation from the well (MDH, 2014).

FEEDLOT

Manure produced on a feedlot can be a potential source of nitrogen pollution if improperly stored or spread. In the Todd County study area there are a total of 334 active feedlots. Only 28 (8%) of the active feedlots are permitted to house 300 or more animal units (AU) (Appendix B; Figure 7).

FERTILIZER STORAGE LOCATION

Bulk fertilizer storage locations are potential point sources of nitrogen because they store large concentrations of nitrogen based chemicals. Licenses are required for individuals and companies that store large quantities of fertilizer. The Todd County study area has a total of 69 fertilizer storage licenses and all are for chemigation (Appendix B; Table 11).

FERTILIZER SPILLS AND INVESTIGATIONS

A total of 2 historic fertilizer spills and investigations were recorded in the Todd County study area. These were both located in West Union Township (Appendix B; Table 13).

TOWNSHIP TESTING METHODS

VULNERABLE TOWNSHIPS

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

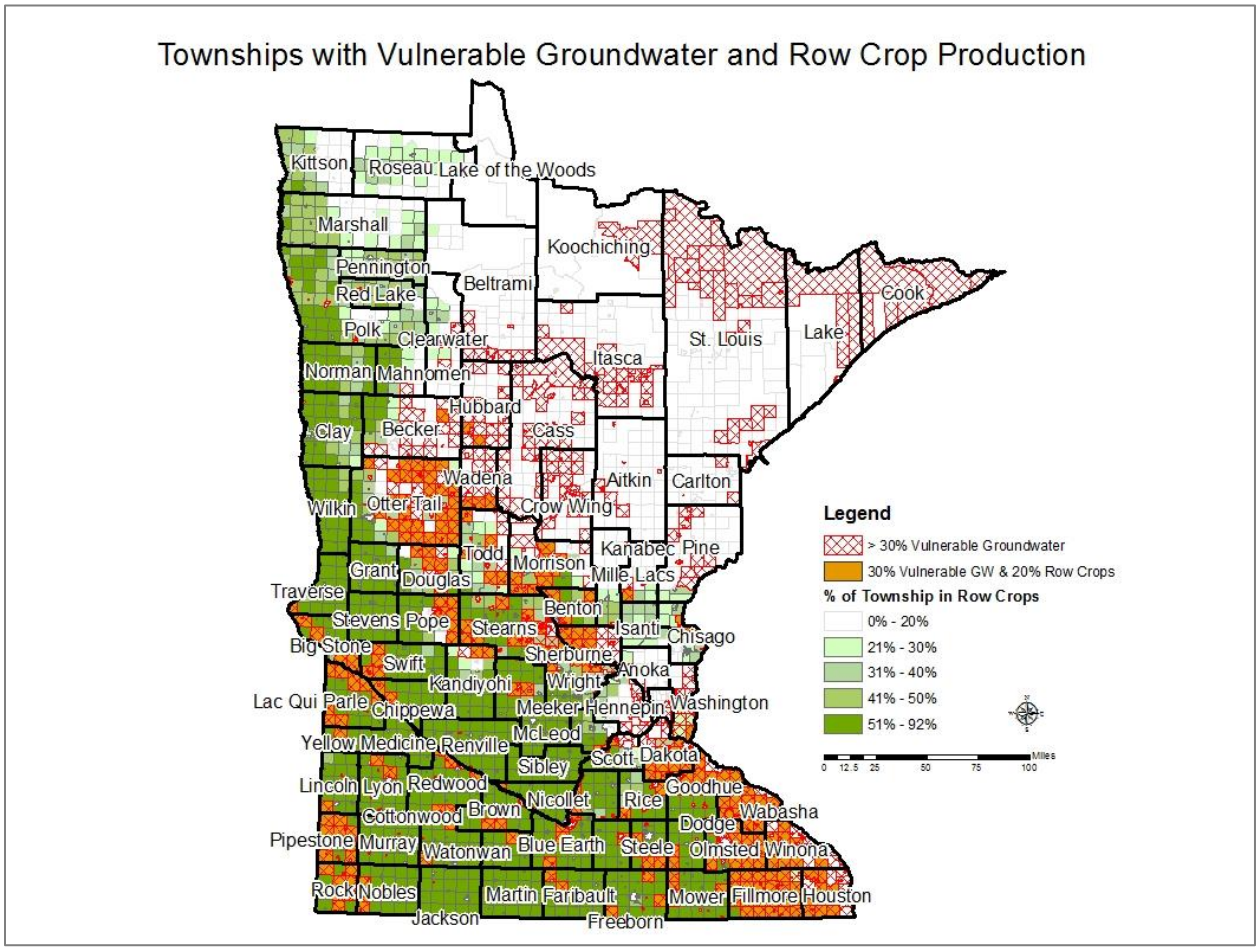


Figure 3. Minnesota Townships with Vulnerable Groundwater and Row Crop Production

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

and Guidelines for Assessing Geologic Sensitivity in Ground Water Resources in Minnesota" (MDNR, 1991). A map of Todd County depicting the aquifer vulnerabilities is shown in Figure 4.

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

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

The National Agriculture Statistics Service data (USDA NASS, 2013) on cropland was used to determine the percentage of row crop agriculture. A map and table depicting the extent of the cropland in Todd County can be found in Appendix C (Figure 9, Table 14). On average 25 percent of the land cover was row crop agriculture.

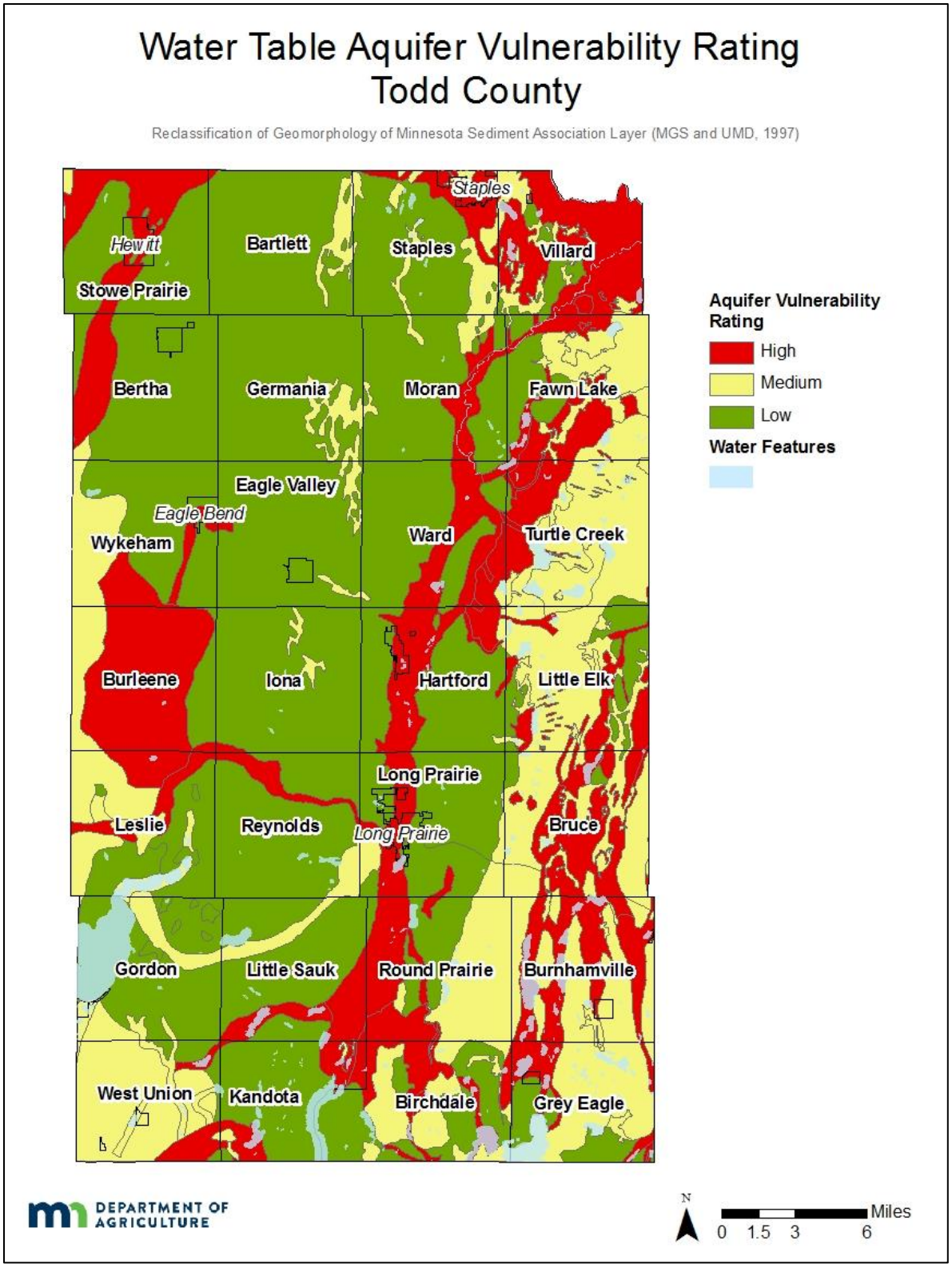


Figure 4. Water Table Aquifer Vulnerability Rating in Todd County

PRIVATE WELL SAMPLING - NITRATE

The testing is done in two steps in each township: "initial" sampling and "follow-up" sampling. The initial nitrate sampling was conducted in 2016. In the initial sampling, all private well owners in the selected townships are sent a nitrate test kit. These kits include instructions on how to collect a water sample, a sample bottle, a voluntary survey, and a prepaid mailer. Each homeowner was mailed the nitrate result for their well along with an explanatory nitrate brochure (Appendix D). Well water samples were collected by 797 homeowners using the mail-in kit (Table 2). These 797 samples are considered the "initial well dataset". On average, 30 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 2017 by MDA staff. A total of 74 follow-up samples were analyzed (Table 2).

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

Township	Kits Sent	Initial Well Dataset	Well Site Visits & Follow-Up Sampling Conducted
Burleene	166	56	2
Burnhamville	579	175	24
Gordon	415	116	5
Hartford	251	82	8
Kandota	370	121	9
Round Prairie	296	87	14
Stowe Prairie	192	50	2
Ward	242	76	7
West Union*	140	34	3
Total	2,651	797	74

*Includes West Union City

Each follow-up visit was conducted at the well site by a trained MDA hydrologist. Well water was purged from the well for 15 minutes before a sample was collected to ensure a fresh water sample. Additionally, precautions were taken to ensure no cross-contamination occurred. A more thorough explanation of the sampling process is described in the sampling and analysis plan (MDA, 2018). As part of the follow-up sampling, homeowners were offered a no cost pesticide test. As pesticide results are finalized, they will be posted online in a separate report (www.mda.state.mn.us/pwps).

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

WELL ASSESSMENT

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

Using the following criteria, a total of 37 wells were removed to create the final well dataset. See Appendix E (Tables 17 and 18) for a summary of the removed wells.

