Final Township Testing Nitrate Report: Wabasha County 2017-2019

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EXECUTIVE SUMMARY

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

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

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

In 2017, private wells in the Wabasha County study area (14 townships) were sampled for nitrate-N. Samples were collected from private wells using homeowner collection and mail-in methods. These initial samples were collected from 1,087 wells representing an average response rate of 34 percent of homeowners. Well log information was obtained when available and correlated with nitrate-N results. Initial well dataset results showed that across the study area, 16.0 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 1,245 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 476 wells in 2018 and 2019. 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 that had nitrate-nitrogen results over 5 mg/L were removed from the initial dataset to form the final dataset if a potential non-fertilizer source or well problem was identified, there was insufficient information on the construction or condition of the well, or for other reasons which are outlined in Appendix E. Point sources of nitrogen can include: feedlots, subsurface sewage treatment systems, fertilizer spills, and bulk storage of fertilizer. A total of 260 (23.9 percent) wells were determined to be unsuitable and were removed from the dataset. The final well dataset had a total of 827 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 15.4 percent. Five of the sampled townships (Hyde Park, Mount Pleasant, Oakwood, Plainview, and West Albany) 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 February 2019, 306 townships in 42 counties have completed the initial sampling.

In 2017, 14 townships in Wabasha 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 Wabasha County occurred during the summer of 2018 and 2019. 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 nitrate-nitrogen results over 5 mg/L were removed from the initial dataset to form the final dataset if a potential non-fertilizer source or well problem was identified, there was insufficient information on the construction or condition of the well, or for other reasons which are outlined in Appendix E. 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

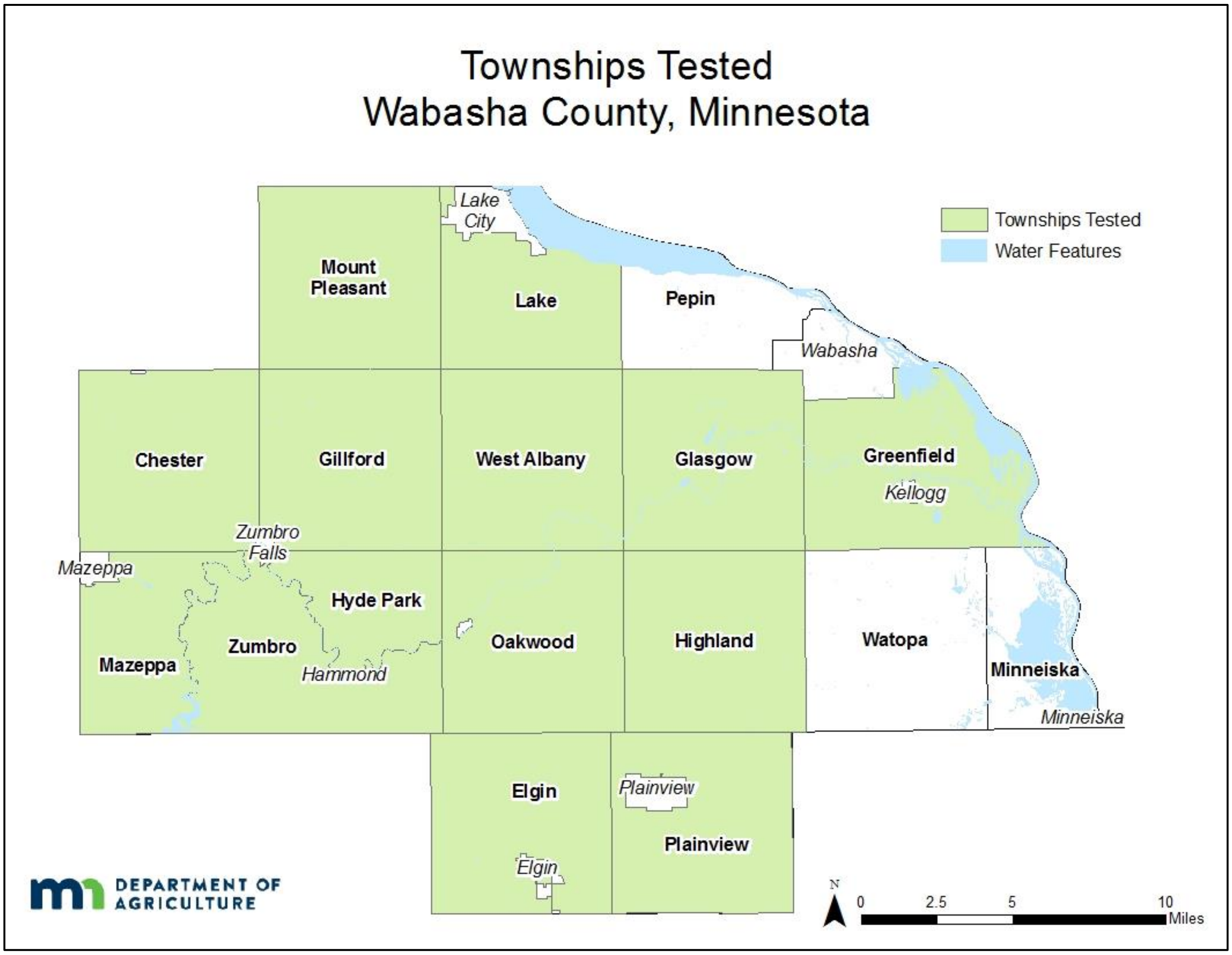


Figure 1. Townships Tested in Wabasha County

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 aquifer systems with thin to no protective unconsolidated glacial sediment or protective bedrock layers, as observed in most of Wabasha County, contaminants such as nitrate can travel quickly to the aquifers, leaving little chance for denitrification or other attenuating processes. As a result aquifers in Wabasha County that lack overlaying protective glacial sediments (Peterson, 2005), and have overlaying 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, 1999).

GEOLOGY AND HYDROGEOLOGY

Less than 2 million years ago glaciers covered much of Minnesota. As glacial lobes from the ice sheet advanced, they picked up rocks and sediment, and then deposited them as an unsorted material known as till when the ice melted. Streams of meltwater flowed from these same glaciers and deposited sorted sand, gravel, and silt which is known as outwash. This time period is known as the Pleistocene Epoch or the Ice Age and is a part of the Quaternary period. Glacial sediments deposited during the Quaternary period are referred to as Quaternary sediments or deposits (Runkel, 2002).

In many parts of modern-day Wabasha County, the unconsolidated Quaternary deposits are either thin or absent. In fact, approximately 41% of the county has 5 feet or less of unconsolidated Quaternary sediment, and 31 percent of land cover has 5-50 feet of unconsolidated Quaternary sediment overlying the bedrock (Peterson, 2005). Much of southeastern Minnesota (including Wabasha County) were not covered by glaciers during most of the ice age. Most of the Quaternary deposits are outwash from the ancient glacial river Mississippi and its tributaries which include modern day Zumbro and Whitewater River. During this time period the rivers cut deep into the banks and created modern-day blufflands which expose different layers of ancient sedimentary bedrock at the surface (Runkel, 2002).

In most of western Wabasha County there is little to no unconsolidated sediment. These areas are distinct “upland” areas as opposed to the river valley areas along the Mississippi and Zumbro Rivers. The lack of overlaying sediment makes the bedrock aquifers more sensitive to pollution (Peterson, 2005). and the uppermost bedrock is the Prairie Du Chien Group, which is comprised of the younger Shakopee formation and the older Oneota Dolomite. This bedrock group formed over 450 MYA (million years ago) when a shallow sea covered the area allowing the formation dolostone and sandstone. Karts features often occur where the Prairie Du Chien is the upper most bedrock. The next paragraph will go into further details on Karst.

Karst features can occur where there is less than 50 feet of unconsolidated material (Quaternary deposits) overlying carbonate bedrock, such as the Prairie Du Chien Group. Karst prone areas are found throughout most of Wabasha County. However, it is not present along the eastern edge where the Prairie Du Chien Group is no longer the uppermost bedrock, but instead older Cambrian sandstones and shales are the uppermost bedrock (Runkel, 2001). Karst is defined as “terrain with distinctive landforms and hydrology created primarily from the dissolution of soluble rocks”. Distinctive features such as sink holes, springs, and caves are visual evidence of karst activity on the land’s surface (Adams, Barry, and Green, 2016). Chester Township has the greatest number of sinkholes in Wabasha County (Runkel, 2001). Karst features are important when discussing groundwater because these features can allow rapid water flow from the surface to the groundwater, which can allow contaminants to move quickly as well (Adams, Barry, and Green, 2016).

Along the Mississippi and Zumbro River valleys, the overlying Quaternary deposits are relatively thick (100-300 feet thick). Therefore, the bedrock is not exposed in these areas and these deposits act as a protective cover to the bedrock aquifers below (Peterson, 2005).

The aquifer systems utilized in Wabasha County are markedly different between upland areas (mainly in the west) and river valleys along the Mississippi and Zumbro Rivers. In the upland areas, bedrock aquifers are typically utilized. The two most commonly utilized bedrock aquifers are the Jordan Sandstone, followed by the Tunnel City Group (previously known as the Franconia Formations). Along the major river valleys wells mainly utilize the unconsolidated Quaternary sand and gravel aquifers (Peterson, 2005).

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 Wabasha County as presented in Figure 2. As discussed above this figure shows that the majority of the county is “bedrock dominated”.

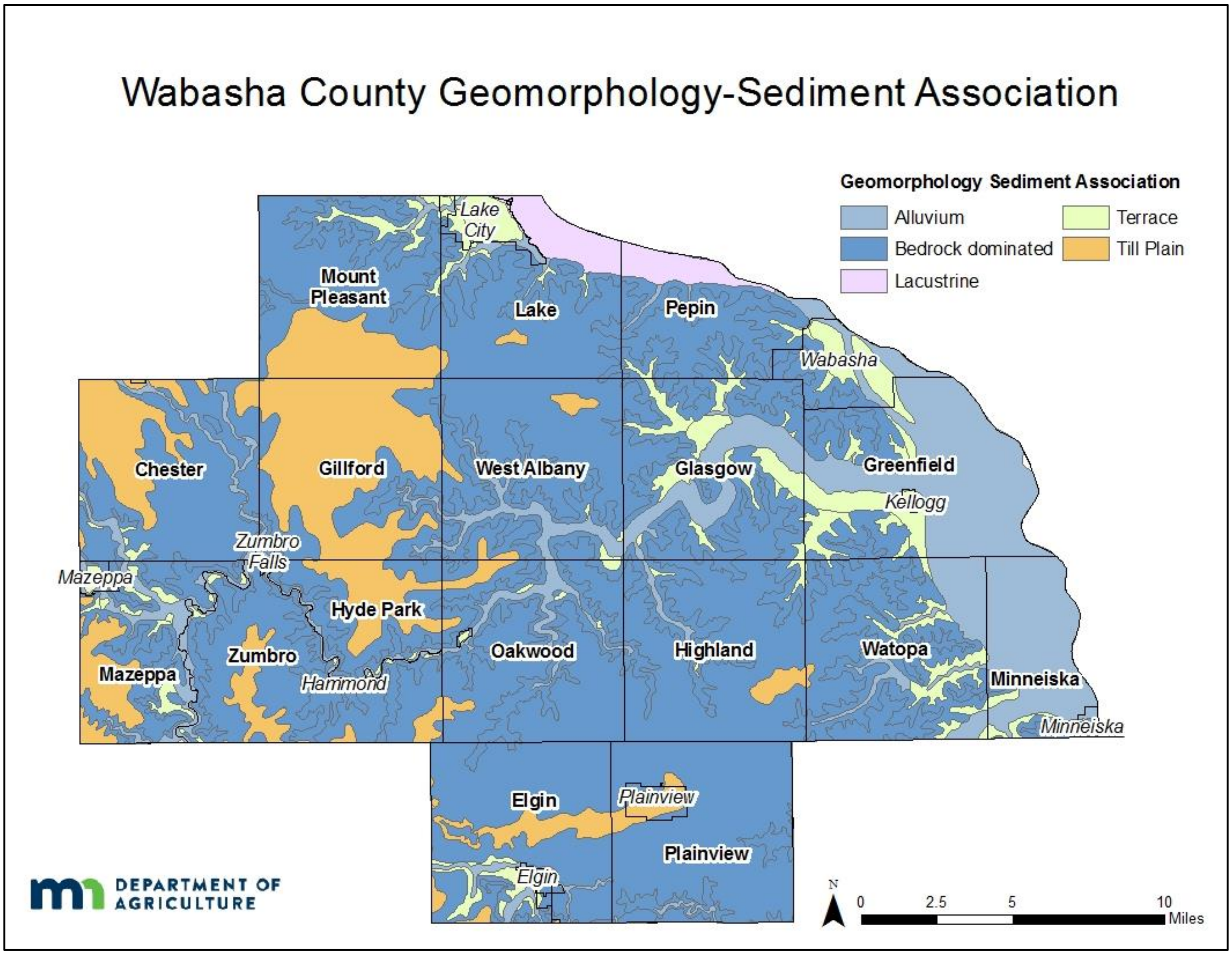


Figure 2. Statewide Geomorphology Layer, Sediment Association in Wabasha County (MDNR, MGS, and UMD, 1997)

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 Wabasha 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 4,316 SSTS were reported in Wabasha County for 2017. Over a recent 16 year period (2002-2017), 1,102 construction permits for new, replacement, or repairs for SSTS were issued. Of all the reported septic systems in Wabasha County, about 1/4th are newer than 2002 or have been repaired since 2002 (MPCA, 2018a). When new SSTS's are installed they are required to be in compliance with the rules at the time of installation. Newer systems meet modern SSTS regulations and must comply with the current well code; which requires a 50 foot horizontal separation from the well (MDH, 2014).

