FINAL TOWNSHIP TESTING NITRATE REPORT: OTTER TAIL COUNTY 2015-2017

July 2018

Minnesota Department of Agriculture

Pesticide and Fertilizer Management Division

ACKNOWLEDGEMENTS

MDA PRIMARY AUTHOR

Nikol Ross

MDA CONTRIBUTORS AND REVIEWERS

Larry Gunderson, Kimberly Kaiser, and Adam McCullough

FUNDING

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

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

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

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

In 2015, private water wells in the Otter Tail County study area (32 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 4,533 wells representing an average response rate of 36 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, 4.1 percent of private wells sampled were at or above the health standard of 10 mg/L for nitrate-N. Based on the initial results, it is estimated that over 851 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 427 wells in 2016 and 2017. A follow-up sampling was offered to all homeowners with wells that had a detectable nitrate-N result.

A well site visit was conducted to identify wells that were unsuitable for final analysis. The final well dataset is intended to only include private drinking water wells potentially impacted by applied commercial agricultural fertilizer. Therefore, wells with construction issues or nearby potential point sources of nitrogen were removed from the final well dataset. Point sources of nitrogen can include: feedlots, subsurface sewage treatment systems, fertilizer spills, and bulk storage of fertilizer. A total of 167 (4 percent) wells were determined to be unsuitable and were removed from the dataset. The final well dataset had a total of 4,366 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 0.0 to 13.5 percent. Parkers Prairie township revealed significant problems with 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 April 2018, 242 townships in 24 counties have completed the initial sampling.

In 2015, 32 townships in Otter Tail County were selected to participate in the Township Testing Program (Figure 1). Areas were chosen based on several criteria. Criteria used include: professional knowledge shared by the local soil and water conservation district (SWCD) or county environmental departments, past high nitrate as nitrogen (nitrate-N) results, vulnerable groundwater, and the amount of row crop production. Initial water samples were collected from private wells by homeowners and mailed to a laboratory. Sample results were mailed by the laboratory to the participating homeowners. The sampling, analysis, and results were provided at no cost to participating homeowners and paid for by the Clean Water Fund.

Well owners with detectable nitrate-N results were offered a no cost pesticide sample and a follow-up nitrate-N sample collected by MDA staff. The MDA began evaluating pesticide presence and concentrations in private water wells at the direction of the Minnesota Legislature. The follow-up pesticide and nitrate-N sampling in Otter Tail County occurred during the summers of 2016 and 2017. The follow-up included a well site visit (when possible) in order to rule out well construction issues and to identify potential point sources of nitrogen (Appendix B).