HAND DUG

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

POINT SOURCE

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

WELL CONSTRUCTION PROBLEM

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

IRRIGATION WELL

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

UNSURE OF WATER SOURCE

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

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

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

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

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

NO SITE VISIT & INSUFFICIENT DATA & NO WELL ID

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

INITIAL RESULTS

INITIAL WELL DATASET

A total of 797 well owners returned water samples for analysis across the nine 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 and median values of nitrate for all townships were less than the detection limit (<DL) which is 0.05 mg/L. The maximum values range from 8.3 to 42.9 mg/L, with West Union Township having the highest result. The mean values ranged from 0.5 to 2.7 mg/L and West Union Township had the highest result. The 90th percentiles range from 0.1 to 7.6 mg/L, with Burnhamville Township having the highest 90th percentile.

Initial results from the sampling showed that none of the townships had ten percent or more of the wells at or over 10 mg/L nitrate. The township testing results are similar to findings from a 2010 USGS report on nitrate concentrations in private wells in the glacial aquifer systems across the upper United States (US) in which less than five percent of sampled private wells had nitrate concentrations greater than 10 mg/L (Warner and Arnold, 2010).

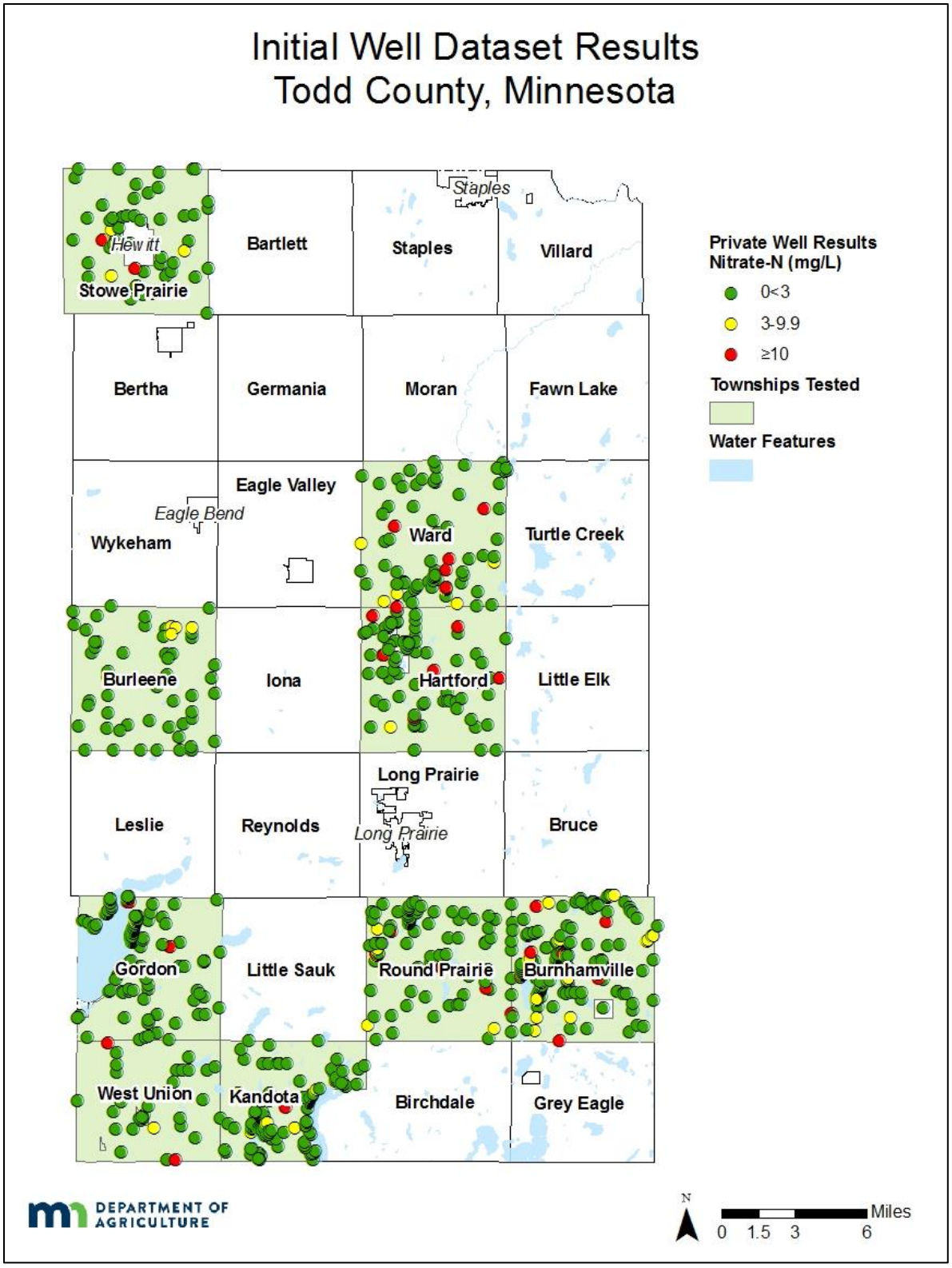


Figure 5. Well Locations and Nitrate Results from Initial Dataset in Todd County

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

Township	Total Wells	Values				Percentiles				Number of Wells					Percent of Wells				
		Min	Max	Mean	Median	75th	90th	95th	99th	<3 mg/L	3<10 mg/L	≥5 mg/L	≥7 mg/L	≥10 mg/L	<3 mg/L	3<10 mg/L	≥5 mg/L	≥7 mg/L	≥10 mg/L
		Nitrate-N mg/L or PPM																	
Burleene	56	<DL	8.3	0.5	<DL	<DL	1.9	3.8	8.1	52	4	1	1	0	92.9%	7.1%	1.8%	1.8%	0.0%
Burnhamville	175	<DL	35.4	2.3	<DL	1.3	7.6	14.1	30.9	140	21	27	18	14	80.0%	12.0%	15.4%	10.3%	8.0%
Gordon	116	<DL	23.2	0.5	<DL	<DL	0.1	1.1	16.3	111	2	5	3	3	95.7%	1.7%	4.3%	2.6%	2.6%
Hartford	82	<DL	23.0	1.5	<DL	<DL	3.0	13.1	22.9	74	1	7	7	7	90.2%	1.2%	8.5%	8.5%	8.5%
Kandota	121	<DL	13.0	0.5	<DL	<DL	0.9	3.5	10.4	114	6	4	3	1	94.2%	5.0%	3.3%	2.5%	0.8%
Round Prairie	87	<DL	24.2	1.5	<DL	0.1	4.8	12.2	22.2	76	6	8	6	5	87.4%	6.9%	9.2%	6.9%	5.7%
Stowe Prairie	50	<DL	12.9	0.8	<DL	<DL	2.2	5.8	12.9	45	3	4	2	2	90.0%	6.0%	8.0%	4.0%	4.0%
Ward	76	<DL	33.2	2.1	<DL	0.1	7.4	12.3	30.9	63	7	12	8	6	82.9%	9.2%	15.8%	10.5%	7.9%
West Union*	34	<DL	42.9	2.7	<DL	<DL	2.2	33.2	42.9	31	1	3	2	2	91.2%	2.9%	8.8%	5.9%	5.9%
Total	797	<DL	42.9	1.4	<DL	<DL	4.4	10.0	23.7	706	51	71	50	40	88.6%	6.4%	8.9%	6.3%	5.0%

<DL stands for less than a detectable limit. This means results are less than 0.05 mg/L. The 50th percentile (75th, 90th, 95th, and 99th) is the value below which 50 percent (75%, 90%, 95%, and 99%) of the observed values fall.

*Includes West Union City

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

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

Township	Estimated 2016 Households on Private Wells*	Estimated 2016 Population on Private Wells*	Estimated Population ≥10 mg/L Nitrate-N**
Burleene	142	337	0
Burnhamville	311	723	58
Gordon	260	658	17
Hartford	234	633	54
Kandota	286	726	6
Round Prairie	256	698	40
Stowe Prairie	182	437	17
Ward	191	440	35
West Union***	137	365	21
Total	1,999	5,017	248

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

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 327 documented wells, of those only 237 wells have a designated aquifer (Table 5). Therefore, approximately 30 percent of the sampled wells had corresponding well logs with an aquifer identified. Thus, the data gathered on aquifers represents approximately less than a third of the total sampled wells.

The aquifers in Table 5 are arranged from the geologically youngest units on the top to the older units, with the expectation of the "multiple aquifers" category. According to the well log data, the most commonly utilized aquifer in the sampled wells was from the Quaternary aquifers. This predominance of these aquifers reflects the overall findings for all documented wells in the study area (Appendix F, Table 19). The average well depth was 97.7 feet deep.

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

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

The Quaternary Water Table (QWTA) wells are defined as having less than ten feet of confining material (typically clay) between the land surface and the well screen (MPCA, 1998). When there is less than ten feet of clay, it allows surface contaminants to travel more quickly to the water table aquifers. In general, shallower wells completed in the QWTA are more susceptible to nitrate contamination.

The Quaternary Buried aquifers are similar to the QWTA except that the confining materials (typically clay) are more than 10 feet thick. Quaternary buried artesian wells are wells that are withdraw water that is under pressure and below a confining unit (MPCA, 1998).

There are were only two wells with aquifers in Cretaceous Regolith bedrock. The composition of regolith is dependent on the underlying rock at the location. If the underlying bedrock is granite the weathered material will create a regolith with a higher clay content. Similarly, if limestone underlies a regolith than a limonite-rich deposit will form (Sloan, 1964). Typically water in the Cretaceous aquifers in Minnesota tend to contain high dissolved solids, however in the northcentral region of Minnesota these dissolved compounds are relatively low (MPCA, 1998).

Only one well withdraws water from the Animikie Group sediments. The Animikie Group was deposited in the northern part of a basin that extended from Minnesota through Wisconsin and into Michigan during the Middle Precambrian Era (Morey, 1969).

Only one well withdraws water from the Archean Granite Pulton deposits. The Archean Granite Pluton is typically a potassium rich granite that was originally deposited in the Precambrian Era (Sylvester, 1994).

Table 5. Nitrate Concentrations within Sampled Groundwater Aquifers

Aquifer Group/Formation	Total Wells	Ave Depth (Feet)	Number of wells			Percent of wells		
			<3	3<10	≥10	<3	3<10	≥10
			Nitrate-N mg/L					
Quaternary Water Table	33	60.4	26	4	3	78.8%	12.1%	9.1%
Quaternary Buried Unconfined Aquifer	7	62.0	6	0	1	85.7%	0.0%	14.3%
Quaternary Buried Artesian Aquifer	192	105.2	188	4	0	97.9%	2.1%	0.0%
Cretaceous Regolith	2	220.0	2	0	0	100.0%	0.0%	0.0%
Cretaceous, Undifferentiated	1	191.0	1	0	0	100.0%	0.0%	0.0%
Animikie Group (Precambrian)	1	60.0	1	0	0	100.0%	0.0%	0.0%
Archean Granite Pluton (Precambrian)	1	130.0	1	0	0	100.0%	0.0%	0.0%
Not Available	90	94.4	80	4	6	88.9%	4.4%	6.7%
Total	327	97.7	305	12	10	93.3%	3.7%	3.1%

WELL OWNER SURVEY

The private well owner survey, sent out with the sampling kit, provided additional information about private wells that were sampled. The survey included questions about the well construction, depth and age, and questions about nearby land use. A blank survey from the initial sampling in 2016 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).