FEEDLOT

Manure produced on a feedlot can be a potential source of nitrogen pollution if improperly stored or spread. In the Wabasha County study area there are a total of 34 active feedlots. Approximately 38 percent of the active feedlots are permitted to house 300 or more animal units (AU) (Appendix B; Figure 9).

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 Wabasha County study area has a total of 11 fertilizer storage licenses and all are for chemigation (Appendix B; Table 11).

FERTILIZER SPILLS AND INVESTIGATIONS

A total of 7 historic fertilizer spills and investigations were recorded in the Wabasha County study area. The majority were located in Greenfield 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.

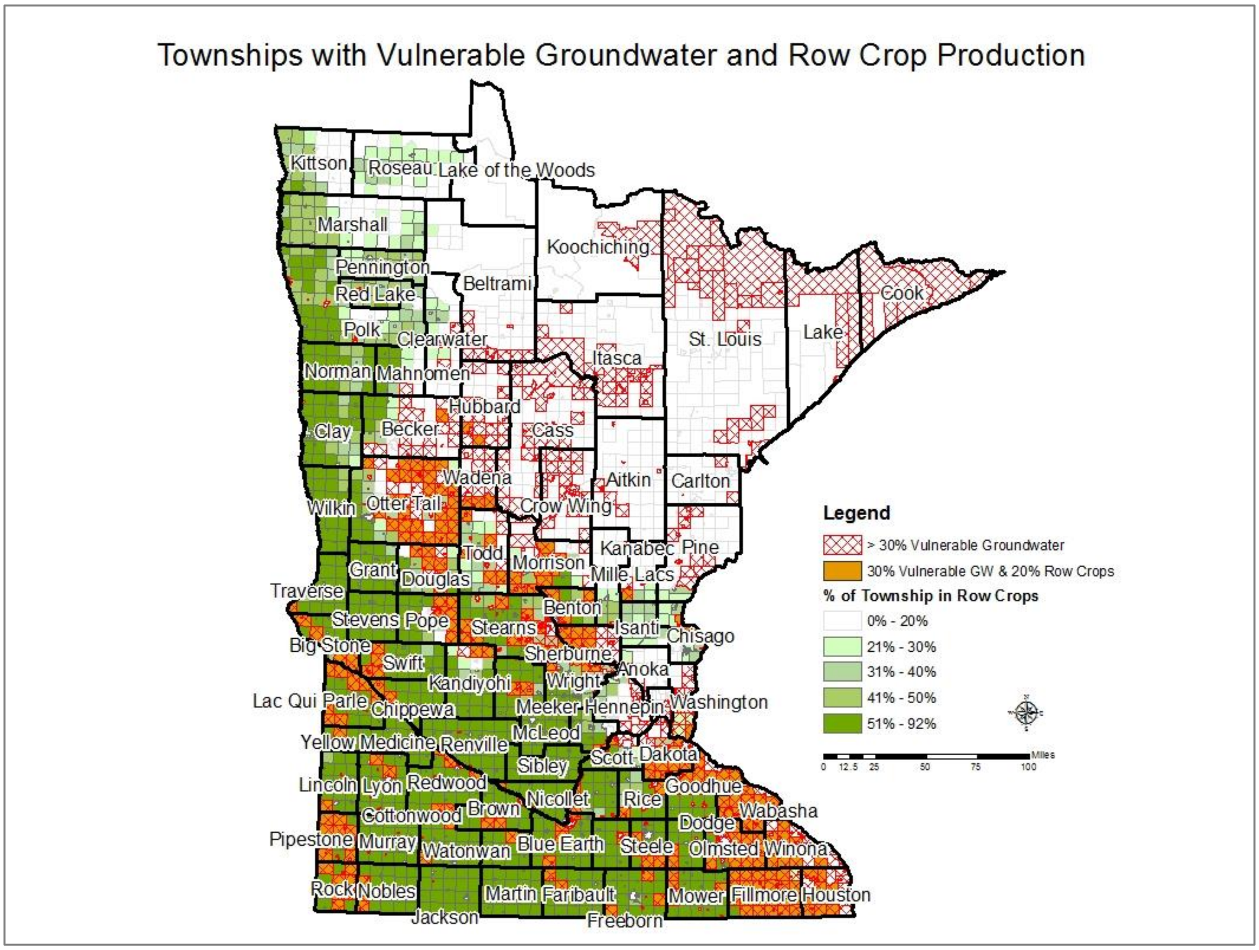


Figure 3. Minnesota Townships with Vulnerable Groundwater and Row Crop Production

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 Wabasha 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 Wabasha County can be found in Appendix C (Figure 11, Table 14). On average 40 percent of the land cover was row crop agriculture.

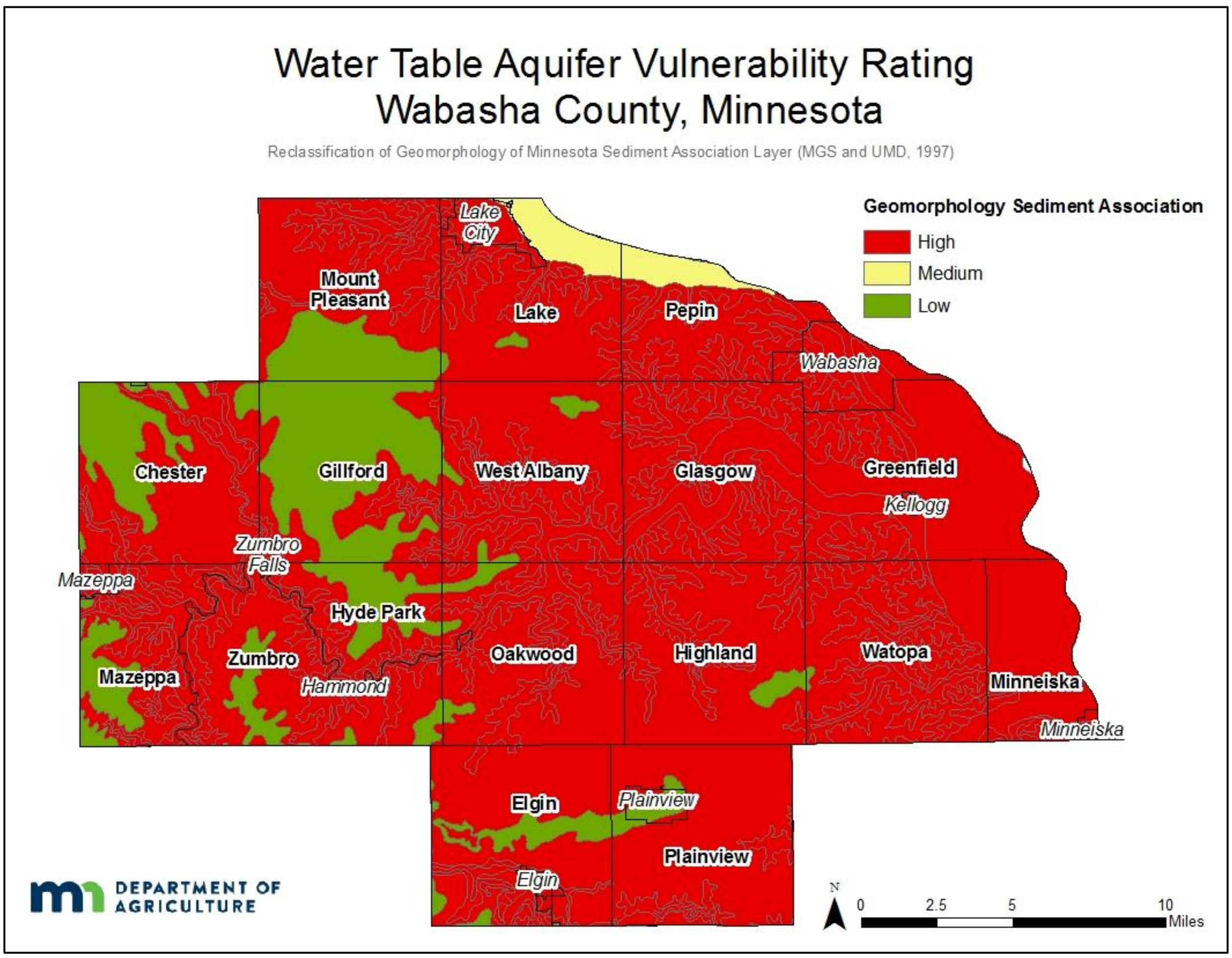


Figure 4. Water Table Aquifer Vulnerability Rating in Wabasha County

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 2017. In the initial sampling, all private well owners in the selected townships are sent a nitrate test kit. These kits include instructions on how to collect a water sample, a sample bottle, a voluntary survey (Appendix G), and a prepaid mailer. Each homeowner was mailed the nitrate result for their well along with an explanatory nitrate brochure (Appendix D). Well water samples were collected by 1,087 homeowners using the mail-in kit (Table 2). These 1,087 samples are considered the "initial well dataset". On average, 34 percent of the homeowners in these townships responded to the free nitrate test offered by MDA.

All of the homeowners with a nitrate detection from the initial sampling were asked to participate in a follow-up well site visit and sampling. The well site visits and follow-up sampling were conducted in 2018 and 2019 by MDA staff. A total of 476 follow-up samples were analyzed (Table 2).

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

Township	Kits Sent	Initial Well Dataset*	Well Site Visits & Follow-Up Sampling Conducted*
Chester	160	53	31
Elgin	276	96	37
Gillford	205	69	29
Glasgow	103	37	16
Greenfield	780	297	146
Highland	162	47	14
Hyde Park	96	38	17
Lake	175	70	27
Mazeppa	294	84	36
Mount Pleasant	161	56	30
Oakwood	145	32	14
Plainview	184	71	26
West Albany	163	37	15
Zumbro	324	100	38
Total	3,228	1,087	476

*The "Initial Well Dataset" incldues46 sites that share wells with other sites. The "Well Site Visits & Follow-Up Sampling Conducted" includes only one well site visit sample and one follow-up sample per well; even if multiple sites share the same well. Shared wells will be removed from the final well dataset, leaving only one representative result per well in the final well dataset.

Each follow-up visit was conducted at the well site by a trained MDA hydrologist. Well water was purged from the well for a minimum of 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). Starting in 2018 a digital version of this form was utilized.

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 260 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.

UNSURE OF WATER SOURCE

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

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

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

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

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.

SHARED WELL

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

INITIAL RESULTS

INITIAL WELL DATASET

A total of 1,087 well owners returned water samples for analysis across the fourteen townships (Figure 5). These wells represent the initial well dataset.

The following paragraphs provide a brief discussion of the statistics presented in Table 3.

The minimum values of nitrate for all townships were less than the detection limit (<DL) which is 0.01 mg/L or 0.03 mg/L. The maximum values range from 12.7 to 37.4 mg/L, Oakwood Township had the highest result. The mean values ranged from 2.9 to 7.2 mg/L, Plainview Township had the highest result. The 90th percentiles range from 7.2 to 17.6 mg/L, Highland Township had the highest 90th percentile.

Initial results from the sampling showed that 13 of the townships had ten percent or more of the wells at or over 10 mg/L nitrate (Figure 6). The township testing results differ from the 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).

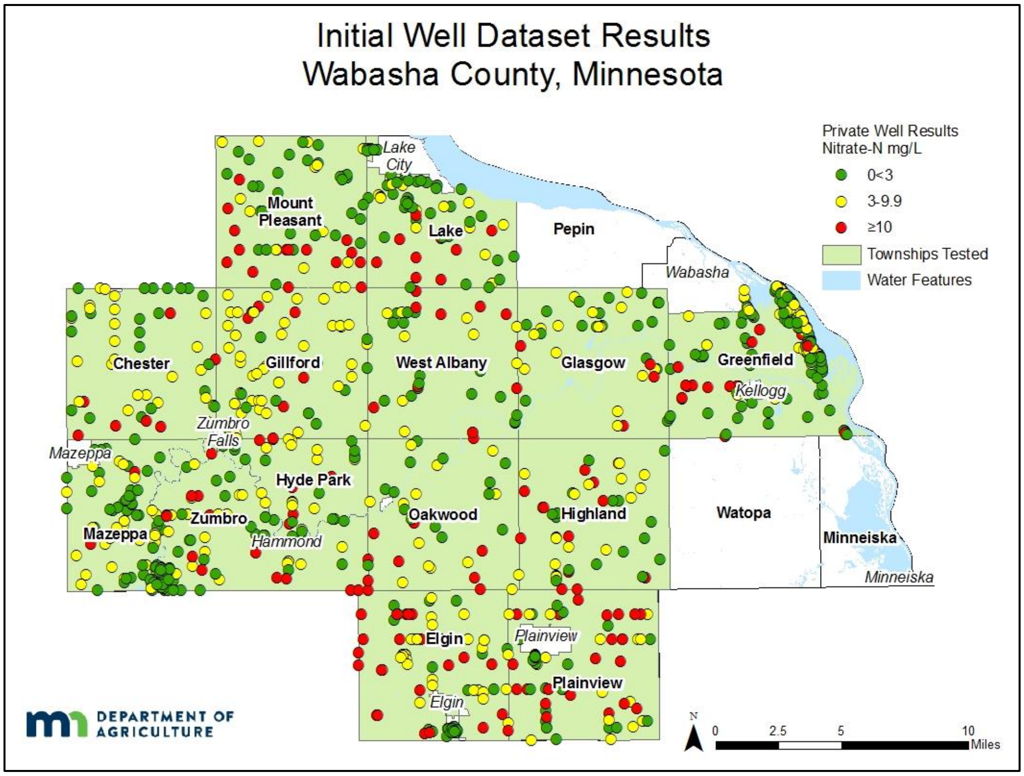


Figure 5. Well Locations and Nitrate Results from Initial Dataset in Wabasha County