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

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

www.mda.state.mn.us/nfmp

www.mda.state.mn.us/townshiptesting

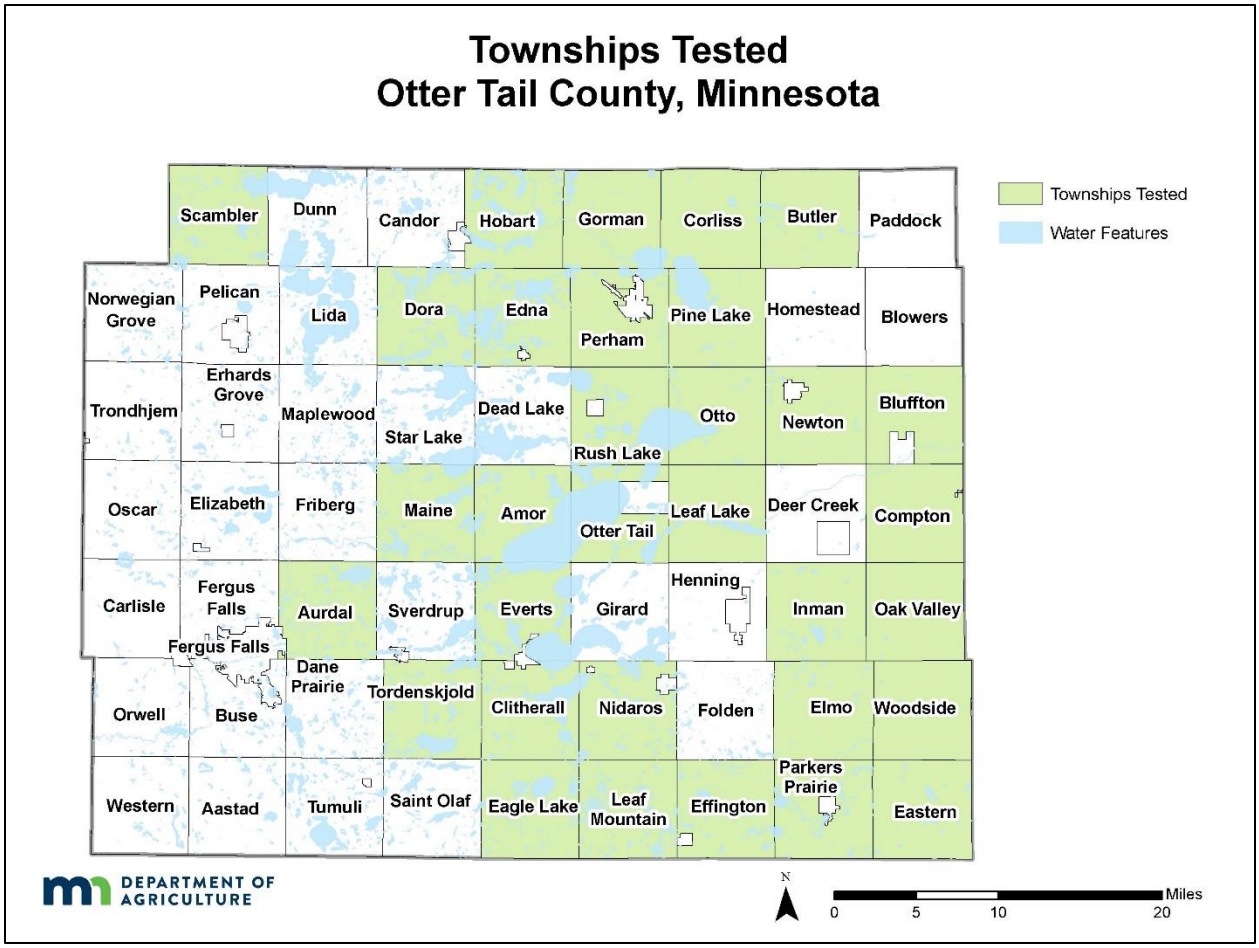


Figure 1. Townships Tested in Otter Tail County

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 shallow coarse-textured groundwater systems. Once in groundwater, nitrate is often considered very stable and can move large distances from its source. However, 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. Shallow groundwater in coarse-textured soils (glacial outwash) generally has low concentrations of organic carbon and is well oxygenated, so denitrification is often limited in these conditions. As a result, areas like Otter Tail County with glacial outwash (Harris, 1999) and intensive row crop agriculture, are particularly vulnerable to elevated nitrate concentrations.

GEOLOGY AND HYDROGEOLOGY

The geology in Otter Tail County is heavily influenced by supraglacial drift complex and outwash plains (Figure 2).

This region's deposits are associated with major glacier ice advances and retreats. The Wadena glacial lobe flowed south-southwest into the easternmost part of Otter Tail County. This ice advance left the landscape marked with drumlins which are geologic features formed at the base of moving glaciers and appear to be smooth, streamlined hills. Additionally the Alexandria Moraine was formed, which runs through the central part of Otter Tail County. More recent sediments have partially buried these features (Harris, 1999; MGS, 1997)

The most recent glacier in the region, the Des Moines Lobe, generally flowed south. This glacial event deposited sediments through several different phases (advances and retreats). In the central and eastern part of Otter Tail County the glacial meltwater left behind glacial outwash which is poorly sorted sand and gravel. Glacial outwash is relatively coarse-textured compared to other glacial deposits such as till, peat and supraglacial drift deposits (Harris, 1999).The coarse-textured deposits associated with glacial outwash often allow contaminants from the surface to travel rapidly to the water table aquifers.

In the western part of Otter Tail County the Des Moines Lobe deposited sediments mainly composed of loam and clay with in the inclusions of cobbles and boulders (Harris, 1999).

After the glacial ice melted the melt water formed glacial Lake Agassiz in what is now known as the Red River Valley. This area is located just west of the Otter Tail County border (MGS, 1997). During this same time period thick layers of organic debris such as peat and bog sediment were deposited in small areas throughout the county (Harris, 1999).

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 Otter Tail County as presented in Figure 2.