Overall the majority of wells are located on country properties. In Hartford and Stowe Prairie over 80 percent of the homeowners responded that their well was located in the country. In Township of Burnhamville over half of the homeowners response that their well was located on lake home properties. Gordon and Kandota also had a significant number of wells (38.8% and 44.6%, respectively) on lake properties.

Approximately 72.1 percent of sampled wells are of drilled construction and 7.5 percent are sand point wells. Sand point (also known as drive-point) wells are typically completed at shallower depths than drilled wells. Sand point wells are also usually installed in areas where sand is the dominant geologic material and where there are no thick confining units such as clay. This makes sand point wells more vulnerable to contamination from the surface. As mentioned previously, hand dug wells are also shallow

and more sensitive to local surface runoff contamination than deeper drilled wells. Two percent of the sampled wells were hand dug wells.

Most of the sampled wells are between 50-299 feet deep, and very few wells (0.8%) are over 300 feet deep. Approximately 23 percent of homeowners did not know or did not response to this question.

Most of the wells (77.8 percent) had not been tested for nitrate within the last ten years or homeowners were unsure if they had been tested. Only three percent of homeowners responded that their well had been tested for nitrate in the last year. Additionally 90.2 percent of homeowners responded they did not know what the nitrate test result was for their well. Therefore, the results most homeowners receive from this study will provide new information and help keep homeowners informed about their drinking water.

POTENTIAL NITRATE SOURCE DISTANCES

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

- On average, farming takes place on 27.2 percent of the properties.
- Agricultural fields further than 300 feet from wells at about 44.4 percent of the properties.
- The majority of well owners (75.2 percent) across all the townships responded that they have do not livestock (greater than ten head of cattle or other equivalent) on their property.
- Less than 8 percent of wells are less than 100 feet from an active or inactive feedlot.
- Very few well owners (1.0 percent) across all townships store more than 500 pounds of fertilizer on their property.
- A small minority of wells (3.9 percent) are less than 50 feet away from septic systems.

FINAL RESULTS

FINAL WELL DATASET

A total of 797 well water samples were collected by homeowners across nine townships. Thirty-seven wells (4.6 percent) were found to be unsuitable and were removed to create the final well dataset. The final analysis was conducted on the remaining 760 wells (Table 6). The wells in the final well dataset represent drinking water wells potentially impacted by applied commercial agricultural fertilizer.

WELL WATER NITROGEN ANALYSIS

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

Table 6 shows the results for all townships sampled. The percent of wells at or over the HRL for the final well dataset ranged from 0.0 to 5.9 percent.

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

Township	Initial Well Dataset	Final well Dataset	Final Wells ≥10 mg/L Nitrate-N	
			Count	Percentage
Burleene	56	56	0	0.0%
Burnhamville	175	165	8	4.8%
Gordon	116	111	1	0.9%
Hartford	82	77	4	5.2%
Kandota	121	118	0	0.0%
Round Prairie	87	85	5	5.9%
Stowe Prairie	50	48	1	2.1%
Ward	76	70	4	5.7%
West Union*	34	30	0	0.0%
Total	797	760	23	3.0%

*Includes West Union City

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 and median values were all below the detection limit (<DL). The maximum values ranged from 1.77 to 35.4 mg/L nitrate, with Burnhamville Township having the highest result. The 90th percentile ranged from <DL to 5.01 mg/L nitrate-N, with Gordon and Stowe Prairie Township having the lowest result and Burnhamville Township having the highest result.

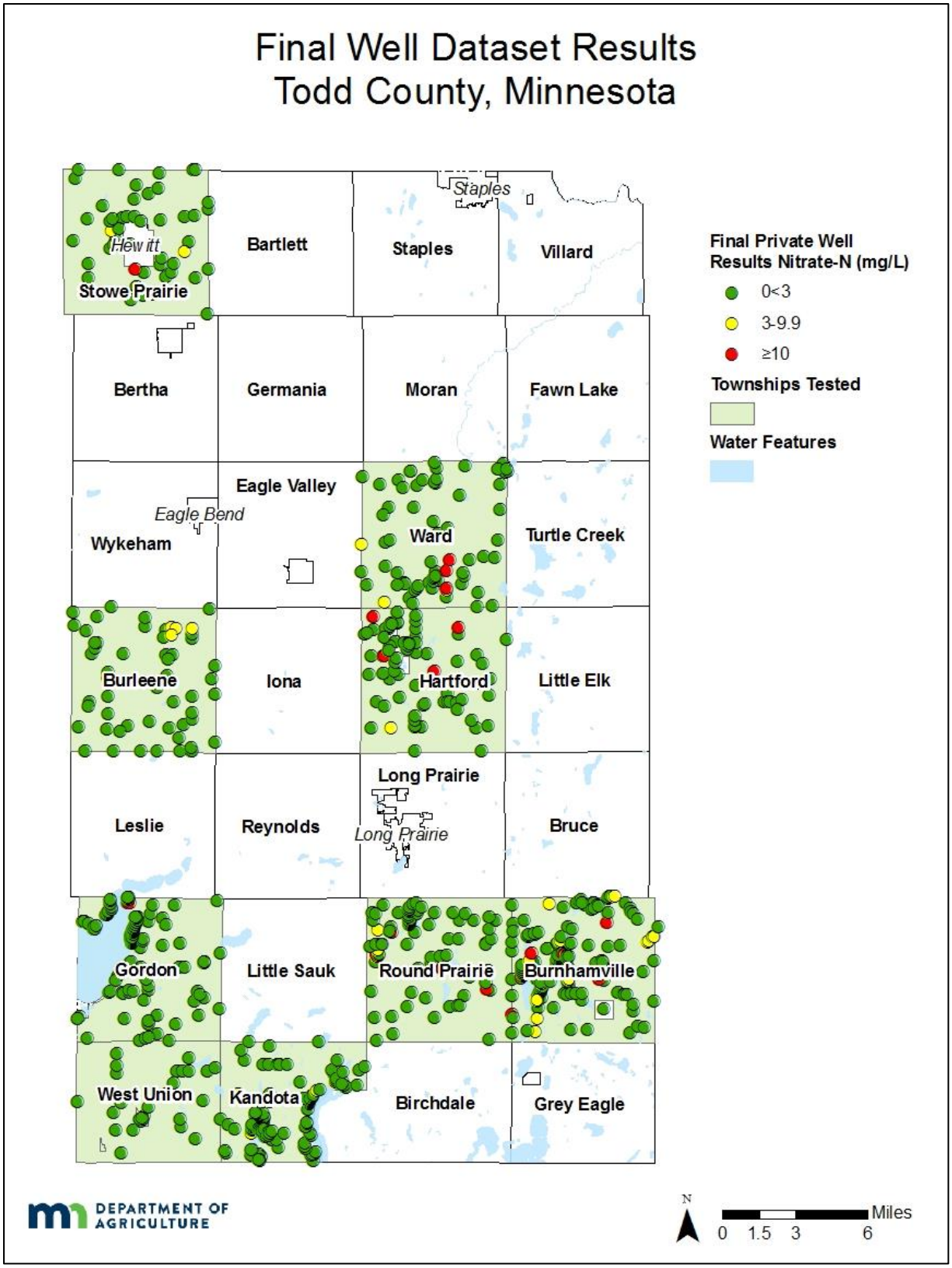


Figure 6. Well Locations and Nitrate Results from Final Well Dataset in Todd County

Table 7. Todd 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)																	
Burleene	56	<DL	8.28	0.46	<DL	<DL	1.9	3.8	8.1	52	4	1	1	0	92.9%	7.1%	1.8%	1.8%	0.0%
Burnhamville	165	<DL	35.4	1.54	<DL	0.6	5.0	9.3	17.8	140	17	17	10	8	84.8%	10.3 %	10.3%	6.1%	4.8%
Gordon	111	<DL	12.8	0.15	<DL	<DL	<DL	0.4	5.8	110	0	1	1	1	99.1%	0.0%	0.9%	0.9%	0.9%
Hartford	77	<DL	22.7	0.96	<DL	<DL	0.6	8.4	21.4	72	1	4	4	4	93.5%	1.3%	5.2%	5.2%	5.2%
Kandota	118	<DL	5.55	0.22	<DL	<DL	0.4	1.5	4.5	114	4	1	0	0	96.6%	3.4%	0.8%	0.0%	0.0%
Round Prairie	85	<DL	24.2	1.41	<DL	0.1	4.4	12.2	22.3	76	4	6	6	5	89.4%	4.7%	7.1%	7.1%	5.9%
Stowe Prairie	48	<DL	12.9	0.48	<DL	<DL	<DL	3.9	12.9	45	2	2	1	1	93.8%	4.2%	4.2%	2.1%	2.1%
Ward	70	<DL	33.2	1.60	<DL	<DL	3.6	11.9	31.4	63	3	6	6	4	90.0%	4.3%	8.6%	8.6%	5.7%
West Union*	30	<DL	1.77	0.11	<DL	<DL	0.1	1.3	1.8	30	0	0	0	0	100%	0.0%	0.0%	0.0%	0.0%
Total	760	<DL	35.4	0.86	<DL	<DL	1.9	5.0	17.7	702	35	38	29	23	92.4%	4.6%	5.0%	3.8%	3.0%

<DL stands for less than detectable limit. The detectable limit is <0.05 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

*Includes West Union City

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, Todd County

Township	Final Well Dataset	Percent of Land in Row Crop Production 2013*	Percent of Land in Vulnerable Geology	Percent ≥7 mg/L	Percent ≥10 mg/L
				Nitrate-N mg/L or parts per million (ppm)	
Burleene	56	10%	73%	1.8%	0.0%
Burnhamville	165	17%	46%	6.1%	4.8%
Gordon	111	27%	0%	0.9%	0.9%
Hartford	77	32%	33%	5.2%	5.2%
Kandota	118	21%	22%	0.0%	0.0%
Round Prairie	85	25%	33%	7.1%	5.9%
Stowe Prairie	48	21%	34%	2.1%	2.1%
Ward	70	25%	34%	8.6%	5.7%
West Union**	30	49%	11%	0.0%	0.0%
Total	760	25%	32%	3.8%	3.0%

*Data retrieved from USDA NASS Cropland Data Layer, 2013
**Includes West Union City

WELL AND WATER CHARACTERISTICS

WELL CONSTRUCTION

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

- The majority of wells were drilled (75 percent), and only 54 wells (7 percent) were identified as sand point wells.
- The median depth of wells was 86 feet, and the deepest was 310 feet.
- The median year the wells were constructed in was 2001.

WELL WATER PARAMETERS

MDA staff conducted the follow-up sampling and well site surveys at 74 wells. Only 61 follow-up wells are included in the final well dataset, and one of these did not have field measurements collected. Field measurements of the well water parameters were recorded on the first page of the Private Well Field Log & Well Survey Form (Appendix J). The measurements included temperature, pH, specific conductivity, and dissolved oxygen. The well was purged for 15 minutes, so that the measurements stabilized, ensuring a fresh sample of water was collected. The stabilized readings for the final well dataset are described below and a more comprehensive view is available in Appendix K (Tables 38-41).