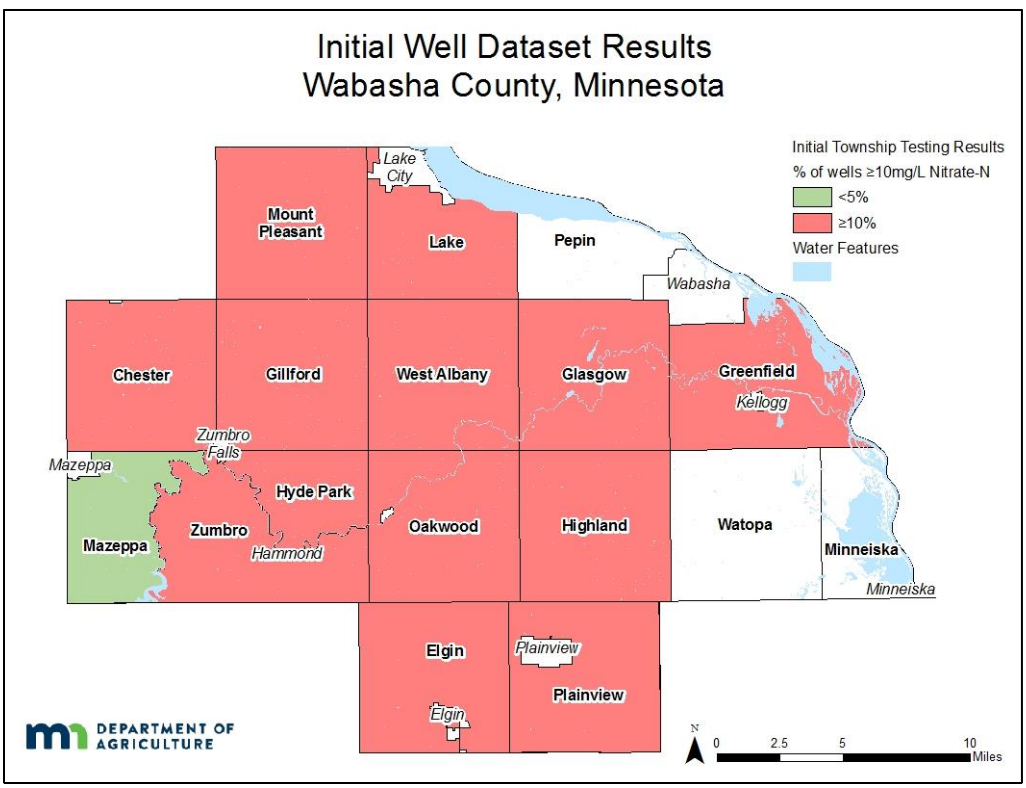


Figure 6. Results of Initial Testing by Township

Table 3. Wabasha 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																	
Chester	53	<DL	32.4	5.6	5.4	7.6	11.4	17.1	32.0	22	24	30	16	7	41.5%	45.3%	56.6%	30.2%	13.2%
Elgin	96	<DL	24.3	5.9	4.0	10.5	16.5	18.4	23.5	41	30	41	33	25	42.7%	31.3%	42.7%	34.4%	26.0%
Gillford	69	<DL	12.7	6.4	7.3	8.8	10.5	11.6	12.6	14	46	48	36	9	20.3%	66.7%	69.6%	52.2%	13.0%
Glasgow	37	<DL	27.8	5.5	3.0	7.1	10.4	24.5	27.8	18	15	15	9	4	48.6%	40.5%	40.5%	24.3%	10.8%
Greenfield	297	<DL	35.3	4.4	2.5	6.0	10.6	13.1	30.7	165	99	90	58	33	55.6%	33.3%	30.3%	19.5%	11.1%
Highland	47	<DL	23.5	6.6	5.0	9.7	17.6	20.5	23.5	20	16	24	22	11	42.6%	34.0%	51.1%	46.8%	23.4%
Hyde Park	38	<DL	21.4	4.9	3.1	6.1	11.7	21.0	21.4	19	13	15	8	6	50.0%	34.2%	39.5%	21.1%	15.8%
Lake	70	<DL	28.8	3.8	0.4	4.8	11.8	20.3	28.6	46	15	16	13	9	65.7%	21.4%	22.9%	18.6%	12.9%
Mazeppa	84	<DL	20.1	2.9	2.2	4.0	7.2	9.4	16.9	49	33	15	9	2	58.3%	39.3%	17.9%	10.7%	2.4%
Mount Pleasant	56	<DL	27.1	5.6	2.6	10.1	14.6	18.1	27.0	30	12	20	19	14	53.6%	21.4%	35.7%	33.9%	25.0%
Oakwood	32	<DL	37.4	5.8	4.3	8.0	13.9	14.3	37.4	14	13	13	9	5	43.8%	40.6%	40.6%	28.1%	15.6%
Plainview	71	<DL	31.8	7.2	6.3	11.0	16.9	18.2	31.0	27	20	37	32	24	38.0%	28.2%	52.1%	45.1%	33.8%
West Albany	37	<DL	16.3	5.5	3.9	10.4	12.6	14.0	16.3	16	10	16	14	11	43.2%	27.0%	43.2%	37.8%	29.7%
Zumbro	100	<DL	20.0	3.8	1.8	4.9	13.1	14.5	19.2	62	24	25	20	14	62.0%	24.0%	25.0%	20.0%	14.0%
Total	1,087	<DL	37.4	5.0	3.0	7.7	12.3	16.6	27.9	543	370	405	298	174	50.0%	34.0%	37.3%	27.4%	16.0%

<DL stands for less than a detectable limit. This means results are less than 0.03 mg/L or 0.01 mg/L. The 50th percentile (75th, 90th, 95th, and 99th) is the value below which 50 percent (75%, 90%, 95%, and 99%) of the observed values fall.

ESTIMATES OF POPULATION AT RISK

The human population at risk of consuming well water at or over the HRL of 10 mg/L nitrate was estimated based on the sampled wells. An estimated 1,245 people in Wabasha County's study area have drinking water over the nitrate HRL (Table 4). Nitrate contamination is a significant problem for many wells in Wabasha County.

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

Township	Estimated 2017 Households on Private Wells*	Estimated 2017 Population on Private Wells*	Estimated Population ≥10 mg/L Nitrate-N**
Chester	167	456	60
Elgin	253	709	185
Gillford	196	542	71
Glasgow	102	257	28
Greenfield	571	1,303	145
Highland	160	438	103
Hyde Park	107	264	42
Lake	170	432	56
Mazeppa	283	717	17
Mount Pleasant	158	431	108
Oakwood	147	400	63
Plainview	172	451	152
West Albany	157	384	114
Zumbro	306	719	101
Total	2,949	7,503	1,245

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

WELL SETTING AND CONSTRUCTION

MINNESOTA WELL INDEX AND WELL LOGS

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

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

In some cases, well owners were able to provide unique well identification numbers (IDs) for their wells, a well tag was located during the follow-up sampling, or unique IDs were found online. 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 293 documented wells, of those only 116 wells have a designated aquifer (Table 5). Therefore, approximately 11 percent of the sampled wells had corresponding well logs with an aquifer identified. Thus, the data gathered on aquifers represents a small portion of the total sampled wells.

The aquifers in Table 5 are arranged from the geologically youngest units on the top to the older units, except for the “multiple aquifers” and “not available” category which are at the bottom of the table. According to the well log data, the most commonly utilized aquifer in the sampled wells was from the Jordon Sandston aquifer. This predominance of this aquifers reflects the overall findings for all documented wells in the study area (Appendix F, Table 19). The average well depth was 166.6 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 Wabasha County. These are unconsolidated sand and gravel materials that were deposited by glaciers. The glacial deposits in Wabasha and in southeastern Minnesota in general are relatively thin compared to other parts of Minnesota (Runkel, 2002).

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, 1999b). 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 Unconfined (QBAA) aquifers are similar to the QWTA except that the confining materials (typically clay) are more than 10 feet thick (MPCA, 1999b).

The Prairie Du Chien Group is the uppermost bedrock aquifer present in Wabasha County. It is comprised of two formations; Lower Ordovician Oneota and Shakopee Formations. This group is mainly comprised of dolostone (carbonate rock formation) and some areas of sandstone (Runkel, 2001).

The Jordan Sandstone is a bedrock aquifer that is comprised of sandstone and is approximately 98 to 146 feet thick. It is the uppermost bedrock aquifer is significant portions of western Wabasha County where the Prairie Du Chien Group is absent (Runkel, 2001).

The St. Lawrence Formation mainly composed of dolostone and siltstone, but the upper part of this unit can be sandstone as well. This unit is between 34-74 feet thick (Runkel, 2001).

The Tunnel City (Franconia formation) is primarily composed of very fine to fine grained sandstone. There are also thin beds of shale and dolostone present in this formation, which is 150-175 feet thick (Runkel, 2001).

The Wonewoc Sandstone is comprised of fine grained to very coarse-grained sandstone that is 50-60 feet thick (formally known as Ironton Sandstone and Galesville Sandstone) (Runkel, 2001).

The Eau Claire Formation is the next deepest formation, but no wells from the township testing program were completed in this formation. It is not commonly utilized as an aquifer and it is composed of sandstone, siltstone, and shale beds.

The Mt. Simon Sandstone is the deepest aquifer utilized in Wabasha County. It is a fine to course grained sandstone comprised of quartz sand. This aquifer is 250-280 feet thick and unlike all the geological layers listed above, it does not appear in outcrops at the surface in Wabasha County (Runkel, 2001).

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	29	67.7	10	17	2	34.5%	58.6%	6.9%
Quaternary Buried Unconfined	1	120.0	0	1	0	0.0%	100.0%	0.0%
Prairie Du Chien Group	8	298.8	5	2	1	62.5%	25.0%	12.5%
Jordan Sandstone	38	322.0	12	23	3	31.6%	60.5%	7.9%
St. Lawrence Formation	4	305.0	1	3	0	25.0%	75.0%	0.0%
Tunnel City	29	333.4	2	27	0	6.9%	93.1%	0.0%
Wonewoc Sandstone	5	161.5	1	4	0	20.0%	80.0%	0.0%
Mt. Simon Sandstone	1	230.0	0	1	0	0.0%	100.0%	0.0%
Multiple	1	480.0	1	0	0	100.0%	0.0%	0.0%
Not Available	177	142.9	51	116	10	28.8%	65.5%	5.6%
Total	293	166.6	83	194	16	28.3%	66.2%	5.5%

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 2017 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 Gillford, Glasgow, and Mount Pleasant Townships over 90 percent of the homeowners responded that their well was in the country. In the Township of Greenfield over 40 percent of the homeowners responded that their well was located on a river home property.

Approximately 73 percent of sampled wells are of drilled construction and 6.4 percent are sand point wells. The majority of sand point wells were in Greenfield Township. 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. Less than one percent of the sampled wells were hand dug wells.

Most of the sampled wells are over 300 feet deep, and very few wells (0.5%) are under 15 feet deep. Approximately 25.7 percent of homeowners did not know or did not respond to this question.

Most of the wells (58.4 percent) had not been tested for nitrate within the last ten years or homeowners were unsure if they had been tested. Only five percent of homeowners responded that their well had been tested for nitrate in the last year. Additionally, 77.6 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 35 percent of the properties.
- Agricultural fields are less than 50 feet from the well at 5.4 percent of the properties.
- The majority of well owners (74.4 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 9 percent of wells are less than 100 feet from an active or inactive feedlot.
- Very few well owners (2.0 percent) across all townships store more than 500 pounds of fertilizer on their property.
- A small percent of wells (2.4 percent) are less than 50 feet away from septic systems.

FINAL RESULTS

FINAL WELL DATASET

A total of 1,087 well water samples were collected by homeowners across 14 townships. 260 wells (23.9 percent) were found to be unsuitable and were removed to create the final well dataset. The final analysis was conducted on the remaining 827 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 and Figure 8 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 15.4 percent.

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

Township	Initial Well Dataset	Final well Dataset	Final Wells ≥10 mg/L Nitrate-N	
			Count	Percentage
Chester	53	41	3	7.3%
Elgin	96	60	5	8.3%
Gillford	69	32	0	0.0%
Glasgow	37	30	1	3.3%
Greenfield	297	263	22	8.4%
Highland	47	27	2	7.4%
Hyde Park	38	30	4	13.3%
Lake	70	54	1	1.9%
Mazeppa	84	69	0	0.0%
Mount Pleasant	56	43	5	11.6%
Oakwood	32	26	4	15.4%
Plainview	71	43	5	11.6%
West Albany	37	25	3	12.0%
Zumbro	100	84	5	6.0%
Total	1,087	827	60	7.3%

The individual nitrate results from this final well dataset are displayed spatially in Figure 7. Due to the inconsistencies with geocoding the locations, the accuracy of the points is variable.

The final well dataset summary statistics are shown in Table 7. The minimum values were all below the detection limit (<DL). The maximum values ranged from 9.4 to 37.4 mg/L nitrate, with Oakwood Township having the highest result. The 90th percentile ranged from 4.3 to 13.8 mg/L nitrate-N, with Lake Township having the lowest result and Oakwood Township having the highest result.