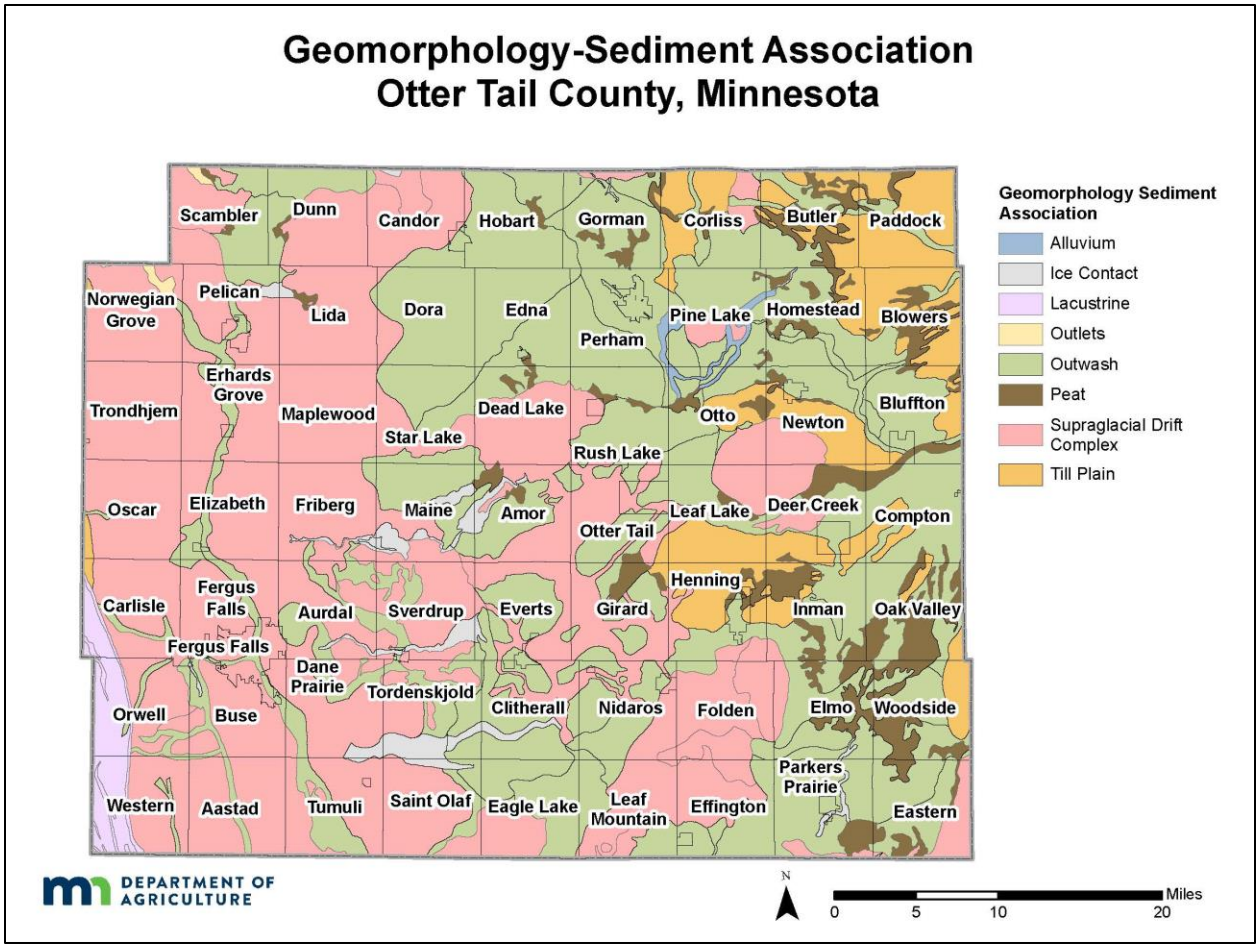


Figure 2. Statewide Geomorphology Layer, Sediment Association in Otter Tail County

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 Otter Tail County. Further details are in Appendix B.

SUBSURFACE SEWAGE TREATMENT SYSTEM

Subsurface Sewage treatment systems (SSTS) can be a potential source for contaminates in groundwater such as nitrate and fecal material (MDH, 2014). A total of 23,888 SSTS were reported in Otter Tail County for 2016. Over a recent 15 year period (2002-2016), 6,621 construction permits for new, replacement, or repairs for SSTS were issued. Of all the reported septic systems in Otter Tail County, 28 percent are newer than 2002 or have been repaired since 2002 (MPCA, 2017a). When new SSTS's are installed they are required to be in compliance with the rules at the time of installation. Newer systems meet modern SSTS regulations and must comply with the current well code; which requires a 50 foot horizontal separation from the well (Minnesota Rules, part 4725.4450; MDH, 2014).