- The temperatures ranged from 8.53 °C to 14.48 °C
- The median specific conductivity was 676 µS/cm, and was as high as 1,500 µS/cm
- The water from the wells had a median pH of 7.29
- The dissolved oxygen readings ranged from 0.11 mg/L to 6.59 mg/L

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

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

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

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

SUMMARY

The focus of this study was to assess nitrate concentrations in groundwater impacted by row crop production in selected townships in Todd County. In order to prioritize testing, the MDA looked at townships with significant row crop production and vulnerable geology. Approximately 25 percent of the land cover is row crop agriculture and there are 13,195 acres (7 percent of land cover) of groundwater irrigation in the study area.

Nine townships were sampled covering over 190,000 acres. The initial (homeowner collected) nitrate sampling resulted in 797 samples. The 797 households that participated represent an approximately 30 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 74 wells.

The MDA conducted a nitrogen source assessment and identified wells near potential point sources and wells with poor construction. A total of 37 (4.6 percent) wells were found to be unsuitable and were removed from the final well dataset of 760 wells. The remaining 760 wells were wells believed to be impacted by nitrogen fertilizer and were included in the final well dataset.

In the final well dataset majority of wells (75 percent) are drilled; about seven percent are sand points. The median depth of the wells is 86 and depths range from 26 to 310 feet.

For the final well dataset, none of the townships had more than 10 percent of wells at or over the nitrate Health Risk Limit of 10 mg/L. The percent of wells at or over the nitrate Health Risk Limit in each township ranged from 0.0 to 5.9 percent.

REFERENCES

Dubrovsky, N., Burow, K.R., Clark, G.M., Gronberg, J.M., Hamilton, P.A.., Hitt, K.J., Mueller, D.K., Munn, M.D., Nolan, B.T., Puckett, L.J., Rupert, M.G., Short, T.M., Spahr, N.E., Sprague, L.A., & Wilber, W.G. (2010). The Quality of Our Nation's Water: Nutrients in the Nation's Streams and Groundwater, 1992-2004 (U.S. Geological Survey Fact Sheet 2010-3078). U.S. Geological Survey. Retrieved from https://pubs.usgs.gov/fs/2010/3078/.

Hem, J.D. (1985). Study and interpretation of the chemical characteristics of natural water. (Water Supply Paper 2254). Alexandria, VA: U.S. Department of the Interior, Geological Survey.

Hernandez, J & A. Schmitt, Michael. (2012). Manure Management in Minnesota. 10.13140/RG.2.2.12053.73447.

Knowles, R. (1982). Denitrification. Microbiol. Rev. 46 (1), 43–70.

Minnesota Department of Agriculture [MDA]. (2018). Township Testing Program Sampling and Analysis Plan. Available Upon Request.

Minnesota Department of Agriculture [MDA]. (2017). Agricultural Chemical Incidents [Data file]. Retrieved from gisdata.mn.gov/dataset/env-agchem-incidents.

Minnesota Department of Health [MDH], Well Management Section. (2014). Well Owner's Handbook – A Consumer's Guide to Water Wells in Minnesota. St. Paul, MN: Minnesota Department of Health. Retrieved from www.health.state.mn.us/divs/eh/wells/construction/handbook.pdf

Minnesota Department of Health [MDH]. (2018). Minnesota Well Index. Retrieved from www.health.state.mn.us/communities/environment/water/mwi/index.html

Minnesota Department of Natural Resources [MDNR]. (1991). Criteria and guidelines for assessing geologic sensitivity of ground water resources in Minnesota, St. Paul, MN: Minnesota Department of Natural Resources. Retrieved from https://files.dnr.state.mn.us/waters/groundwater_section/mapping/sensitivity/docs/assessing_geologic_sensitivity.pdf.

Minnesota Department of Natural Resources [MDNR]. (2017). Minnesota Water Use Data [Data File]. Retrieved from dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html.

Minnesota Department of Natural Resources [MDNR]. (2018). DNR Water Permits. Retrieved from www.dnr.state.mn.us/permits/water/index.html.

Minnesota Department of Natural Resources, Minnesota Geologic Survey, and University of Minnesota – Duluth [MDNR, MGS, and UMD]. (1997). Geomorphology of Minnesota [map]. (ca. 1:100,000).

Minnesota Geologic Survey [MGS]. (2012). County Atlas Website. St. Paul, MN: Minnesota Geologic Survey. Retrieved from www.mngs.umn.edu/county_atlas/countyatlas.htm.

Minnesota Pollution Control Agency [MPCA]. (1998). Baseline Water Quality of Minnesota's Principal Aquifers, Region 2, North Central Minnesota. Retrieved from https://www.pca.state.mn.us/sites/default/files/baselinenc-rpt.pdf.

Minnesota Pollution Control Agency [MPCA]. (2011). Land Application of Manure: Minimum State Requirements (wq-f8-11). St. Paul, MN: Minnesota Pollution Control Agency. Retrieved from, from www.pca.state.mn.us/sites/default/files/wq-f8-11.pdf.

Minnesota Pollution Control Agency [MPCA]. (2013a). Compliance Inspections for Subsurface Sewage Treatment Systems (SSTS) (wq-wwists4-39). St. Paul, MN: Minnesota Pollution Control Agency. Retrieved from https://www.pca.state.mn.us/sites/default/files/wq-wwists4-39.pdf.

Minnesota Pollution Control Agency [MPCA]. (2013b). *Nitrogen in Minnesota Surface Waters: Conditions, trends, sources, and reductions* (wq-s6-26a). St. Paul, MN: Minnesota Pollution Control Agency. Retrieved from www.pca.state.mn.us/sites/default/files/wq-s6-26a.pdf.

Minnesota Pollution Control Agency [MPCA]. (2015). *State of Minnesota General Animal Feedlots NPDES Permit* (wq-f3-53). St. Paul, MN: Minnesota Pollution Control Agency. Retrieved from www.pca.state.mn.us/sites/default/files/wq-f3-53.pdf.

Minnesota Pollution Control Agency [MPCA]. (2017a). *2016 SSTS Annual Report, Subsurface Sewage Treatment Systems in Minnesota*. St. Paul, MN: Minnesota Pollution Control Agency. Retrieved from www.pca.state.mn.us/sites/default/files/wq-wwists1-56.pdf.

Minnesota Pollution Control Agency [MPCA]. (2017b). *Feedlot Registration Form* (wq-f4-12). St. Paul, MN: Minnesota Pollution Control Agency. Retrieved from www.pca.state.mn.us/quick-links/registration-permits-and-environmental-review.

Minnesota Pollution Control Agency [MPCA]. (2017c). *Livestock and the Environment: MPCA Feedlot Program Overview* (wq-f1-01). St. Paul, MN: Minnesota Pollution Control Agency. Retrieved from www.pca.state.mn.us/sites/default/files/wq-f1-01.pdf.

Minnesota Pollution Control Agency [MPCA]. (2018). *Feedlots in Minnesota* [Data file]. St. Paul, MN: Minnesota Pollution Control Agency. Retrieved from https://gisdata.mn.gov/dataset/env-feedlots.

Minnesota State Demographic Center. (2017). *Latest annual estimates of Minnesota and its cities and townships' population and households, 2016* [Data file]. Retrieved from https://mn.gov/admin/demography/data-by-topic/population-data/our-estimates/pop-finder2.jsp.

Minnesota Statutes 2015, section 115.55, subdivision 5.

Morey, G.B. (1969). *The Geology of the Middle Precambrian Rove Formation in Northeastern Minnesota.* Minneapolis, MN: Minnesota Geological Survey. Retrieved from: https://conservancy.umn.edu/bitstream/handle/11299/59958/mgs-378.pdf?sequence=1

National Secondary Drinking Water Regulations, 40 C.F.R. §143 (2011).

Nolan, B.T., & Stoner, J.D. (2000). Nutrients in Groundwaters of the Conterminous United States, 1992-95. *Environmental Science and Technology*, *34*(7), 1156-1165. Retrieved from https://doi.org/10.1021/es9907663.

Peterson, T. A. (2010a). Distribution of the Surficial and Buried Sand Aquifers [Plate 7] C-18 Geologic atlas of Todd County, Minnesota [Part B] . Minnesota Geological Survey. Retrieved from https://www.dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/toddcga.html.

Peterson, T. A. (2010b). Hydrogeology of the Surficial and Buried Sand Aquifers [Plate 9] C-18 Geologic atlas of Todd County, Minnesota [Part B]. Minnesota Geological Survey. Retrieved from https://www.dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/toddcga.html.

Bedrock Geology [Plate 2] in the Geologic Atlas of Benton County, Minnesota: Minnesota Geological Survey Atlas Series C-23, scale 1:100,000. Retrieved from

Sanders, L.L. (1998). *A Manual of Field Hydrogeology*. Upper Saddle River, NJ: Prentice Hall.

Setterholm, D.R.. (2007). C-18 Geologic atlas of Todd County, Minnesota [Part A]. Minnesota Geological Survey. Retrieved from http://hdl.handle.net/11299/58719.

Sloan, R.E. (1964). *The Cretaceous System in Minnesota.* St. Paul, MN: Minnesota Geological Survey. Retrieved from https://conservancy.umn.edu/bitstream/handle/11299/60189/mgs-225.pdf?sequence=3&isAllowed=y

Sylvester, Paul J. (1994). *Developments in Precambrian Geology 11 Archean Crustal Evolution.* Socorro, NM. New Mexico Institute of Mining & Technology, Department of Geoscience. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0166263508702251

United States Environmental Protection Agency [US EPA]. (2009). National primary drinking water regulations list (EPA 816-F-09-004). Retrieved from www.epa.gov/sites/production/files/2016-06/documents/npwdr_complete_table.pdf

United States Geological Survey [USGS]. (2016). *Water properties: Temperature*. Retrieved from https://water.usgs.gov/edu/temperature.html.

United States Department of Agriculture National Statistics Service [USDA NASS]. (2013). *Cropland Data Layer, 2013* [Data file]. Retrieved from https://gisdata.mn.gov/dataset/agri-cropland-data-layer-2013.

Warner, K.L., & Arnold, T.L. (2010). *Relations that Affect the Probability and Prediction of Nitrate Concentration in Private Wells in the Glacial Aquifer System in the United States* (Scientific Investigations Report 2010-5100). Reston, VA: U.S. Geological Survey. Retrieved from https://pubs.usgs.gov/sir/2010/5100/pdf/sir2010-5100.pdf.

APPENDIX A

Well information and Potential Nitrate Source Inventory Form

Site ID_____Unique ID_____ Date _____

MDA -Private Well Field Log & Well Survey Form

Water Treatment Information

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

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

   If yes, what type?_____

Well Construction Information

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

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

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

Field Survey Information

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

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

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

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

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

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

Updated: March, 2017

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

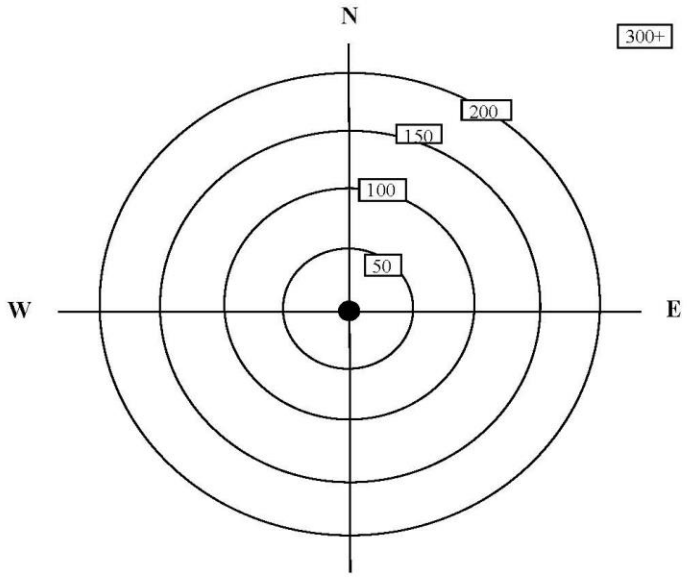
MDA -Private Well Field Log & Well Survey Form

DIRECTIONS

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

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

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



ADDITIONAL SURVEY NOTES

Updated: March, 2017

APPENDIX B

SUBSURFACE SEWAGE TREATMENT SYSTEM

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

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

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

In 2016 Todd County reported a total of 5,734 SSTS and 5.1 percent were inspected for compliance. However, Stowe Prairie Township did not submit its annual report. Compliance inspections are conducted in Todd County during property transfers, which is common in Minnesota but it is not a state-level requirement (MPCA, 2017a).