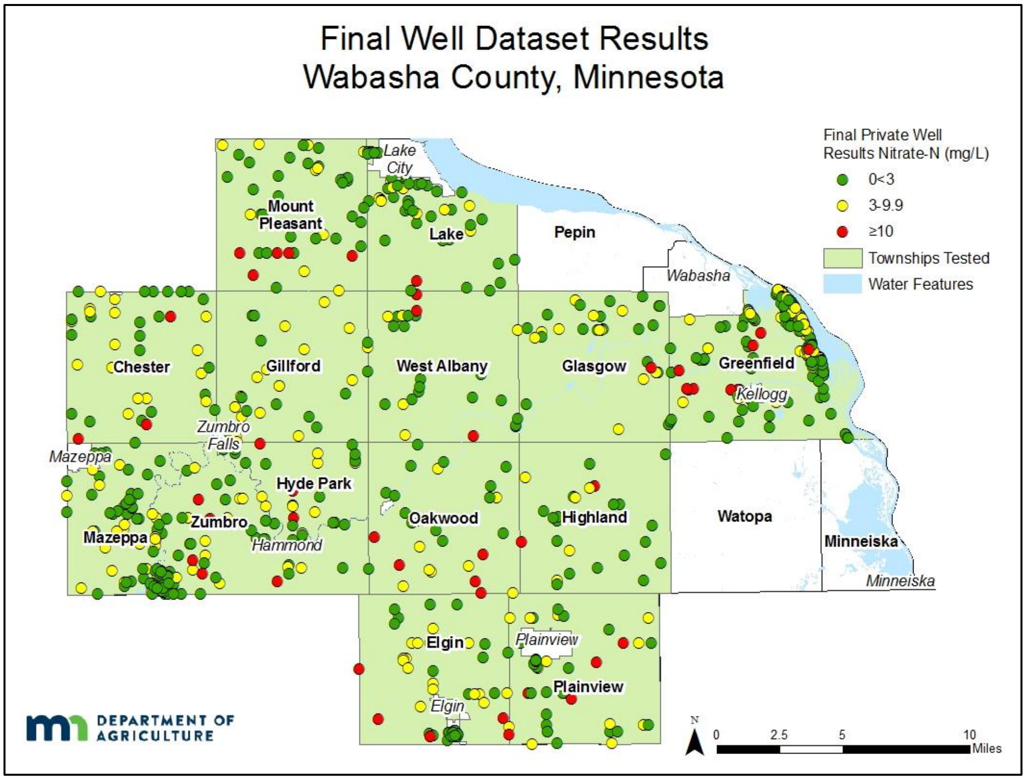


Figure 7. Well Locations and Nitrate Results from Final Well Dataset in Wabasha County

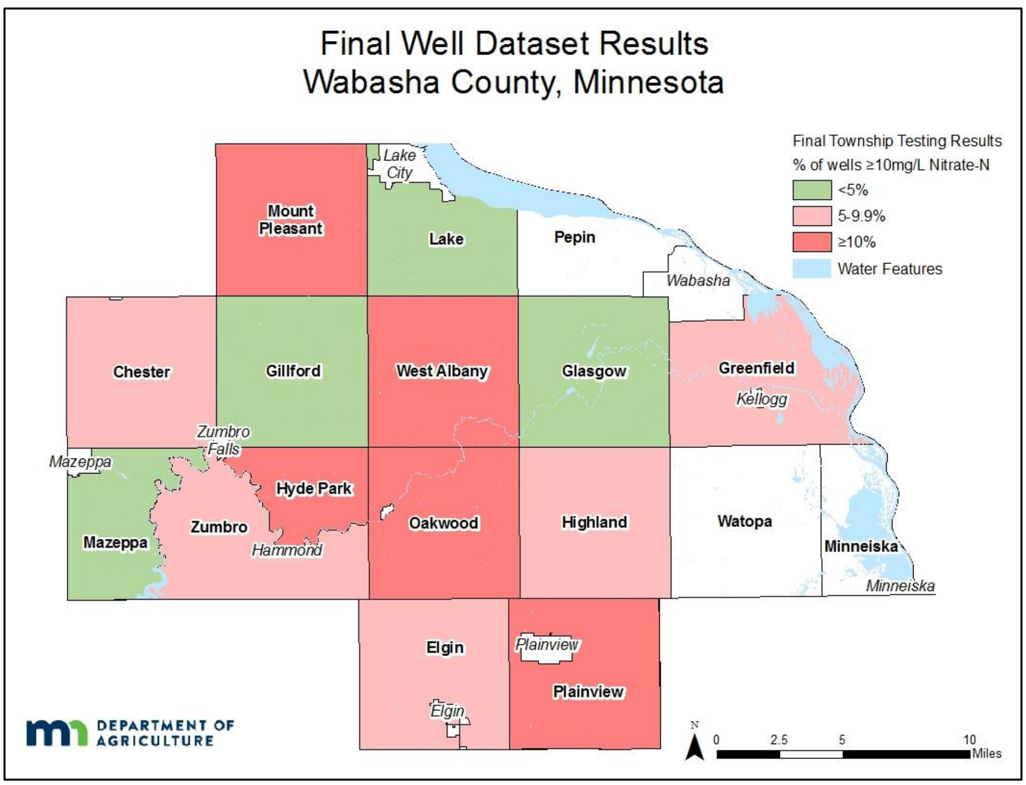


Figure 8. Results of Final Testing by Township

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

Township	Total Wells	Values			Percentiles					Number of Wells					Percent of Wells				
		Min	Max	Mean	50^{th} (Median)	75^{th}	90^{th}	95^{th}	99^{th}	<3	3<10	≥5	≥7	≥10	<3	3<10	≥5	≥7	≥10
		Nitrate-N mg/L or parts per million (ppm)																	
Chester	41	<DL	32.4	4.3	2.8	6.3	8.3	11.4	32.4	22	16	18	8	3	53.7%	39.0%	43.9%	19.5%	7.3%
Elgin	60	<DL	17.5	2.9	1.2	4.1	8.2	11.8	17.3	39	16	11	9	5	65.0%	26.7%	18.3%	15.0%	8.3%
Gillford	32	<DL	9.5	3.7	3.7	7.0	7.8	8.3	9.5	14	18	11	7	0	43.8%	56.3%	34.4%	21.9%	0.0%
Glasgow	30	<DL	27.8	3.8	2.5	5.6	8.1	9.3	27.8	18	11	8	4	1	60.0%	36.7%	26.7%	13.3%	3.3%
Greenfield	263	<DL	35.3	3.6	2.0	4.3	8.4	11.5	30.9	164	77	57	32	22	62.4%	29.3%	21.7%	12.2%	8.4%
Highland	27	<DL	20.0	2.6	0.3	3.4	7.8	13.7	20.0	20	5	4	3	2	74.1%	18.5%	14.8%	11.1%	7.4%
Hyde Park	30	<DL	21.4	3.9	1.6	4.9	11.4	21.2	21.4	19	7	7	4	4	63.3%	23.3%	23.3%	13.3%	13.3%
Lake	54	<DL	13.9	1.5	0.04	2.8	4.3	5.2	13.6	43	10	3	1	1	79.6%	18.5%	5.6%	1.9%	1.9%
Mazeppa	69	<DL	9.4	2.2	1.9	3.6	4.9	7.1	9.4	46	23	6	3	0	66.7%	33.3%	8.7%	4.3%	0.0%
Mount Pleasant	43	<DL	25.2	3.5	1.5	4.1	11.7	15.6	25.2	29	9	8	7	5	67.4%	20.9%	18.6%	16.3%	11.6%
Oakwood	26	<DL	37.4	5.1	2.4	5.9	13.8	18.9	37.4	14	8	7	4	4	53.8%	30.8%	26.9%	15.4%	15.4%
Plainview	43	<DL	17.4	3.7	2.7	6.0	10.8	13.3	17.4	25	13	11	9	5	58.1%	30.2%	25.6%	20.9%	11.6%
West Albany	25	<DL	16.3	3.1	1.8	4.0	10.0	12.2	16.3	16	6	4	4	3	64.0%	24.0%	16.0%	16.0%	12.0%
Zumbro	84	<DL	20.0	2.5	1.1	3.2	5.4	12.4	18.7	61	18	11	7	5	72.6%	21.4%	13.1%	8.3%	6.0%
Total	827	<DL	37.4	3.3	1.8	4.2	8.0	11.7	26.8	530	237	166	102	60	64.1%	28.7%	20.1%	12.3%	7.3%

<DL stands for less than detectable limit. The detectable limit is 0.01 and 0.03 nitrate-N. The 50^{th} percentile (75^{th}, 90^{th}, 95^{th}, and 99^{th}, respectively) is the value below which 50 percent (75%, 90%, 95% and 99%) of the observed values fall

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

Table 8. Township Nitrate Results Related to Vulnerable Geology and Row Crop Production, Wabasha 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)	
Chester	41	51%	71.5%	19.5%	7.3%
Elgin	60	70%	87.7%	15.0%	8.3%
Gillford	32	49%	32.2%	21.9%	0.0%
Glasgow	30	22%	100.0%	13.3%	3.3%
Greenfield	263	25%	99.7%	12.2%	8.4%
Highland	27	36%	96.5%	11.1%	7.4%
Hyde Park	30	37%	61.6%	13.3%	13.3%
Lake	54	29%	82.0%	1.9%	1.9%
Mazeppa	69	27%	76.5%	4.3%	0.0%
Mount Pleasant	43	52%	74.8%	16.3%	11.6%
Oakwood	26	34%	95.6%	15.4%	15.4%
Plainview	43	56%	97.8%	20.9%	11.6%
West Albany	25	28%	96.1%	16.0%	12.0%
Zumbro	84	35%	87.0%	8.3%	6.0%
Total	827	39%	82.8%	12.3%	7.3%

*Data retrieved from USDA NASS Cropland Data Layer, 2013

WELL AND WATER CHARACTERISTICS

WELL CONSTRUCTION

Unique identification numbers from well logs were compiled for the wells in the Wabasha 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 (84 percent), and only 52 wells (6 percent) were identified as sand point wells.
- The median depth of wells was 150 feet, and the deepest was 620 feet.
- The median year the wells were constructed in was 2002. It is important to note that this data was compiled from well logs only; the homeowner responses are not included. Most wells do not have a well log if they were constructed before 1974.

WELL WATER PARAMETERS

MDA staff conducted the follow-up sampling and well site surveys at 476 wells. Only 402 follow-up wells are included in the final well dataset, 11 of these did not have field measurements collected, and 12 did not have specific conductivity measures recorded. Field measurements of the well water parameters were recorded on the first page of the Private Well Field Log & Well Survey Form (Appendix J). The measurements included temperature, pH, specific conductivity, and dissolved oxygen. The well was purged for 15 minutes, so that the measurements stabilized, ensuring a fresh sample of water was collected. The stabilized readings for the final well dataset are described below and a more comprehensive view is available in Appendix K (Tables 38-41).

- The temperatures ranged from 8.54 °C to 17.66 °C
- The median specific conductivity was 530 µS/cm, and was as high as 1,242 µS/cm
- The water from the wells had a median pH of 7.59
- The dissolved oxygen readings ranged from 0.08 mg/L to 16.36 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 Wabasha County. In order to prioritize testing, the MDA looked at townships with significant row crop production and vulnerable geology. Approximately 40 percent of the land cover is row crop agriculture and there are very few acres (1,710 acres, <1 percent of land cover) of groundwater irrigation in the study area.

Fourteen townships were sampled covering over 291,179 acres. The initial (homeowner collected) nitrate sampling resulted in 1,087 samples. The 1,087 households that participated represent an approximately 34 percent return rate of homeowner offered sampling kits. The initial well dataset represents private well drinking water regardless of the potential source of nitrate. Well owners with measurable nitrate results were offered a follow-up nitrate sample and a pesticide sample. The MDA visited and collected follow-up samples at 476 wells.

The MDA conducted a nitrogen source assessment and identified wells near potential point sources and wells with poor construction. A total of 260 (23.9 percent) wells were found to be unsuitable and were removed from the final well dataset of 827 wells. The remaining 827 wells were wells believed to be impacted by nitrogen fertilizer and were included in the final well dataset.

In the final well dataset, most of the wells (84 percent) are drilled; and about six percent are sand points. The median depth of the wells is 150 and depths range from 45 to 620 feet deep.

For the final well dataset, five 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 15.4 percent.

REFERENCES

Adams, R., Barry, J., Green, J. (2016). Minnesota regions prone to surface karst feature development: St. Paul, Minnesota Department of Natural Resources, Ecological and Water Resources Division, Series GW-01. Retrieved from http://water.usgs.gov/nawqa/nutrients/pubs/circ1350.

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 http://water.usgs.gov/nawqa/nutrients/pubs/circ1350.

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 https://www.health.state.mn.us/communities/environment/water/docs/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]. (1999a). Baseline Water Quality of Minnesota's Principal Aquifers, Region 5, Southeast Minnesota. Retrieved from www.pca.state.mn.us/sites/default/files/baselinese-rpt.pdf.

Minnesota Pollution Control Agency [MPCA]. (1999b). Baseline Water Quality of Minnesota's Principal Aquifers, Region 6, Twin Cities Metropolitan Region. Retrieved from https://dehs.umn.edu/sites/dehs.umn.edu/files/19990101_mpca_baselinegwreport_metroarea.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]. (2013). *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). *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]. (2017b). *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]. (2018a). *2017 SSTS Annual Report, Subsurface Sewage Treatment Systems in Minnesota*. St. Paul, MN: Minnesota Pollution Control Agency. Retrieved from https://www.pca.state.mn.us/water/ssts-annual-report.

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

Minnesota Pollution Control Agency [MPCA]. (2019). 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 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.

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. (2005). C-14 Geologic atlas of Wabasha County, Minnesota [Part B] . Minnesota Geological Survey. Retrieved from https://www.dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/wabacga.html.

Runkel, A.C. (2001). C-14 Geologic atlas of Wabasha County, Minnesota [Part A]. Minnesota Geological Survey. Retrieved from the University of Minnesota Digital Conservancy., http://hdl.handle.net/11299/58557.