FEEDLOT

Manure produced on a feedlot can be a potential source of nitrogen pollution if improperly stored or spread. In the Otter Tail County study area there are a total of 322 active feedlots. The majority of the feedlots are permitted to house less than 300 animal units (AU) (Appendix B; Figure 7). Gorman Township has the most AU, houses feedlots with the most AU per feedlot, and has the most permitted AU per square mile (Appendix B; Table 10).

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 Otter Tail County study area has a total of 588 fertilizer storage licenses. Perham township overall has the most licenses and hosts the majority of the bulk fertilizer facilities within the study area (Appendix B; Table 11).

FERTILIZER SPILLS AND INVESTIGATIONS

A total of 9 historic fertilizer spills and investigations, 1 related to anhydrous ammonia, occurred in the Otter Tail County study area. The majority of these were small spills and investigations (Appendix B; Table 12)

TOWNSHIP TESTING METHODS

VULNERABLE TOWNSHIPS

Well water sampling is focused on areas that are considered vulnerable to groundwater contamination by commercial nitrogen fertilizer. Typically townships and cities are selected for sampling if more than 30 percent of the underlying geology is considered vulnerable and more than 20 percent of the land cover is row crop agriculture. These are not rigid criteria, but are instead used as a starting point for creating an initial plan. A map depicting the areas that meet 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.