FEEDLOT

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

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

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

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

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

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

Farmers must register a feedlot through the Minnesota Pollution Control Agency (MPCA) if they have at least 50 AU, or 10 AU if the feedlot is located near shoreline. Larger feedlots must follow additional regulations. Feedlots with more than 300 AU must submit a manure management plan if they do not use a licensed commercial applicator. Feedlots with more than 1,000 AU are regulated through federal National Pollutant Discharge Elimination (NPDES) permits (MPCA, 2011) and must submit an annual manure management plan as part of their permit (MPCA, 2015).

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

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

Township	Total Feedlots	Active Feedlots	Inactive Feedlots	Average AU Permitted** Per Feedlot	Total Permitted** AU	Total Square Miles	Permitted** AU per Square Mile
Burleene	48	35	13	103	3,597	36	100
Burnhamville	58	43	15	275	11,804	35	338
Gordon	37	33	4	80	2,624	35	75
Hartford	56	47	9	156	7,352	35	210
Kandota	23	21	2	104	2,191	24	91
Round Prairie	57	46	11	75	3,428	36	95
Stowe Prairie	36	30	6	80	2,404	34	72
Ward	59	42	17	106	4,439	36	122
West Union***	49	37	12	140	5,179	30	175
Total	423	334	89	129*	43,018	301	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.
***Includes West Union City

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 Todd County study area livestock densities average 0.90 AU per acre of row crops (MPCA, 2018; USDA NASS, 2013).

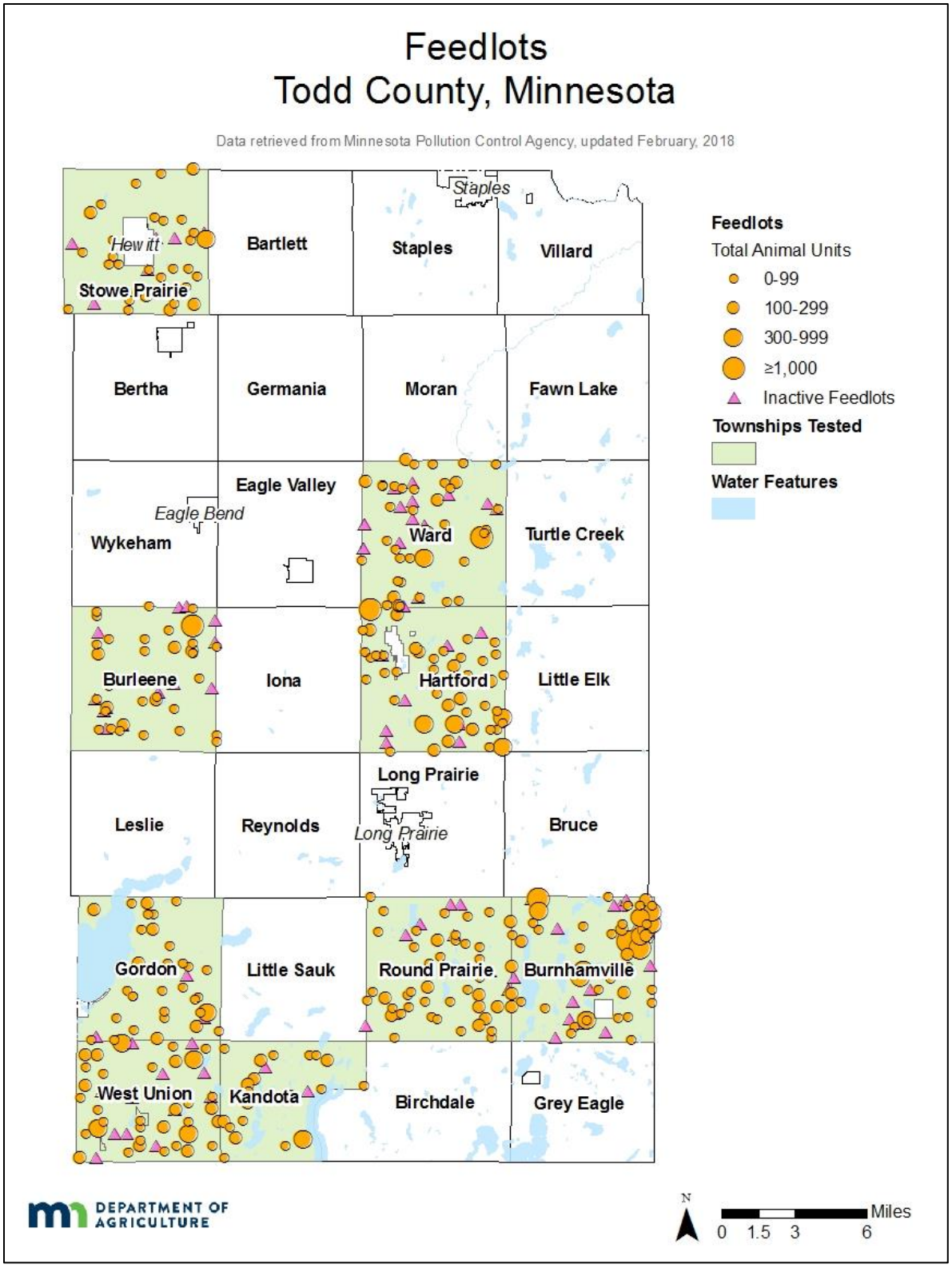


Figure 7. Feedlot Locations in Todd County (MPCA, 2018)

FERTILIZER STORAGE LOCATION

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

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

Township	Bulk Fertilizer Facility	Anhydrous Ammonia	Abandoned Sites	Chemigation Sites	Total
Burleene	0	0	0	1	1
Burnhamville	0	0	0	0	0
Gordon	0	0	0	0	0
Hartford	0	0	0	20	20
Kandota	0	0	0	4	4
Round Prairie	0	0	0	12	12
Stowe Prairie	0	0	0	16	16
Ward	0	0	0	15	15
West Union*	0	0	0	1	1
Total	0	0	0	69	69

Data retrieved from MDA Pesticide and Fertilizer Management Division, 2018; updated March 2018
*Includes West Union City

SPILLS AND INVESTIGATIONS

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

The MDA tracks several types of incidents. Incident investigations are typically for larger spills. Contingency areas are locations that have not been remediated because they were inaccessible or the contaminant could not be removed for some other reason. They are often a part of an incident investigation. There are no incident investigations or contingency areas in this study area. Old emergency incidents were closed prior to March 1st, 2004 (MDA, 2017), but they can still be a point source. At most of these older sites, the contaminants are unknown and their location may not be precise. There is one in the study area. Small spills and investigations are typically smaller emergency spills such as a truck spilling chemicals. There is one in the study area. It is important to note that while the locations of the incidents described are as accurate as possible, it is an incomplete dataset (MDA, 2017). A breakdown of chemical type of these incidents can be found in Table 12. A breakdown of the fertilizer specific spills and investigations, by township, can be found in Table 13.

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

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

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

Township	Incidents and Spills
Burleene	0
Burnhamville	0
Gordon	0
Hartford	0
Kandota	0
Round Prairie	0
Stowe Prairie	0
Ward	0
West Union*	2
Total	2

*Includes West Union City

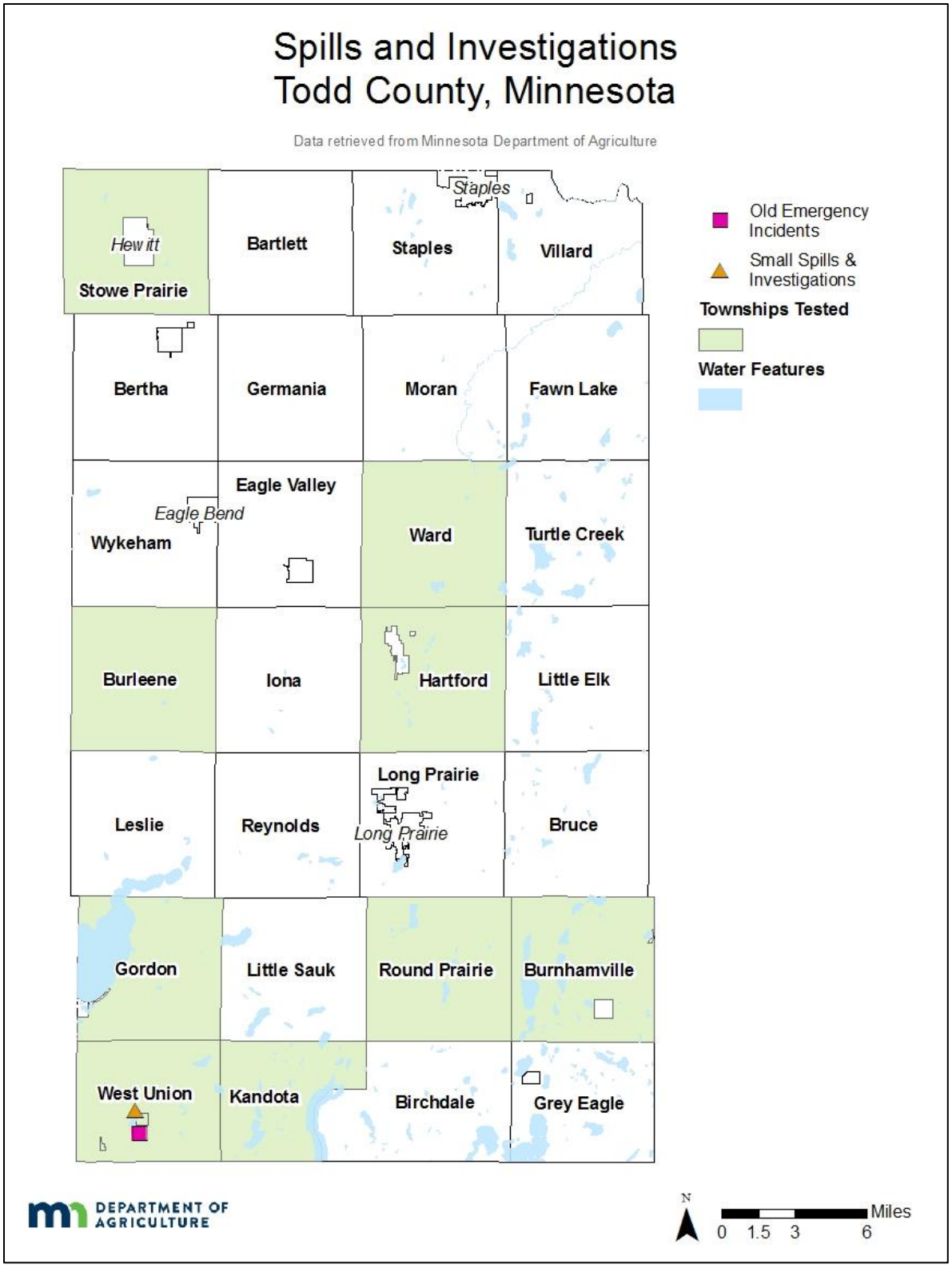


Figure 8. Fertilizer Spills and Investigations in Todd County (MDA, 2017)

APPENDIX C

LAND AND WATER USE

LAND COVER

Typically locations were selected for the Township Testing Program if at least 20 percent of the land cover was in row crop production. Todd County is a rural county located in central Minnesota and it has a significant amount of land devoted to row crop agriculture (Figure 9; Table 14). Row crops can include: corn, sweet corn, soybeans, alfalfa, sugar beets, potatoes, durum wheat, dry beans and double crops involving corn and soybeans.