Runkel, A. C. (2002). Contributions to the Geology of Wabasha County, Minnesota. Minnesota Geological Survey Report of Investigations. Retrieved from http://hdl.handle.net/11299/58807

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

Wabasha County (2014). *Subsurface Sewage Treatment System Ordinance Wabasha County*. Retrieved from https://www.co.wabasha.mn.us/index.php/documents/auditortreasurer/918-wabasha-county-ordinances

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 ______________________________

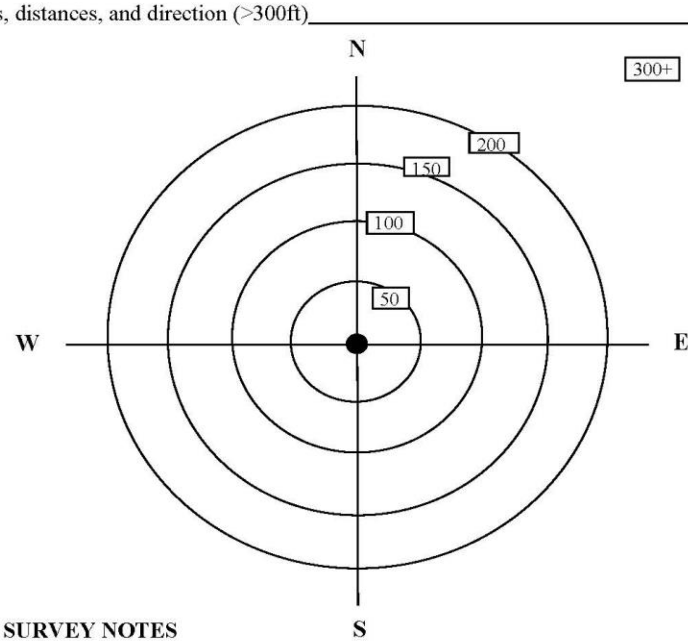
MDA -Private Well Field Log & Well Survey Form

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. 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, 2019.

In the 2017 SSTS Annual Report Minnesota reported a 53,000 SSTS from 211 different local government units including 83 counties. Wabasha County reported a total of 4,316 SSTS and 1.7 percent of existing SSTS were inspected for compliance (MPCA, 2018a). Compliance inspections are conducted in Wabasha County for all newly constructed and replacement SSTS, or if an existing SSTS needs a building permit, the use of the building changes or expands and may impact the SSTS performance, when a construction permit is required for the SSTS, or anytime deemed appropriate such as a complaint. Some counties also require an inspection upon property transfers, but Wabasha County does not have this requirement. If a SSTS is found to be FTPGW or and ITPHS then the system must be upgraded, repaired or abandoned, within 10 months for FTPGW and 30 days for ITPHS, upon notice of noncompliance (Wabasha County, 2014).

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, 2013).

Government agencies regulate feedlots to reduce the risk of contamination to water resources. Rules pertaining to feedlots have been in place since the 1970’s; they were revised in 2000 and 2014

(MPCA, 2017b). The degree of regulation of a feedlot is dependent on the amount of manure that is produced; measured in animal units (AU) (MPCA, 2011). One AU is equal to the amount of manure produced by one beef cow (Table 9) (MPCA, 2017b).

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

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

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

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

As part of new feedlot construction, an environmental assessment must be completed for feedlots with a proposed capacity of greater than 1,000 AU. If the feedlot is located in a sensitive area the requirement for an environmental assessment is 500 AU (MPCA, 2017b). Farmers must register their feedlot if it is in active status. Feedlots are considered active until no animals have been present on the feedlot for at least five years. To register, farmers fill out paperwork which includes a chart with the type and maximum number of animals on the feedlot (MPCA, 2017a). Registration is required to be completed at least once during a set four year period, the current period runs from January 2018 to December 2021. As of November 2017, approximately 24,000 feedlots were registered in Minnesota (MPCA, 2017b). A map and table of the feedlots located in the Wabasha County study area can be found below (Figure 9; Table 10).

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

Township	Total Feedlots	Active Feedlots	Inactive Feedlots	Average AU Permitted** Per Feedlot	Total Permitted** AU	Total Square Miles	Permitted** AU per Square Mile
Chester	82	7	75	658	4,605	35.5	130
Elgin	37	0	37	0	0	34.5	0
Gillford	70	6	64	247	1,479	35.4	42
Glasgow	38	0	38	0	0	35.5	0
Greenfield	21	0	21	0	0	37.8	0
Highland	62	2	60	446	892	35.8	25
Hyde Park	24	2	22	352	704	16.0	44
Lake	35	1	34	220	220	29.4	7
Mazeppa	25	0	25	0	0	22.0	0
Mount Pleasant	63	3	60	488	1,464	36.0	41
Oakwood	55	3	52	107	320	35.7	9
Plainview	64	5	59	180	899	33.4	27
West Albany	51	4	47	102	408	35.7	11
Zumbro	35	1	34	48	48	32.1	1
Total	662	34	628	325*	11,040	454.9	24*

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

On average there are 24 AU per square mile (0.04 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 Wabasha County study area livestock densities average 0.10 AU per acre of row crops (MPCA, 2018b; USDA NASS, 2013).

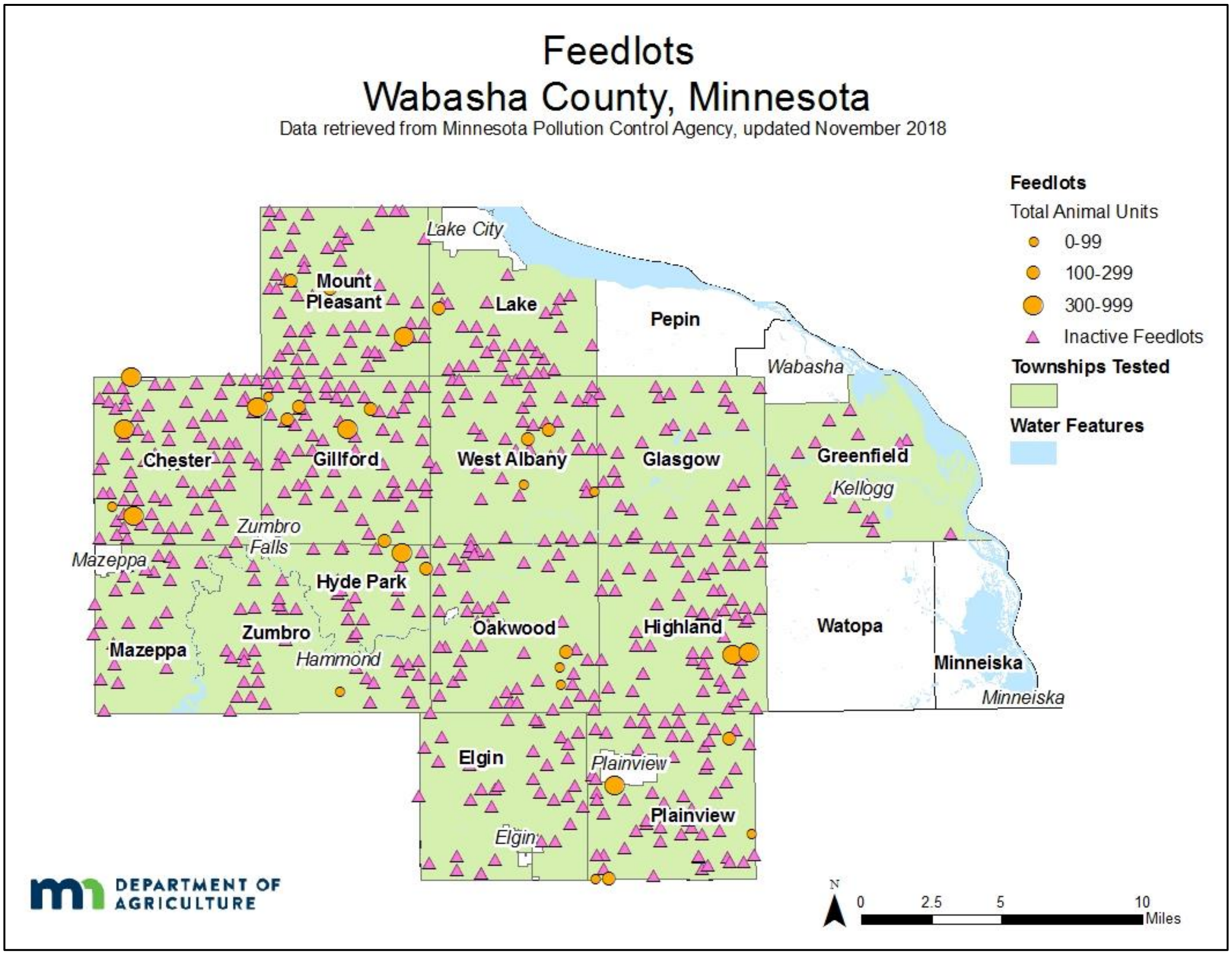


Figure 9. Feedlot Locations in Wabasha County (MPCA, 2018b)

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, Wabasha County

Township	Bulk Fertilizer Facility	Anhydrous Ammonia	Abandoned Sites	Chemigation Sites	Total
Chester	0	0	0	0	0
Elgin	1	0	0	0	1
Gillford	0	0	1	0	1
Glasgow	0	0	0	1	1
Greenfield	2	1	0	0	3
Highland	0	0	0	0	0
Hyde Park	0	0	0	0	0
Lake	0	0	0	0	0
Mazeppa	0	0	0	0	0
Mount Pleasant	0	0	1	0	1
Oakwood	0	0	0	0	0
Plainview	1	1	1	0	3
West Albany	0	0	0	0	0
Zumbro	1	0	0	0	1
Total	5	2	3	1	11

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

SPILLS AND INVESTIGATIONS

The MDA is responsible for investigating any fertilizer spills within Minnesota. Figure 10 shows the locations of mapped historic fertilizer spills within the Wabasha 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 two incident investigations, and no contingency areas in this study area. Old emergency incidents were closed prior to March 1st, 2004 (MDA, 2017), but they can still be a point source. At most of these older sites, the contaminants are unknown and their location may not be precise. There is one located in the study area. Small spills and investigations are typically smaller emergency spills such as a truck spilling chemicals. There are four located 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, Wabasha County

Contaminant	Incident Investigations	Contingency Areas	Small Spills and Investigations	Old Emergency Incidents	Total
Fertilizer	0	0	1	1	2
Pesticides & Fertilizer	2	0	0	0	2
Anhydrous Ammonia	0	0	3	0	3
Total	2	0	4	1	7

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

Township	Incidents and Spills
Chester	0
Elgin	1
Gillford	0
Glasgow	0
Greenfield	5
Highland	0
Hyde Park	0
Lake	1
Mazeppa	0
Mount Pleasant	0
Oakwood	0
Plainview	0
West Albany	0
Zumbro	0
Total	7

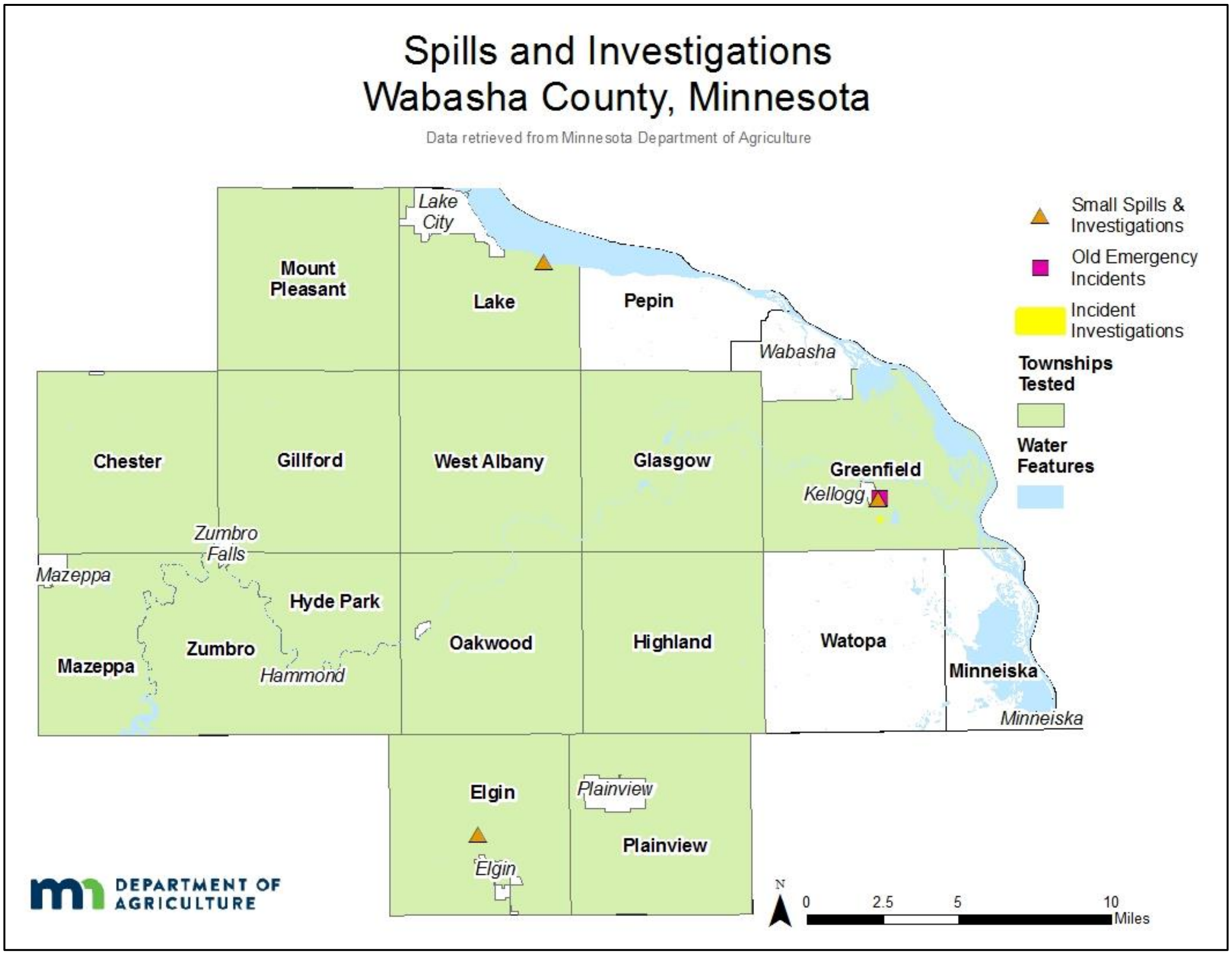


Figure 10. Fertilizer Spills and Investigations in Wabasha County (MDA, 2017)

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. Wabasha County is located in southeast Minnesota and has a significant amount of land devoted to row crop agriculture (Figure 11; 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.