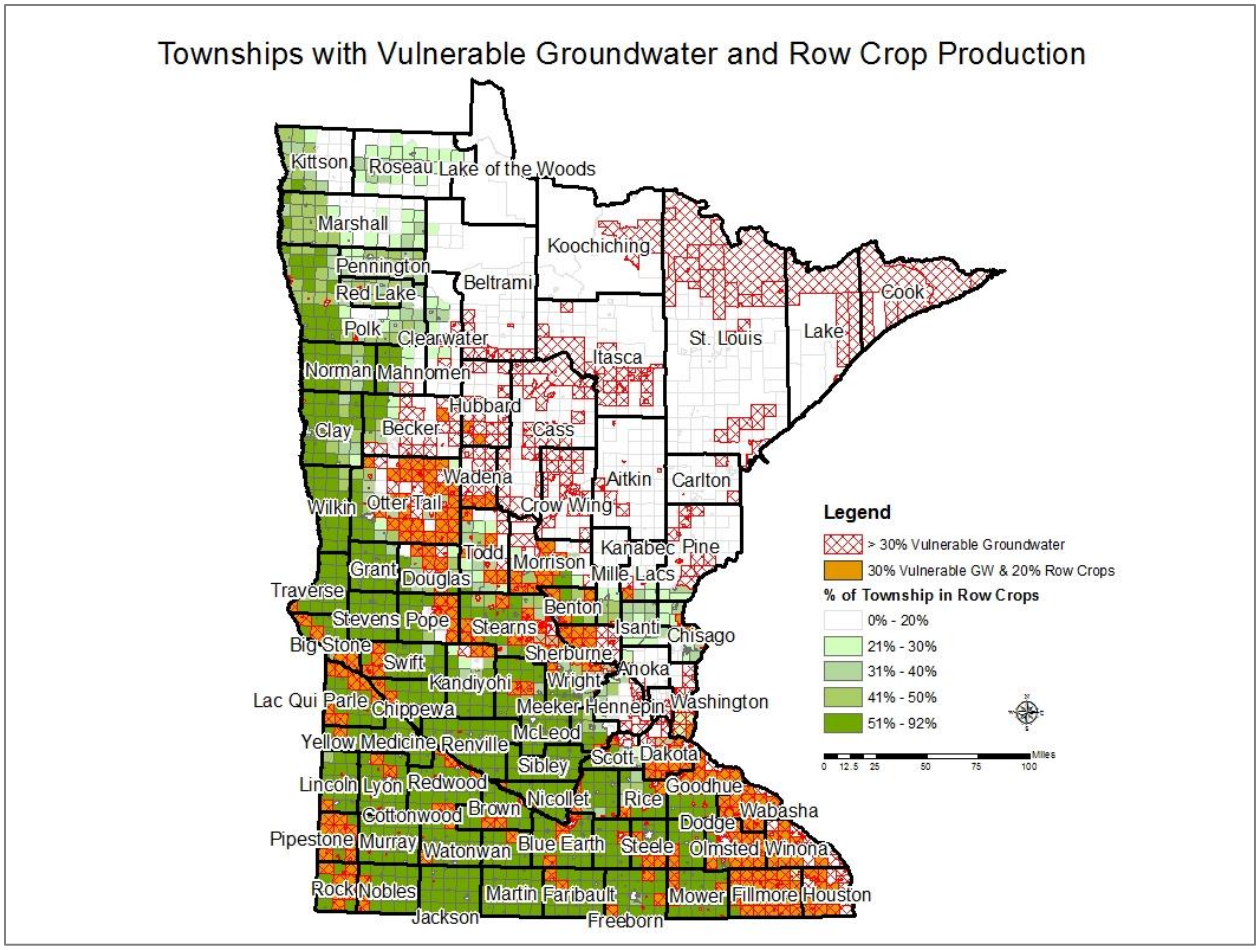


Figure 3. Minnesota Townships with Vulnerable Groundwater and Row Crop Production

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 Otter Tail County depicting the aquifer vulnerabilities is shown below 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