In all of the study townships at least 26 percent of the land is considered pastureland. Relatively little land (4%) in the study area is considered developed. Forests are also an important feature in these townships. Overall 18 percent of the land is considered forested.

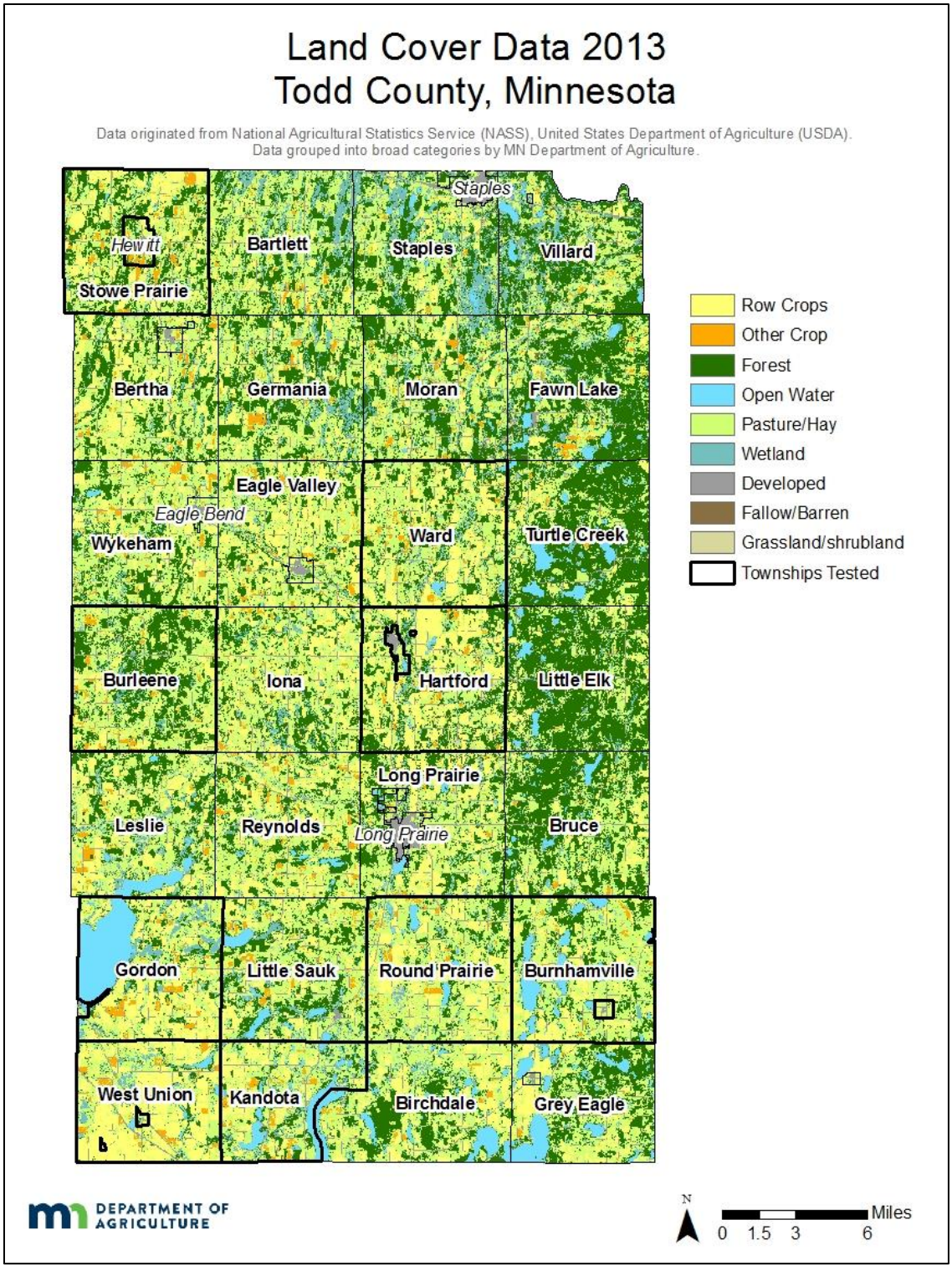


Figure 9. Land Cover in Todd County (USDA NASS Cropland Data Layer, 2013)

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

Township	Total Acres	Row Crops	Other Crops	Forest	Open Water	Pasture/ Hay	Wetland	Developed	Fallow/ Barren	Grassland/ Shrubland
Burleene	22,969	10%	4%	34%	0%	40%	4%	4%	0%	3%
Burnhamville	22,395	17%	2%	19%	10%	44%	3%	4%	0%	1%
Gordon	22,386	27%	4%	8%	20%	27%	9%	4%	0%	1%
Hartford	22,371	32%	3%	23%	1%	27%	4%	5%	0%	5%
Kandota	15,483	21%	4%	12%	10%	37%	9%	5%	0%	2%
Round Prairie	23,093	25%	4%	11%	3%	45%	5%	5%	0%	3%
Stowe Prairie	21,510	21%	5%	28%	0%	36%	4%	4%	0%	2%
Ward	23,204	25%	4%	20%	1%	37%	5%	4%	0%	3%
West Union**	19,203	49%	5%	5%	2%	26%	6%	5%	0%	1%
Average	192,614*	25%	4%	18%	5%	36%	5%	4%	0%	2%

*Represents a Total
**Includes West Union City

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, 2018). There are a total of 169 active groundwater well permits in the study area, 152 of which are used for agricultural irrigation (Figure 10). About 13,195 acres of cropland are permitted for groundwater irrigation in this area (Table 15). Most permitted wells are withdrawing groundwater from Quaternary aquifers (Table 16; MDNR, 2017).

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

Township	Major Crop Irrigation Well Permits	Average Depth (feet)	Irrigated Acres Permitted
Burleene	2	111	179
Burnhamville	5	68	435
Gordon	0	0	0
Hartford	46	73	3,838
Kandota	4	143	445
Round Prairie	25	79	2,320
Stowe Prairie	21	66	2,320
Ward	45	57	3,163
West Union*	4	61	495
Total	152	70	13,195

*Includes West Union City, no permits in the city

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

Water Use Well Permits	Total	Average Depth (feet)	Aquifer			
			Quaternary Water Table	Quaternary Buried	Paleozoic	Not Classified
Agricultural Irrigation	152	70	78	57	0	17
Non-Crop Irrigation	2	134	0	2	0	0
Water Supply	1	88	0	1	0	0
Industrial Processing	6	115	0	6	0	0
Water Level Maintenance	2	134	0	2	0	0
Special Categories	6	115	0	6	0	0
Total	169	75	78	74	0	17

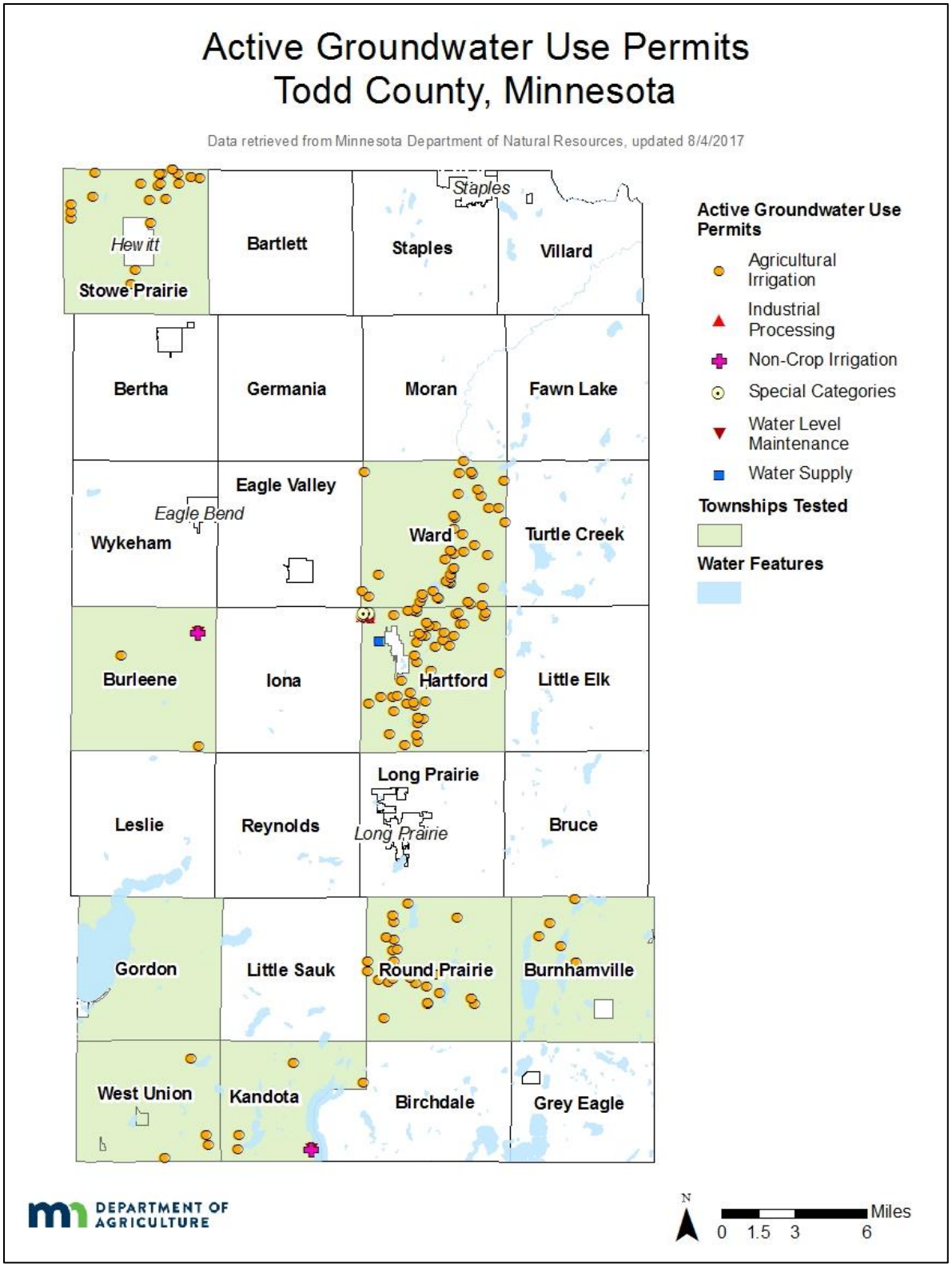


Figure 10. Active Groundwater Use Permits in Todd County (MDNR, 2017)