Wabasha County abuts the Mississippi River and Wisconsin boarder to the east. Townships along this border have a higher percentage of water in their land cover. For instance, Lake Township has the highest percentage of open water at 16 percent and in Greenfield has the most wetland land cover at 18 percent. Across all the townships 40 percent of the land is considered row crops, making it the dominate landscape in this county. Forests are also an important feature in these townships. Overall 20 percent of the land is considered forested. Relatively little land (4%) in the study area is considered developed.

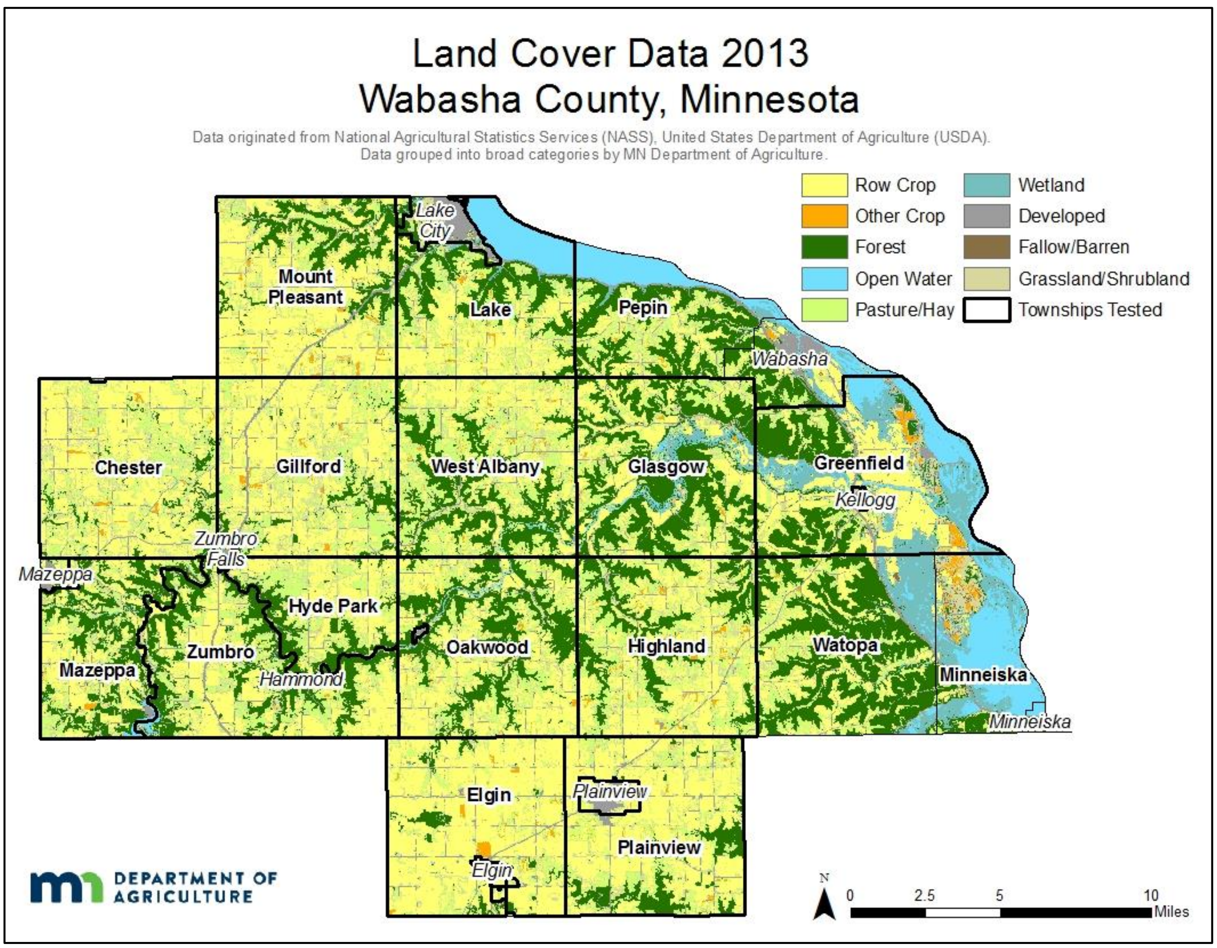


Figure 11. Land Cover in Wabasha County (USDA NASS Cropland Data Layer, 2013)

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

Township	Total Acres	Row Crop	Other Crops	Forest	Open Water	Pasture/ Hay	Wetland	Developed	Fallow/ Barren	Grassland/ Shrubland
Chester	22,701	51%	1%	5%	0%	22%	0%	4%	0%	17%
Elgin	22,091	70%	2%	5%	0%	11%	0%	4%	0%	8%
Gilford	22,684	49%	1%	7%	0%	23%	0%	5%	0%	15%
Glasgow	22,744	22%	1%	41%	1%	17%	5%	3%	0%	10%
Greenfield	24,203	25%	2%	21%	13%	6%	18%	5%	0%	9%
Highland	22,891	36%	2%	22%	0%	25%	0%	3%	0%	12%
Hype Park	10,280	37%	0%	20%	1%	23%	0%	5%	0%	14%
Lake	18,844	29%	1%	22%	16%	18%	1%	3%	0%	9%
Mazeppa	14,104	27%	1%	34%	2%	18%	1%	4%	0%	14%
Mount Pleasant	23,031	52%	2%	16%	0%	14%	0%	4%	0%	11%
Oakwood	22,827	34%	1%	28%	0%	22%	0%	3%	0%	12%
Plainview	21,369	56%	1%	12%	0%	17%	0%	4%	0%	10%
West Albany	22,834	28%	1%	26%	0%	28%	0%	3%	0%	13%
Zumbro	20,575	35%	0%	27%	2%	19%	1%	4%	0%	12%
Average	291,179*	40%	1%	20%	3%	19%	2%	4%	0%	12%

*Represents a Total

WATER USE

Water use permits are required for wells withdrawing more than 10,000 gallons of water per day or 1,000,000 gallons of water per year (MDNR, 2018). There are a total of 35 active groundwater well permits in the study area, 16 of which are used for agricultural irrigation (Figure 12). About 1,710 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, Wabasha County

Township	Major Crop Irrigation Well Permits	Average Depth (feet)	Irrigated Acres Permitted
Chester	0	0	0
Elgin	0	0	0
Gilford	0	0	0
Glasgow	2	152	149
Greenfield	13	189	1,501
Highland	0	0	0
Hyde Park	0	0	0
Lake	1	580	60
Mazeppa	0	0	0
Mount Pleasant	0	0	0
Oakwood	0	0	0
Plainview	0	0	0
West Albany	0	0	0
Zumbro	0	0	0
Total	16	209*	1,710

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

Water Use Well Permits	Total	Average Depth (feet)	Aquifer			
			Quaternary Water Table	Quaternary Buried	Paleozoic	Not Classified
Agricultural Irrigation	16	209	9	4	3	16
Water Supply	1	186	0	1	0	1
Industrial Processing	5	309	0	5	0	5
Special Categories	13	431	0	5	8	13
Total	35	305	9	15	11	35

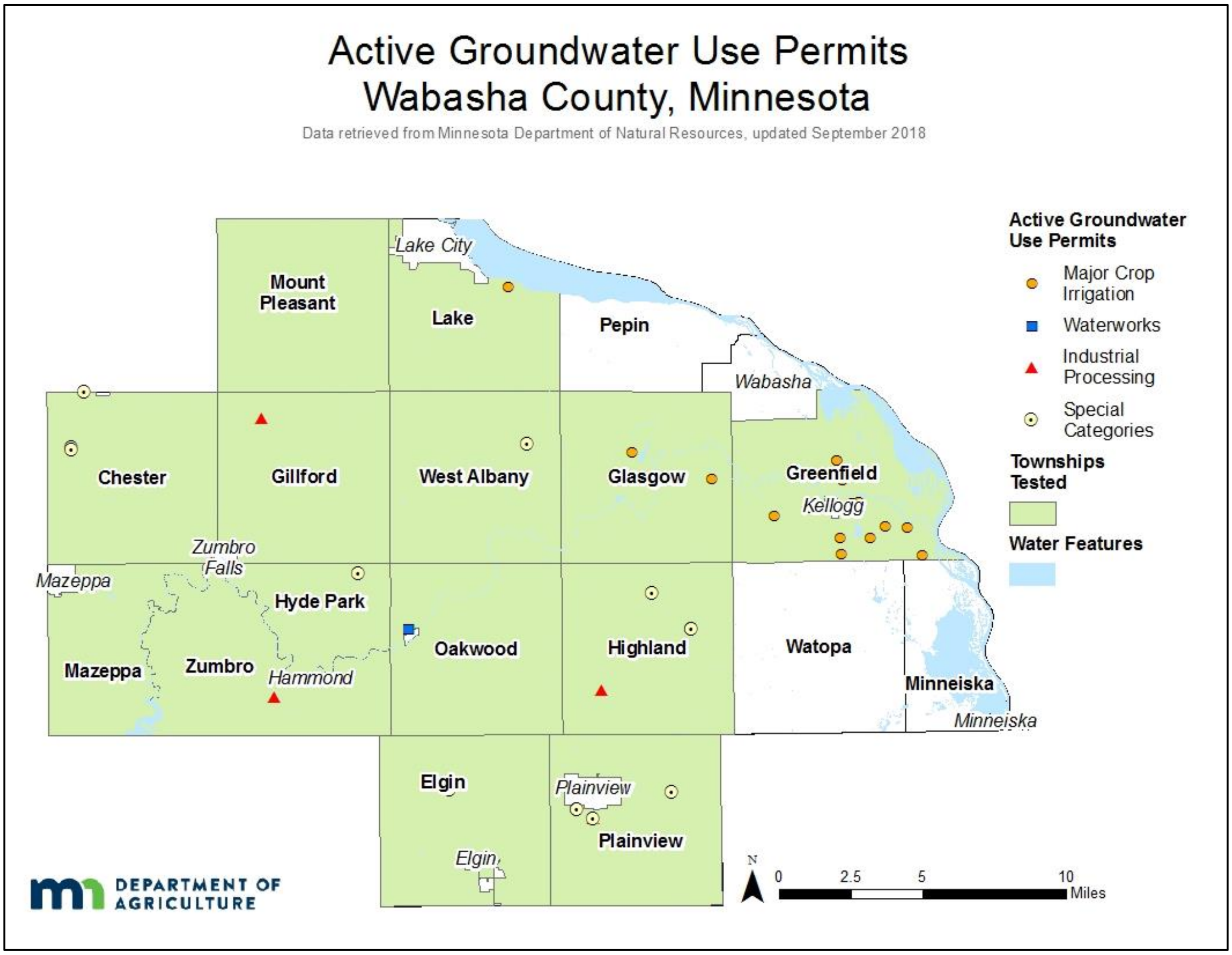


Figure 12. Active Groundwater Use Permits in Wabasha County (MDNR, 2017)

APPENDIX D

Nitrate Brochure

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

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

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

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

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

If the Nitrate result is above 10 mg/L:

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

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

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

APPENDIX E

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

Township	Point Source	Well Construction Problem	Hand Dug well	Unsure of water source	Site Visit Completed - Well Not Found & Constructed before 1975 or Age Unknown & No Well ID	No Site Visit & Constructed before 1975 or Age Unknown & No Well ID	No Site Visit & Insufficient Data & No Well ID	Shared Well	Total
Chester	1	3	0	0	0	6	1	1	12
Elgin	8	5	0	2	3	7	2	9	36
Gillford	9	1	0	0	6	21	0	0	37
Glasgow	2	1	0	1	0	3	0	0	7
Greenfield	8	2	0	2	5	9	6	2	34
Highland	1	2	0	0	3	11	2	1	20
Hyde Park	0	1	0	0	0	7	0	0	8
Lake	3	2	0	0	2	6	0	3	16
Mazeppa	1	0	0	0	4	4	0	6	15
Mount Pleasant	2	3	1	1	1	4	1	0	13
Oakwood	0	0	1	0	1	3	1	0	6
Plainview	4	3	0	0	2	16	1	2	28
West Albany	1	1	0	1	1	4	4	0	12
Zumbro	3	1	0	0	1	8	1	2	16
Total	43	25	2	7	29	109	19	26	260

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

Township	Site Visit	No Site Visit	Total
Chester	4	8	12
Elgin	21	15	36
Gillford	11	26	37
Glasgow	2	5	7
Greenfield	12	22	34
Highland	6	14	20
Hyde Park	1	7	8
Lake	9	7	16
Mazeppa	10	5	15
Mount Pleasant	7	6	13
Oakwood	2	4	6
Plainview	8	20	28
West Albany	3	9	12
Zumbro	4	12	16
Total	100	160	260

APPENDIX F

MINNESOTA WELL INDEX

The MWI was used to gather information about the 14 study area townships in Wabasha County. This section includes all documented drinking water wells in the study area, not just wells the 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 763 documented (have a verified location in the MWI) drinking water wells.