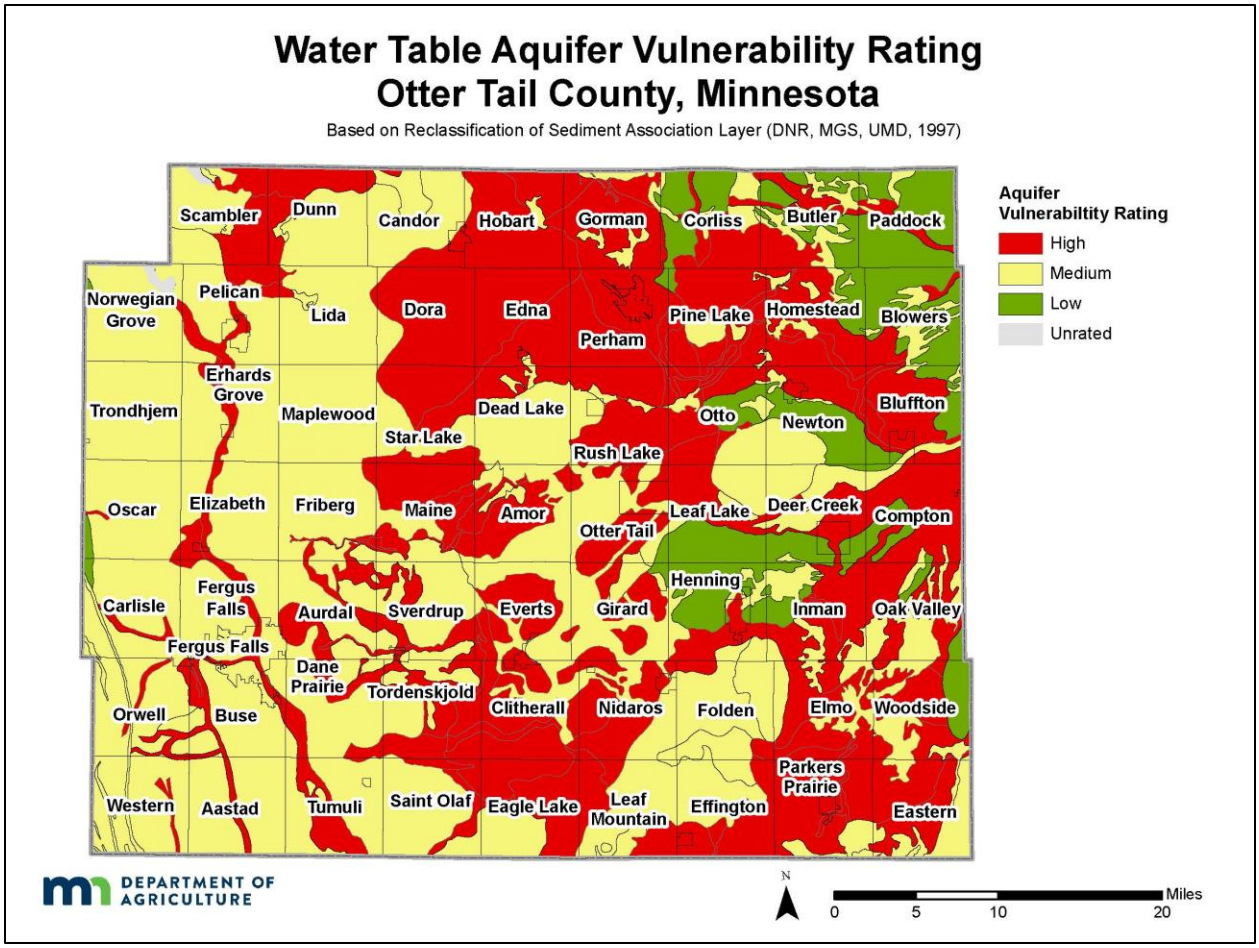


Figure 4. Water Table Aquifer Vulnerability Rating in Otter Tail County

The National Agriculture Statistics Service data (USDA NASS, 2013) on cropland was used to determine the percentage of row crop agriculture. A map and table depicting the extent of the cropland in Otter Tail County can be found in Appendix C (Figure 9, Table 14). On average 20 percent of the land cover was row crop agriculture.

PRIVATE WELL SAMPLING - NITRATE

The testing is done in two steps in each township: "initial" sampling and "follow-up" sampling. The initial nitrate sampling was conducted in 2015. In the initial sampling, all private well owners in the selected townships are sent a nitrate test kit. These kits include instructions on how to collect a water sample, a sample bottle, a voluntary survey, and a prepaid mailer. Each homeowner was mailed the nitrate result for their well along with an explanatory nitrate brochure (Appendix D). Well water samples were collected by 4,533 homeowners using the mail-in kit (Table 2). These 4,533 samples are considered the "initial well dataset". On average, 36 percent of the homeowners in these townships responded to the free nitrate test offered by MDA.

All of the homeowners with a nitrate detection from the initial sampling were asked to participate in a follow-up well site visit and sampling. The well site visit and follow-up sampling was conducted in 2016 and 2017 by MDA staff. A total of 427 follow-up samples were analyzed (Table 2).

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

Township	Kits Sent	Initial Well Dataset	Well Site Visits & Follow-Up Sampling Conducted
Amor	502	211	16
Aurdal	638	205	4
Bluffton	180	40	9
Butler	127	23	1
Clitherall	476	192	32
Compton	272	85	13
Corliss	331	123	7
Dora	775	294	22
Eagle Lake	348	130	19
Eastern	126	38	3
Edna	777	313	16
Effington	133	34	0
Elmo	168	44	5
Everts	871	360	29
Gorman	269	113	14
Hobart	597	228	19
Inman	137	36	13
Leaf Lake	411	140	11
Leaf Mountain	217	63	9
Maine	561	201	23
Newton	346	100	7
Nidaros	327	128	12
Oak Valley	162	42	4
Otter Tail	650	250	25
Otto	352	121	14
Parkers Prairie	184	56	14
Perham	418	152	37
Pine Lake	451	192	15
Rush Lake	748	267	14
Scambler	506	178	7
Tordenskjold	432	139	6
Woodside	148	35	7
Total	12,640	4,533	427

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

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

WELL ASSESSMENT

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

Using the following criteria, a total of 167 wells were removed to create the final well dataset. See Appendix E (Table 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 higher concentration of nitrate 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, a few wells were missing bolts from the cap, making the groundwater 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 & 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.

NO SITE VISIT & CONSTRUCTED BEFORE 1975 & NO WELL ID

Additionally if there was no site visit conducted, and the well is an older well (pre-1975) the well would not be used in the final analysis.

NO SITE VISIT & INSUFFICIENT DATA & NO WELL ID

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

INITIAL RESULTS

INITIAL WELL DATASET

A total of 4,533 well owners returned water samples for analysis across the 32 townships (Figure 5). These wells represent the initial well dataset.

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

The minimum values of nitrate-N for all townships were less than the detection limit (<DL) which is 0.03 mg/L. The maximum values ranged from 4.6 to 44.0 mg/L, with Otter Tail Township having the highest result. Mean values range from 0.1 to 4.5 mg/L, with Parkers Prairie Township having the highest mean value. The 90th percentiles range from <DL to 15.2 mg/L, with Woodside Township having the highest 90th percentile.