APPENDIX D

Nitrate Brochure

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

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

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

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

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

If the Nitrate result is above 10 mg/L:

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

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

---

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, Todd County

Township	Point Source	Well Construction Problem	Hand Dug well	Unsure of water source	Irrigation well	Site Visit Completed - Well Not Found & Constructed before 1975 & No Well ID	No Site Visit & Constructed before 1975 & No Well ID	No Site Visit & Insufficient Data & No Well ID	Total
Burleene	0	0	0	0	0	0	0	0	0
Burnhamville	2	1	0	0	0	1	5	1	10
Gordon	0	1	1	0	0	0	2	1	5
Hartford	0	1	1	0	1	1	0	1	5
Kandota	1	0	0	0	0	1	1	0	3
Round Prairie	0	0	0	0	0	0	1	1	2
Stowe Prairie	0	1	0	0	0	0	1	0	2
Ward	2	0	1	0	0	1	2	0	6
West Union	0	0	1	1	0	0	1	1	4
Total	5	4	4	1	1	4	13	5	37

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

Township	Site Visit	No Site Visit	Total
Burleene	0	0	0
Burnhamville	2	8	10
Gordon	1	4	5
Hartford	2	3	5
Kandota	2	1	3
Round Prairie	0	2	2
Stowe Prairie	1	1	2
Ward	3	3	6
West Union	2	2	4
Total	13	24	37

APPENDIX F

MINNESOTA WELL INDEX

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

In these townships, there are 1,872 documented (have a verified location in the MWI) drinking water wells:

- The vast majority, approximately 82 percent, of the wells were completed in Quaternary aquifers. These are the shallowest aquifers in Todd County.
    - The Quaternary Water table represent about 9 percent of wells within the Todd County study area townships. These wells have an average depth of 57.6 feet.
    - Only 35 wells (<2 percent) were completed in Quaternary Buried Unconfined Aquifers.
    - The majority of wells (71 percent) were completed in the Quaternary Buried Artesian Aquifers. These are the deepest of the Quaternary Aquifer wells, averaging 103.8 feet deep.
    - There were 7 wells that were completed in the Quaternary strata, but the well log does not differentiate which type of aquifer.
- Very few wells (8 total) were completed in Cretaceous aquifers. All 8 of these wells were located in Burnhamville Township.
- Less than 1 percent of wells were completed in Precambrian aquifers. The majority of these wells were found in Burnhamville.
- Only 5 wells were completed in multiple aquifers. The average depth of these wells is 156.6 feet.
- Approximately 17 percent of wells with a well log did not have a defined aquifer.

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

Township	Burnhamville	Burleene	Gordon	Hartford	Kandota	Round Prairie	Stowe Prairie	Ward	West Union	Total	Average Well Depth (feet)
	Number of wells drawing water from an aquifer										
Quaternary Water Table	99	0	0	16	13	12	0	19	1	160	57.6
Quaternary Buried Unconfined Aquifer	25	0	1	0	3	0	0	4	2	35	58.6
Quaternary Buried Artesian Aquifer	739	44	120	61	110	80	77	49	41	1,321	103.8
Quaternary Undifferentiated	7	0	1	0	0	2	0	0	0	10	37.7
Cretaceous Regolith	2	0	0	0	0	0	0	0	0	2	220.0
Cretaceous, Undifferentiated	6	0	0	0	0	0	0	0	0	6	159.3
Animikie Group (Precambrian)	4	0	0	0	0	1	0	0	0	5	187.6
Archean Granite Pluton (Precambrian)	1	0	0	0	0	0	0	0	0	1	130.0
Multiple	4	0	0	0	1	0	0	0	0	5	156.6
Not Available	181	8	29	17	39	20	10	10	13	327	107.1
Total	1,068	52	151	94	166	115	87	82	57	1,872	99.7

APPENDIX G

Minnesota Department of Agriculture

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 private 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. Year well was built? ☐ before 1975 ☐ 1975 to 1984 ☐ 1985 to 1993 ☐ 1994-Present ☐Don't Know

9. Approximate **depth** of your well? ☐ 0-15 Feet ☐ 16 - 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?

APPENDIX H

Table 20. Property Setting for Well Location

Township	Total	Country	Municipal	River home	Lake Home	Sub-division	Other	Not Available
Burleene	56	69.6%	0.0%	0.0%	1.8%	1.8%	1.8%	25.0%
Burnhamville	175	32.6%	0.0%	1.1%	53.1%	0.0%	0.6%	12.6%
Gordon	116	36.2%	0.0%	1.7%	38.8%	2.6%	2.6%	18.1%
Hartford	82	81.7%	0.0%	1.2%	0.0%	2.4%	1.2%	13.4%
Kandota	121	34.7%	0.0%	3.3%	44.6%	3.3%	1.7%	12.4%
Round Prairie	87	69.0%	1.1%	0.0%	19.5%	1.1%	0.0%	9.2%
Stowe Prairie	50	88.0%	0.0%	0.0%	2.0%	0.0%	0.0%	10.0%
Ward	76	67.1%	0.0%	1.3%	13.2%	2.6%	1.3%	14.5%
West Union*	34	64.7%	0.0%	0.0%	0.0%	0.0%	5.9%	29.4%
Total	797	53.2%	0.1%	1.3%	27.7%	1.6%	1.4%	14.7%

*Includes West Union City

Table 21. Well Construction Type

Township	Total	Drilled	Sand point	Hand dug	Not Available
Burleene	56	73.2%	5.4%	0.0%	21.4%
Burnhamville	175	66.9%	16.0%	0.0%	17.1%
Gordon	116	66.4%	5.2%	0.9%	27.6%
Hartford	82	76.8%	2.4%	1.2%	19.5%
Kandota	121	76.0%	5.8%	0.0%	18.2%
Round Prairie	87	81.6%	3.4%	0.0%	14.9%
Stowe Prairie	50	78.0%	4.0%	0.0%	18.0%
Ward	76	67.1%	11.8%	1.3%	19.7%
West Union*	34	70.6%	0.0%	0.0%	29.4%
Total	797	72.1%	7.5%	0.4%	19.9%

*Includes West Union City

Table 22. Age of Well

Township	Total	1994-Present	1985 to 1993	1975 to 1984	before 1975	Not Available
Burleene	56	23.2%	5.4%	16.1%	21.4%	33.9%
Burnhamville	175	38.3%	8.0%	10.3%	16.6%	26.9%
Gordon	116	27.6%	9.5%	11.2%	13.8%	37.9%
Hartford	82	24.4%	8.5%	12.2%	19.5%	35.4%
Kandota	121	34.7%	9.1%	14.9%	19.0%	22.3%
Round Prairie	87	31.0%	11.5%	18.4%	14.9%	24.1%
Stowe Prairie	50	30.0%	18.0%	10.0%	14.0%	28.0%
Ward	76	31.6%	7.9%	9.2%	26.3%	25.0%
West Union*	34	32.4%	8.8%	0.0%	26.5%	32.4%
Total	797	31.5%	9.3%	12.0%	18.2%	29.0%

*Includes West Union City

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
Burleene	56	1.8%	8.9%	23.2%	33.9%	0.0%	32.1%
Burnhamville	175	0.0%	21.7%	37.7%	20.0%	1.7%	18.9%
Gordon	116	0.0%	11.2%	25.9%	33.6%	0.9%	28.4%
Hartford	82	1.2%	9.8%	50.0%	18.3%	0.0%	20.7%
Kandota	121	0.0%	5.0%	24.8%	43.0%	0.0%	27.3%
Round Prairie	87	1.1%	8.0%	48.3%	24.1%	2.3%	16.1%
Stowe Prairie	50	0.0%	6.0%	36.0%	38.0%	0.0%	20.0%
Ward	76	2.6%	9.2%	44.7%	19.7%	0.0%	23.7%
West Union*	34	2.9%	2.9%	44.1%	20.6%	0.0%	29.4%
Total	797	0.8%	11.0%	36.3%	27.9%	0.8%	23.3%

*Includes West Union City

Table 24. Unique Well ID Known

Township	Total	No, Unique Well ID not known	Yes, Unique Well ID known	Not Available
Burleene	56	28.6%	10.7%	60.7%
Burnhamville	175	24.6%	24.0%	51.4%
Gordon	116	22.4%	21.6%	56.0%
Hartford	82	25.6%	19.5%	54.9%
Kandota	121	20.7%	19.8%	59.5%
Round Prairie	87	25.3%	17.2%	57.5%
Stowe Prairie	50	30.0%	12.0%	58.0%
Ward	76	23.7%	23.7%	52.6%
West Union*	34	26.5%	26.5%	47.1%
Total	797	24.5%	20.2%	55.3%

*Includes West Union City

Table 25. Livestock Located on Property

Township	Total	No Livestock	Yes Livestock	Not Available
Burleene	56	67.9%	8.9%	23.2%
Burnhamville	175	83.4%	5.1%	11.4%
Gordon	116	75.9%	5.2%	19.0%
Hartford	82	70.7%	15.9%	13.4%
Kandota	121	82.6%	3.3%	14.0%
Round Prairie	87	73.6%	13.8%	12.6%
Stowe Prairie	50	62.0%	26.0%	12.0%
Ward	76	69.7%	15.8%	14.5%
West Union*	34	61.8%	8.8%	29.4%
Total	797	75.2%	9.7%	15.2%

*Includes West Union City

Table 26. Fertilizer Stored on Property

Township	Total	No Fertilizer Stored	Yes Fertilizer Stored	Not Available
Burleene	56	78.6%	0.0%	21.4%
Burnhamville	175	86.3%	1.1%	12.6%
Gordon	116	80.2%	0.9%	19.0%
Hartford	82	85.4%	1.2%	13.4%
Kandota	121	86.8%	0.0%	13.2%
Round Prairie	87	87.4%	2.3%	10.3%
Stowe Prairie	50	84.0%	4.0%	12.0%
Ward	76	84.2%	0.0%	15.8%
West Union*	34	73.5%	0.0%	26.5%
Total	797	84.1%	1.0%	14.9%

*Includes West Union City

Table 27. Farming on Property

Township	Total	No Farming	Yes Farming	Not Available
Burleene	56	35.7%	42.9%	21.4%
Burnhamville	175	70.9%	16.0%	13.1%
Gordon	116	54.3%	25.9%	19.8%
Hartford	82	54.9%	31.7%	13.4%
Kandota	121	71.9%	14.0%	14.0%
Round Prairie	87	51.7%	36.8%	11.5%
Stowe Prairie	50	44.0%	44.0%	12.0%
Ward	76	48.7%	36.8%	14.5%
West Union*	34	44.1%	29.4%	26.5%
Total	797	57.5%	27.2%	15.3%