- Just over one quarter (26%) of the wells were completed in Quaternary aquifers. These are the shallowest aquifers in Wabasha County. The vast majority (178 of 196) of these wells are located in Greenfield Township which abuts the Mississippi River.
    - The Quaternary Water table represent about 23 percent of wells within the Wabasha County study area townships. These wells have an average depth of 74 feet.
    - Only 12 wells (<2 percent) were completed in Quaternary Buried Unconfined Aquifers.
    - Only 9 wells (<2 percent) were completed in the Quaternary Buried Artesian Aquifers. These are the deepest of the Quaternary Aquifer wells, averaging 128 feet deep.
- The uppermost bedrock aquifer if the Prairie Du Chien, and six percent of wells withdraw water from this aquifer.
- The Jordon aquifer is the most heavily utilized within the Wabasha study area. About 30 percent of the domestic wells withdraw water from this aquifer.
- A total of 40 wells (five percent) withdraw water from the St. Lawrence aquifer, many of these are located in Mazeppa Township which is in the southwest corner of the county.
- The Tunnel City aquifer is well represented in Wabasha County, with approximately 23 percent of wells withdrawing water from this aquifer.
- Only 22 wells (three percent) utilize the Wonewoc Sandstone aquifer for domestic well water.
- There are only 2 wells withdrawing water from the Eau Claire aquifer and both are in Greenfield Township.
- Only one well utilizes the Mt. Simon Sandstone Aquifer and it is in Greenfield Township.
- Just under four percent of wells were completed in multiple aquifers. The average depth of these wells is 295 feet.
- Approximately three 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, Wabasha County

Township	Chester	Elgin	Gillford	Glasgow	Greenfield	Highland	Hyde Park	Lake	Mazeppa	Mount Pleasant	Oakwood	Plainview	West Albany	Zumbro	Total	Average Well Depth (ft)
	Number of wells drawing water from an aquifer															
Quaternary Water Table	0	0	0	8	164	0	0	0	0	1	0	0	0	2	175	74
Quaternary Buried Unconfined	0	0	0	1	10	0	0	0	0	0	0	0	1	0	12	89
Quaternary Buried Artesian	0	0	0	3	4	0	0	0	1	0	0	0	1	0	9	128
Prairie Du Chien Group	3	11	7	1	0	1	1	1	3	3	1	4	2	6	44	217
Jordan Sandstone	20	35	28	1	0	5	11	1	20	15	21	17	16	40	230	329
St. Lawrence	1	1	2	0	0	1	1	4	16	0	2	2	3	7	40	295
Tunnel City	5	4	3	12	5	16	1	25	40	13	7	18	14	9	172	363
Wonewoc Sandstone	0	0	0	6	9	0	0	5	0	0	0	0	1	1	22	251
Eau Claire	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	210
Mt. Simon Sandstone	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	230
Multiple Aquifers	1	0	0	3	2	5	1	3	0	3	1	4	1	6	30	351
Not Available	4	2	0	3	2	2	0	0	4	0	1	1	4	3	26	295
Total	34	53	40	38	199	30	15	39	84	35	33	46	43	74	763	261

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
Chester	53	81.1%	0.0%	0.0%	0.0%	1.9%	0.0%	17.0%
Elgin	96	58.3%	0.0%	0.0%	0.0%	26.0%	2.1%	13.5%
Gillford	69	97.1%	0.0%	0.0%	0.0%	0.0%	0.0%	2.9%
Glasgow	37	97.3%	0.0%	0.0%	0.0%	0.0%	0.0%	2.7%
Greenfield	297	32.7%	0.0%	41.4%	2.7%	7.7%	2.4%	13.1%
Highland	47	85.1%	0.0%	2.1%	0.0%	0.0%	0.0%	12.8%
Hyde Park	38	86.8%	0.0%	10.5%	0.0%	2.6%	0.0%	0.0%
Lake	70	71.4%	0.0%	1.4%	0.0%	17.1%	0.0%	10.0%
Mazeppa	84	59.5%	0.0%	10.7%	8.3%	4.8%	1.2%	15.5%
Mount Pleasant	56	91.1%	0.0%	0.0%	0.0%	0.0%	1.8%	7.1%
Oakwood	32	87.5%	3.1%	0.0%	0.0%	0.0%	0.0%	9.4%
Plainview	71	76.1%	0.0%	2.8%	1.4%	4.2%	1.4%	14.1%
West Albany	37	81.1%	0.0%	0.0%	0.0%	0.0%	2.7%	16.2%
Zumbro	100	56.0%	0.0%	3.0%	25.0%	2.0%	0.0%	14.0%
Total	1,087	63.6%	0.1%	13.2%	3.8%	6.5%	1.2%	11.7%

Table 21. Well Construction Type

Township	Total	Drilled	Sand Point	Hand Dug	Other	Not Available
Chester	53	71.7%	3.8%	0.0%	0.0%	24.5%
Elgin	96	77.1%	0.0%	0.0%	0.0%	22.9%
Gillford	69	89.9%	0.0%	0.0%	0.0%	10.1%
Glasgow	37	70.3%	2.7%	0.0%	0.0%	27.0%
Greenfield	297	63.6%	16.2%	0.0%	0.3%	19.9%
Highland	47	76.6%	4.3%	0.0%	0.0%	19.1%
Hyde Park	38	84.2%	5.3%	0.0%	0.0%	10.5%
Lake	70	77.1%	1.4%	0.0%	1.4%	20.0%
Mazeppa	84	69.0%	9.5%	0.0%	0.0%	21.4%
Mount Pleasant	56	87.5%	0.0%	0.0%	0.0%	12.5%
Oakwood	32	78.1%	0.0%	3.1%	3.1%	15.6%
Plainview	71	73.2%	0.0%	0.0%	0.0%	26.8%
West Albany	37	73.0%	5.4%	0.0%	2.7%	18.9%
Zumbro	100	72.0%	4.0%	1.0%	1.0%	22.0%
Total	1,087	73.0%	6.4%	0.2%	0.5%	19.9%

Table 22. Age of Well

Township	Total	1994 to Present	1985 to 1993	1975 to 1984	Before 1975	Not Available
Chester	53	13.2%	3.8%	5.7%	50.9%	26.4%
Elgin	96	10.4%	10.4%	17.7%	31.3%	30.2%
Gillford	69	11.6%	4.3%	11.6%	44.9%	27.5%
Glasgow	37	24.3%	13.5%	5.4%	32.4%	24.3%
Greenfield	297	49.8%	9.1%	9.4%	11.1%	20.5%
Highland	47	10.6%	21.3%	6.4%	36.2%	25.5%
Hyde Park	38	34.2%	2.6%	7.9%	42.1%	13.2%
Lake	70	35.7%	5.7%	7.1%	31.4%	20.0%
Mazeppa	84	29.8%	8.3%	14.3%	19.0%	28.6%
Mount Pleasant	56	33.9%	0.0%	8.9%	37.5%	19.6%
Oakwood	32	37.5%	9.4%	6.3%	31.3%	15.6%
Plainview	71	22.5%	2.8%	4.2%	40.8%	29.6%
West Albany	37	27.0%	8.1%	5.4%	27.0%	32.4%
Zumbro	100	19.0%	10.0%	18.0%	28.0%	25.0%
Total	1,087	30.0%	8.0%	10.2%	27.8%	24.0%

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
Chester	53	0.0%	1.9%	11.3%	45.3%	15.1%	26.4%
Elgin	96	0.0%	0.0%	2.1%	32.3%	30.2%	35.4%
Gillford	69	0.0%	0.0%	4.3%	47.8%	29.0%	18.8%
Glasgow	37	0.0%	2.7%	5.4%	35.1%	27.0%	29.7%
Greenfield	297	0.7%	10.1%	43.8%	17.5%	2.4%	25.6%
Highland	47	0.0%	2.1%	4.3%	23.4%	42.6%	27.7%
Hyde Park	38	0.0%	5.3%	10.5%	28.9%	44.7%	10.5%
Lake	70	0.0%	0.0%	7.1%	30.0%	34.3%	28.6%
Mazeppa	84	3.6%	7.1%	4.8%	28.6%	33.3%	22.6%
Mount Pleasant	56	0.0%	1.8%	0.0%	35.7%	33.9%	28.6%
Oakwood	32	0.0%	3.1%	9.4%	21.9%	43.8%	21.9%
Plainview	71	0.0%	0.0%	4.2%	22.5%	45.1%	28.2%
West Albany	37	0.0%	8.1%	5.4%	37.8%	27.0%	21.6%
Zumbro	100	0.0%	1.0%	5.0%	39.0%	31.0%	24.0%
Total	1,087	0.5%	4.3%	15.7%	29.1%	24.7%	25.7%

Table 24. Unique Well ID Known

Township	Total	No, Unique Well ID Not Known	Yes, Unique Well ID Known	Not Available
Chester	53	30.2%	13.2%	56.6%
Elgin	96	26.0%	16.7%	57.3%
Gillford	69	43.5%	7.2%	49.3%
Glasgow	37	24.3%	16.2%	59.5%
Greenfield	297	18.9%	31.0%	50.2%
Highland	47	23.4%	10.6%	66.0%
Hyde Park	38	31.6%	18.4%	50.0%
Lake	70	22.9%	28.6%	48.6%
Mazeppa	84	16.7%	22.6%	60.7%
Mount Pleasant	56	25.0%	23.2%	51.8%
Oakwood	32	31.3%	28.1%	40.6%
Plainview	71	23.9%	9.9%	66.2%
West Albany	37	24.3%	16.2%	59.5%
Zumbro	100	23.0%	21.0%	56.0%
Total	1,087	24.1%	21.4%	54.5%

Table 25. Livestock Located on Property

Township	Total	No Livestock	Yes Livestock	Not Available
Chester	53	54.7%	28.3%	17.0%
Elgin	96	79.2%	9.4%	11.5%
Gillford	69	60.9%	36.2%	2.9%
Glasgow	37	81.1%	16.2%	2.7%
Greenfield	297	85.2%	3.0%	11.8%
Highland	47	57.4%	34.0%	8.5%
Hyde Park	38	78.9%	18.4%	2.6%
Lake	70	78.6%	12.9%	8.6%
Mazeppa	84	82.1%	3.6%	14.3%
Mount Pleasant	56	57.1%	33.9%	8.9%
Oakwood	32	62.5%	28.1%	9.4%
Plainview	71	64.8%	19.7%	15.5%
West Albany	37	37.8%	48.6%	13.5%
Zumbro	100	86.0%	5.0%	9.0%
Total	1,087	74.4%	15.1%	10.5%

Table 26. Fertilizer Stored on Property

Township	Total	No Fertilizer Stored	Yes Fertilizer Stored	Not Available
Chester	53	77.4%	3.8%	18.9%
Elgin	96	86.5%	1.0%	12.5%
Gillford	69	91.3%	2.9%	5.8%
Glasgow	37	91.9%	2.7%	5.4%
Greenfield	297	87.5%	0.7%	11.8%
Highland	47	89.4%	2.1%	8.5%
Hyde Park	38	94.7%	5.3%	0.0%
Lake	70	84.3%	5.7%	10.0%
Mazeppa	84	85.7%	0.0%	14.3%
Mount Pleasant	56	91.1%	1.8%	7.1%
Oakwood	32	81.3%	6.3%	12.5%
Plainview	71	80.3%	4.2%	15.5%
West Albany	37	86.5%	0.0%	13.5%
Zumbro	100	89.0%	1.0%	10.0%
Total	1,087	86.9%	2.0%	11.0%

Table 27. Farming on Property

Township	Total	No Farming	Yes Farming	Not Available
Chester	53	28.3%	54.7%	17.0%
Elgin	96	55.2%	34.4%	10.4%
Gillford	69	24.6%	71.0%	4.3%
Glasgow	37	43.2%	51.4%	5.4%
Greenfield	297	81.1%	6.7%	12.1%
Highland	47	44.7%	46.8%	8.5%
Hyde Park	38	50.0%	50.0%	0.0%
Lake	70	57.1%	31.4%	11.4%
Mazeppa	84	59.5%	26.2%	14.3%
Mount Pleasant	56	30.4%	62.5%	7.1%
Oakwood	32	25.0%	62.5%	12.5%
Plainview	71	31.0%	52.1%	16.9%
West Albany	37	27.0%	59.5%	13.5%
Zumbro	100	59.0%	31.0%	10.0%
Total	1,087	54.1%	35.0%	10.9%

Table 28. Distance to an Active or Inactive Feedlot

Township	Total	0-49 Feet to Feedlot	50-99 Feet to Feedlot	100-299 Feet to Feedlot	≥300 Feet to Feedlot	Not Available
Chester	53	1.9%	9.4%	17.0%	54.7%	17.0%
Elgin	96	4.2%	0.0%	10.4%	57.3%	28.1%
Gillford	69	1.4%	4.3%	18.8%	66.7%	8.7%
Glasgow	37	5.4%	8.1%	21.6%	51.4%	13.5%
Greenfield	297	6.1%	1.7%	1.7%	62.6%	27.9%
Highland	47	2.1%	4.3%	10.6%	63.8%	19.1%
Hyde Park	38	0.0%	5.3%	18.4%	65.8%	10.5%
Lake	70	4.3%	7.1%	8.6%	54.3%	25.7%
Mazeppa	84	3.6%	3.6%	6.0%	65.5%	21.4%
Mount Pleasant	56	7.1%	5.4%	16.1%	58.9%	12.5%
Oakwood	32	6.3%	6.3%	15.6%	43.8%	28.1%
Plainview	71	2.8%	9.9%	9.9%	49.3%	28.2%
West Albany	37	10.8%	2.7%	18.9%	54.1%	13.5%
Zumbro	100	5.0%	1.0%	7.0%	61.0%	26.0%
Total	1,087	4.6%	3.9%	9.5%	59.4%	22.6%

Table 29. Distance to Septic System

Township	Total	0-49 Feet to Septic	50-99 Feet to Septic	100-299 Feet to Septic	≥300 Feet to Septic	Not Available
Chester	53	1.9%	13.2%	35.8%	30.2%	18.9%
Elgin	96	5.2%	14.6%	40.6%	16.7%	22.9%
Gillford	69	1.4%	24.6%	39.1%	26.1%	8.7%
Glasgow	37	5.4%	29.7%	35.1%	21.6%	8.1%
Greenfield	297	3.0%	38.0%	33.0%	7.1%	18.9%
Highland	47	0.0%	10.6%	46.8%	34.0%	8.5%
Hyde Park	38	0.0%	36.8%	34.2%	28.9%	0.0%
Lake	70	1.4%	27.1%	38.6%	17.1%	15.7%
Mazeppa	84	2.4%	16.7%	46.4%	15.5%	19.0%
Mount Pleasant	56	0.0%	17.9%	44.6%	28.6%	8.9%
Oakwood	32	0.0%	28.1%	50.0%	3.1%	18.8%
Plainview	71	0.0%	12.7%	47.9%	21.1%	18.3%
West Albany	37	8.1%	21.6%	27.0%	27.0%	16.2%
Zumbro	100	1.0%	27.0%	34.0%	23.0%	15.0%
Total	1,087	2.3%	25.5%	38.3%	18.0%	15.9%

Table 30. Distance to an Agricultural Field

Township	Total	0-49 Feet to Field	50-99 Feet to Field	100-299 Feet to Field	≥300 Feet to Field	Not Available
Chester	53	7.5%	18.9%	35.8%	20.8%	17.0%
Elgin	96	4.2%	8.3%	28.1%	38.5%	20.8%
Gillford	69	7.2%	13.0%	24.6%	47.8%	7.2%
Glasgow	37	2.7%	13.5%	35.1%	43.2%	5.4%
Greenfield	297	5.1%	3.0%	10.8%	57.6%	23.6%
Highland	47	4.3%	8.5%	53.2%	23.4%	10.6%
Hyde Park	38	13.2%	13.2%	28.9%	39.5%	5.3%
Lake	70	4.3%	17.1%	18.6%	41.4%	18.6%
Mazeppa	84	1.2%	4.8%	20.2%	54.8%	19.0%
Mount Pleasant	56	7.1%	14.3%	33.9%	33.9%	10.7%
Oakwood	32	9.4%	15.6%	28.1%	34.4%	12.5%
Plainview	71	2.8%	22.5%	28.2%	26.8%	19.7%
West Albany	37	8.1%	10.8%	16.2%	48.6%	16.2%
Zumbro	100	7.0%	10.0%	10.0%	54.0%	19.0%
Total	1,087	5.4%	10.0%	21.9%	45.1%	17.6%

Table 31. Drinking Water Well

Township	Total	Not Drinking Water	Yes, Drinking Water	Not Available
Chester	53	1.9%	81.1%	17.0%
Elgin	96	3.1%	86.5%	10.4%
Gillford	69	2.9%	94.2%	2.9%
Glasgow	37	5.4%	89.2%	5.4%
Greenfield	297	2.0%	87.5%	10.4%
Highland	47	2.1%	89.4%	8.5%
Hyde Park	38	0.0%	100.0%	0.0%
Lake	70	1.4%	88.6%	10.0%
Mazeppa	84	1.2%	86.9%	11.9%
Mount Pleasant	56	0.0%	92.9%	7.1%
Oakwood	32	0.0%	90.6%	9.4%
Plainview	71	2.8%	80.3%	16.9%
West Albany	37	2.7%	83.8%	13.5%
Zumbro	100	2.0%	89.0%	9.0%
Total	1,087	2.0%	88.0%	9.9%

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

Township	Total	None	Distillation	Filtering System	Reverse Osmosis	Other	Not Available
Chester	53	60.4%	0.0%	15.1%	3.8%	0.0%	20.8%
Elgin	96	59.4%	0.0%	13.5%	5.2%	5.2%	16.7%
Gillford	69	75.4%	0.0%	10.1%	4.3%	2.9%	7.2%
Glasgow	37	67.6%	2.7%	13.5%	8.1%	0.0%	8.1%
Greenfield	297	71.7%	0.0%	9.8%	4.7%	0.3%	13.5%
Highland	47	55.3%	0.0%	19.1%	12.8%	0.0%	12.8%
Hyde Park	38	71.1%	0.0%	18.4%	2.6%	2.6%	5.3%
Lake	70	48.6%	0.0%	30.0%	5.7%	2.9%	12.9%
Mazeppa	84	58.3%	0.0%	11.9%	7.1%	2.4%	20.2%
Mount Pleasant	56	53.6%	0.0%	17.9%	8.9%	5.4%	14.3%
Oakwood	32	59.4%	0.0%	21.9%	6.3%	3.1%	9.4%
Plainview	71	56.3%	1.4%	14.1%	7.0%	2.8%	18.3%
West Albany	37	54.1%	0.0%	13.5%	13.5%	5.4%	13.5%
Zumbro	100	70.0%	0.0%	18.0%	2.0%	0.0%	10.0%
Total	1,087	63.8%	0.2%	14.6%	5.8%	1.9%	13.6%

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
Chester	53	0.0%	1.9%	17.0%	32.1%	7.5%	24.5%	17.0%
Elgin	96	3.1%	5.2%	13.5%	22.9%	6.3%	38.5%	10.4%
Gillford	69	7.2%	5.8%	14.5%	31.9%	18.8%	18.8%	2.9%
Glasgow	37	2.7%	13.5%	18.9%	29.7%	21.6%	10.8%	2.7%
Greenfield	297	3.0%	11.1%	20.5%	22.9%	14.1%	17.8%	10.4%
Highland	47	0.0%	10.6%	17.0%	36.2%	8.5%	19.1%	8.5%
Hyde Park	38	13.2%	13.2%	21.1%	23.7%	5.3%	23.7%	0.0%
Lake	70	8.6%	10.0%	14.3%	17.1%	15.7%	25.7%	8.6%
Mazeppa	84	8.3%	3.6%	20.2%	19.0%	14.3%	22.6%	11.9%
Mount Pleasant	56	8.9%	5.4%	21.4%	28.6%	8.9%	17.9%	8.9%
Oakwood	32	3.1%	12.5%	18.8%	28.1%	3.1%	25.0%	9.4%
Plainview	71	8.5%	11.3%	14.1%	22.5%	8.5%	21.1%	14.1%
West Albany	37	8.1%	10.8%	10.8%	27.0%	16.2%	13.5%	13.5%
Zumbro	100	6.0%	9.0%	19.0%	26.0%	8.0%	23.0%	9.0%
Total	1,087	5.2%	8.8%	17.8%	24.9%	11.8%	21.7%	9.7%

Table 34. Last Nitrate Test Result

Township	Total	<3 mg/L Nitrate-N	3<10 mg/L Nitrate-N	≥10 mg/L Nitrate-N	Not Available
Chester	53	3.8%	7.5%	1.9%	86.8%
Elgin	96	8.3%	7.3%	7.3%	77.1%
Gillford	69	4.3%	13.0%	0.0%	82.6%
Glasgow	37	8.1%	5.4%	0.0%	86.5%
Greenfield	297	9.8%	8.8%	1.3%	80.1%
Highland	47	17.0%	10.6%	2.1%	70.2%
Hyde Park	38	13.2%	13.2%	5.3%	68.4%
Lake	70	20.0%	7.1%	2.9%	70.0%
Mazeppa	84	7.1%	8.3%	1.2%	83.3%
Mount Pleasant	56	17.9%	5.4%	5.4%	71.4%
Oakwood	32	15.6%	6.3%	3.1%	75.0%
Plainview	71	14.1%	9.9%	5.6%	70.4%
West Albany	37	10.8%	10.8%	5.4%	73.0%
Zumbro	100	12.0%	9.0%	2.0%	77.0%
Total	1,087	10.9%	8.7%	2.8%	77.6%

APPENDIX I

Table 35. Well Construction Type for Final Well Dataset

Township	Total Wells	Drilled	Sand Point	Other	Not Available
Chester	41	38	0	0	3
Elgin	60	55	0	0	5
Gillford	32	32	0	0	0
Glasgow	30	28	0	0	2
Greenfield	263	202	37	1	23
Highland	27	24	0	0	3
Hyde Park	30	24	3	0	3
Lake	54	50	0	0	4
Mazeppa	69	55	5	0	9
Mount Pleasant	43	41	0	0	2
Oakwood	26	23	0	0	3
Plainview	43	36	0	0	7
West Albany	25	21	2	1	1
Zumbro	84	67	5	0	12
Total	827	696	52	2	77

Data compiled from well logs and homeowner responses.

Table 36. Well Depth for Final Well Dataset

Township	Total Wells	Minimum	Maximum	Median	Mean
Chester	9	140	400	320	283
Elgin	14	340	475	400	402
Gillford	6	228	475	370	376
Glasgow	7	66	580	146	235
Greenfield	119	45	230	66	75
Highland	6	140	484	395	372
Hyde Park	8	56	400	343	287
Lake	21	88	620	515	430
Mazeppa	17	130	415	330	294
Mount Pleasant	14	140	500	278	284
Oakwood	9	72	453	340	317
Plainview	7	380	600	480	474
West Albany	7	64	452	338	266
Zumbro	23	100	478	325	311
Total	267	45	620	150	220

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

Table 37. Year of Well Construction for Final Well Dataset

Township	Total Wells	Minimum	Maximum	Median	Mean
Chester	8	1993	2007	2003	2000
Elgin	15	1930	2017	1996	1991
Gillford	7	1940	2006	1995	1985
Glasgow	7	1993	2013	2003	2003
Greenfield	119	1982	2017	2003	2003
Highland	6	1988	2017	1992	1997
Hyde Park	8	1993	2015	2002	2002
Lake	21	1993	2011	2002	2001
Mazeppa	19	1930	2012	2001	1995
Mount Pleasant	15	1970	2010	2001	1999
Oakwood	9	1992	2005	1995	1997
Plainview	7	1992	2017	2001	2005
West Albany	8	1950	2015	1997	1992
Zumbro	23	1966	2015	1998	1996
Total	272	1930	2017	2002	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.

APPENDIX J

Private Well Field Log

Site ID__________Unique ID_________________ Date ______________________________

MDA -Private Well Field Log & Well Survey Form

Sample#____________________

Duplicate#__________________Field Blank#____________________

Additional Samples____

Well Owner Contact Information

Name____

Address____

Phone #____________________Township______________________County_____________________

Sampling Information

Sampler____________________Time Arrived____________________

Pump Start Time______________Discharge Rate__________________Time Collected_________________

Sample Point Location____

Well Location____

GPS Location________________UTM Easting (X)________________UTM Northing (Y)______________

Weather______________________________Wind Speed/Direction (mph)________Air Temp (°F)_______

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

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

Field Comments - sample specific notes

Updated: March, 2017

APPENDIX K

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

Township	Samples	Minimum	Maximum	Median	Mean
Chester	28	9.49	11.86	10.60	10.65
Elgin	25	8.56	13.53	11.55	11.55
Gillford	18	9.89	13.80	10.42	10.93
Glasgow	14	10.52	13.95	11.45	11.79
Greenfield	131	9.99	15.06	11.38	11.60
Highland	9	9.89	11.72	10.17	10.46
Hyde Park	15	9.75	15.06	11.44	11.74
Lake	21	9.49	14.56	11.98	11.78
Mazeppa	31	8.54	14.00	11.12	11.29
Mount Pleasant	22	9.28	13.98	10.34	10.48
Oakwood	11	9.33	11.21	10.20	10.24
Plainview	19	9.68	12.48	10.49	10.60
West Albany	12	9.64	12.54	10.24	10.66
Zumbro	35	9.84	17.66	11.43	11.90
Total	391	8.54	17.66	11.10	11.32

Table 39. pH of Well Water for Final Well Dataset

Township	Samples	Minimum	Maximum	Median	Mean
Chester	28	6.99	7.94	7.35	7.38
Elgin	25	7.14	7.95	7.55	7.55
Gillford	18	7.29	7.66	7.54	7.51
Glasgow	14	6.97	7.89	7.39	7.40
Greenfield	131	6.89	8.67	7.76	7.78
Highland	9	7.33	7.71	7.61	7.58
Hyde Park	15	6.89	7.78	7.13	7.23
Lake	21	6.52	8.01	7.72	7.67
Mazeppa	31	7.25	8.32	7.56	7.64
Mount Pleasant	22	6.98	8.09	7.54	7.51
Oakwood	11	7.10	7.64	7.36	7.35
Plainview	19	7.04	7.65	7.38	7.38
West Albany	12	7.02	7.90	7.48	7.48
Zumbro	35	7.41	8.28	7.87	7.85
Total	391	6.52	8.67	7.59	7.62

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

Township	Samples	Minimum	Maximum	Median	Mean
Chester	28	380	933	589	597
Elgin	25	424	771	512	552
Gillford	18	414	733	590	571
Glasgow	14	509	793	547	600
Greenfield	130	101	829	434	432
Highland	9	477	1,242	663	698
Hyde Park	15	434	961	551	612
Lake	21	453	880	557	568
Mazeppa	31	477	790	621	608
Mount Pleasant	22	336	933	493	508
Oakwood	11	478	1,140	671	695
Plainview	19	440	1,025	680	686
West Albany	12	441	1,154	553	608
Zumbro	35	340	724	490	515
Total	390	101	1,242	530	535

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

Township	Samples	Minimum	Maximum	Median	Mean
Chester	28	0.13	10.47	7.93	7.27
Elgin	25	1.11	12.28	5.65	5.48
Gillford	18	3.26	13.86	6.32	7.19
Glasgow	14	3.03	13.28	4.94	5.30
Greenfield	131	0.08	16.36	4.39	4.91
Highland	9	2.03	7.50	4.78	4.86
Hyde Park	15	3.74	10.68	5.73	6.18
Lake	21	0.64	13.85	3.35	4.40
Mazeppa	31	0.25	11.28	4.87	5.24
Mount Pleasant	22	0.73	12.85	3.49	3.96
Oakwood	11	1.50	9.04	5.53	5.67
Plainview	19	0.10	12.82	5.44	5.92
West Albany	12	0.19	12.16	4.29	4.61
Zumbro	35	1.39	12.00	3.92	4.93
Total	391	0.08	16.36	4.73	5.29