*Includes West Union City

Table 28. Distance to an Active or Inactive Feedlot

Township	Total	0-49 Feet to Feedlot	50-99 Feet to Feedlot	100-299 Feet to Feedlot	Over 300 Feet to Feedlot	Not Available
Burleene	56	7.1%	10.7%	12.5%	41.1%	28.6%
Burnhamville	175	6.3%	2.3%	4.0%	61.7%	25.7%
Gordon	116	0.0%	4.3%	3.4%	56.9%	35.3%
Hartford	82	4.9%	2.4%	9.8%	52.4%	30.5%
Kandota	121	1.7%	2.5%	2.5%	67.8%	25.6%
Round Prairie	87	5.7%	3.4%	12.6%	51.7%	26.4%
Stowe Prairie	50	4.0%	4.0%	20.0%	50.0%	22.0%
Ward	76	7.9%	5.3%	13.2%	52.6%	21.1%
West Union*	34	0.0%	0.0%	14.7%	47.1%	38.2%
Total	797	4.3%	3.6%	8.2%	56.2%	27.7%

*Includes West Union City

Table 29. Distance to Septic System

Township	Total	0-49 Feet to Septic	50-99 Feet to Septic	100-299 Feet to Septic	Over 300 Feet to Septic	Not Available
Burleene	56	1.8%	25.0%	39.3%	8.9%	25.0%
Burnhamville	175	8.0%	28.6%	37.1%	10.9%	15.4%
Gordon	116	5.2%	31.9%	30.2%	12.9%	19.8%
Hartford	82	1.2%	26.8%	41.5%	13.4%	17.1%
Kandota	121	4.1%	32.2%	40.5%	7.4%	15.7%
Round Prairie	87	1.1%	29.9%	40.2%	17.2%	11.5%
Stowe Prairie	50	0.0%	28.0%	48.0%	8.0%	16.0%
Ward	76	2.6%	26.3%	42.1%	11.8%	17.1%
West Union*	34	2.9%	14.7%	35.3%	20.6%	26.5%
Total	797	3.9%	28.5%	38.6%	11.8%	17.2%

*Includes West Union City

Table 30. Distance to an Agricultural Field

Township	Total	0-49 Feet to Field	50-99 Feet to Field	100-299 Feet to Field	Over 300 Feet to Field	Not Available
Burleene	56	3.6%	3.6%	26.8%	37.5%	28.6%
Burnhamville	175	2.9%	7.4%	20.6%	50.9%	18.3%
Gordon	116	3.4%	6.9%	25.9%	43.1%	20.7%
Hartford	82	4.9%	8.5%	31.7%	36.6%	18.3%
Kandota	121	1.7%	5.8%	22.3%	50.4%	19.8%
Round Prairie	87	4.6%	9.2%	27.6%	44.8%	13.8%
Stowe Prairie	50	0.0%	4.0%	36.0%	46.0%	14.0%
Ward	76	2.6%	6.6%	30.3%	42.1%	18.4%
West Union*	34	2.9%	5.9%	35.3%	26.5%	29.4%
Total	797	3.0%	6.8%	26.5%	44.4%	19.3%

*Includes West Union City

Table 31. Drinking Water Well

Township	Total	Not Drinking Water	Yes, Drinking Water	Not Available
Burleene	56	0.0%	80.4%	19.6%
Burnhamville	175	4.6%	85.1%	10.3%
Gordon	116	0.9%	81.9%	17.2%
Hartford	82	2.4%	85.4%	12.2%
Kandota	121	1.7%	86.8%	11.6%
Round Prairie	87	0.0%	90.8%	9.2%
Stowe Prairie	50	2.0%	86.0%	12.0%
Ward	76	2.6%	84.2%	13.2%
West Union*	34	2.9%	73.5%	23.5%
Total	797	2.1%	84.7%	13.2%

*Includes West Union City

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

Township	Total	None	Distillation	Filtering System	Reverse Osmosis	Other	Not Available
Burleene	56	60.7%	0.0%	12.5%	1.8%	0.0%	25.0%
Burnhamville	175	58.3%	0.0%	14.3%	8.0%	1.7%	17.7%
Gordon	116	49.1%	0.9%	19.0%	7.8%	0.9%	22.4%
Hartford	82	63.4%	0.0%	12.2%	8.5%	0.0%	15.9%
Kandota	121	49.6%	0.8%	21.5%	6.6%	0.0%	21.5%
Round Prairie	87	57.5%	0.0%	14.9%	11.5%	1.1%	14.9%
Stowe Prairie	50	64.0%	2.0%	10.0%	4.0%	2.0%	18.0%
Ward	76	64.5%	0.0%	13.2%	3.9%	0.0%	18.4%
West Union*	34	35.3%	8.8%	20.6%	8.8%	0.0%	26.5%
Total	797	56.2%	0.8%	15.7%	7.2%	0.8%	19.4%

*Includes West Union City

Table 33. Last Tested for Nitrate

Township	Total	Within the past year	Within the last 3 years	Within the last 10 years	Greater than 10 years	Never Tested	Homeowner Unsure	Not Available
Burleene	56	5.4%	3.6%	5.4%	19.6%	21.4%	25.0%	19.6%
Burnhamville	175	2.3%	8.0%	10.3%	14.9%	29.7%	24.0%	10.9%
Gordon	116	1.7%	2.6%	13.8%	10.3%	29.3%	25.0%	17.2%
Hartford	82	1.2%	4.9%	20.7%	15.9%	23.2%	20.7%	13.4%
Kandota	121	5.0%	8.3%	8.3%	14.9%	28.9%	23.1%	11.6%
Round Prairie	87	4.6%	8.0%	17.2%	14.9%	16.1%	29.9%	9.2%
Stowe Prairie	50	0.0%	10.0%	20.0%	16.0%	28.0%	16.0%	10.0%
Ward	76	2.6%	9.2%	10.5%	17.1%	34.2%	13.2%	13.2%
West Union*	34	5.9%	5.9%	5.9%	8.8%	35.3%	17.6%	20.6%
Total	797	3.0%	6.8%	12.4%	14.7%	27.4%	22.6%	13.2%

*Includes West Union City

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
Burleene	56	5.4%	1.8%	0.0%	92.9%
Burnhamville	175	8.0%	1.7%	0.0%	90.3%
Gordon	116	6.9%	0.9%	0.0%	92.2%
Hartford	82	11.0%	3.7%	0.0%	85.4%
Kandota	121	9.9%	2.5%	0.0%	87.6%
Round Prairie	87	4.6%	3.4%	3.4%	88.5%
Stowe Prairie	50	6.0%	0.0%	0.0%	94.0%
Ward	76	7.9%	1.3%	0.0%	90.8%
West Union*	34	2.9%	0.0%	0.0%	97.1%
Total	797	7.5%	1.9%	0.4%	90.2%

*Includes West Union City

APPENDIX I

Table 35. Well Construction Type for Final Well Dataset

Township	Total Wells	Drilled	Sand Point	Not Available
Burleene	56	41	3	12
Burnhamville	165	115	25	25
Gordon	111	76	5	30
Hartford	77	62	2	13
Kandota	118	91	6	21
Round Prairie	85	72	4	9
Stowe Prairie	48	38	1	9
Ward	70	51	8	11
West Union*	30	23	0	7
Total	760	569	54	137

Data compiled from well logs and homeowner responses. *Includes West Union City

Table 36. Well Depth for Final Well Dataset

Township	Total Wells	Min	Max	Median	Mean
Burleene	17	48	232	130	133
Burnhamville	84	26	310	58	87
Gordon	50	27	215	107	114
Hartford	29	42	274	75	87
Kandota	52	42	210	113	106
Round Prairie	30	29	194	86	96
Stowe Prairie	19	33	236	95	111
Ward	28	40	119	64	69
West Union*	12	56	137	103	96
Total	321	26	310	86	98

Data compiled from well logs only; homeowner responses are not included. *Includes West Union City

Table 37. Year of Well Construction for Final Well Dataset

Township	Total Wells	Min	Max	Median	Mean
Burleene	17	1975	2015	2002	1999
Burnhamville	83	1975	2015	2002	2000
Gordon	50	1977	2015	2000	1999
Hartford	29	1968	2014	1999	1997
Kandota	52	1975	2015	2000	1999
Round Prairie	30	1976	2013	2001	1998
Stowe Prairie	19	1988	2013	2004	2002
Ward	28	1990	2014	1999	2000
West Union*	12	1985	2015	1997	1999
Total	320	1968	2015	2001	1999

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. *Includes West Union City

APPENDIX J

Private Well Field Log

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

MDA -Private Well Field Log & Well Survey Form

Sample#_____

Duplicate#_____**Field Blank#**_____

Additional Samples_____

Well Owner Contact Information

Name_____

Address_____

Phone #_____Township_____County_____

Sampling Information

Sampler_____Time Arrived_____

Pump Start Time_____Discharge Rate_____Time Collected_____

Sample Point Location_____

Well Location_____

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

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

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

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

Field Comments - sample specific notes

Updated: March, 2017

APPENDIX K

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

Township	Samples	Min	Max	Median	Mean
Burleene	2	9.61	10.58	10.10	10.10
Burnhamville	22	9.03	14.48	10.24	10.66
Gordon	4	8.53	12.63	9.86	10.22
Hartford	6	9.73	10.71	10.24	10.24
Kandota	7	9.93	12.15	10.39	10.60
Round Prairie	13	8.85	14.12	10.62	10.80
Stowe Prairie	1	11.66	11.66	11.66	11.66
Ward	4	9.60	11.03	10.33	10.32
West Union*	1	9.24	9.24	9.24	9.24
Total	60	8.53	14.48	10.33	10.56

Table 39. pH of Well Water for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Burleene	2	7.36	7.48	7.42	7.42
Burnhamville	22	6.78	7.55	7.175	7.209
Gordon	4	7.1	7.55	7.24	7.282
Hartford	6	7.11	7.5	7.32	7.32
Kandota	7	7.21	7.65	7.33	7.4
Round Prairie	13	6.89	7.65	7.3	7.262
Stowe Prairie	1	7.36	7.36	7.36	7.36
Ward	4	7.25	7.52	7.44	7.412
West Union*	1	7.34	7.34	7.34	7.34
Total	60	6.78	7.65	7.29	7.284

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

Township	Samples	Min	Max	Median	Mean
Burleene	2	478	560	519	519
Burnhamville	22	527	1,500	699	749
Gordon	4	518	983	787	769
Hartford	6	579	788	607	658
Kandota	7	540	1,129	554	637
Round Prairie	13	540	952	692	701
Stowe Prairie	1	652	652	652	652
Ward	4	580	745	656	659
West Union*	1	945	945	945	945
Total	60	478	1,500	676	706

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

Township	Samples	Min	Max	Median	Mean
Burleene	2	4.05	5.84	4.95	4.95
Burnhamville	22	0.14	6.59	2.70	2.77
Gordon	4	0.13	5.34	0.82	1.78
Hartford	6	0.32	5.79	1.69	2.60
Kandota	7	0.19	3.14	0.75	1.12
Round Prairie	13	0.11	6.40	0.86	2.34
Stowe Prairie	1	3.10	3.10	3.10	3.10
Ward	4	5.55	6.43	5.85	5.92
West Union*	1	0.12	0.12	0.12	0.12
Total	60	0.11	6.59	1.68	2.64

*Includes West Union City