Initial results from the sampling showed that in Parkers Prairie Township, ten percent or more of the wells were at or over 10 mg/L nitrate-N. The township testing results contrast findings from a 2010 USGS report on nitrate concentrations in private wells in the glacial aquifer systems across the upper United States (US) in which less than five percent of sampled private wells had nitrate concentrations greater than 10 mg/L (Warner and Arnold, 2010). Data from the township testing program suggests that private well water in Parkers Prairie Township is more heavily impacted by nitrate than other areas of the upper United States. Both the USGS and the township testing studies indicate that nitrate concentrations can vary considerably over short distances.

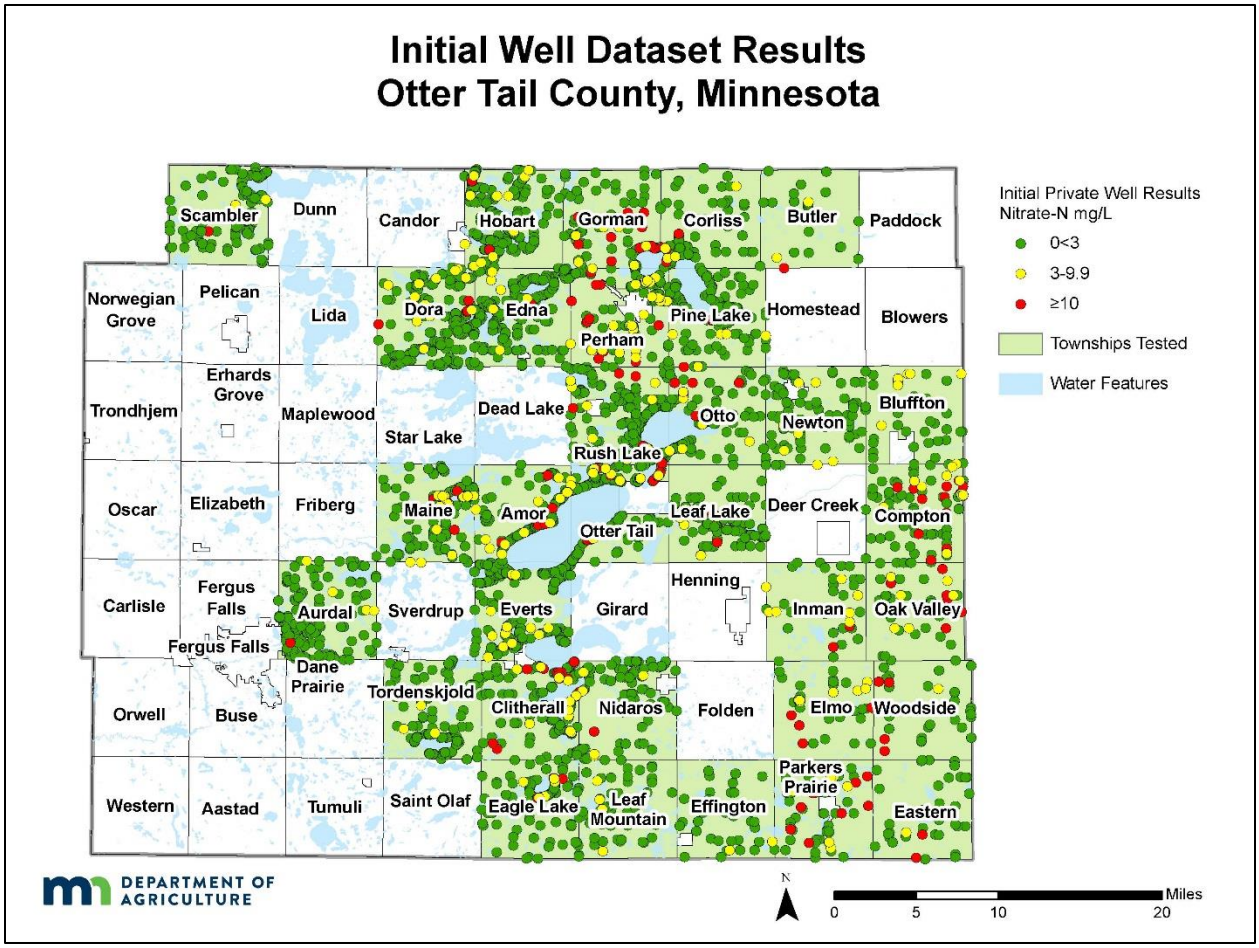


Figure 5. Well Locations and Nitrate Results from Initial Dataset in Otter Tail County

Table 3. Otter Tail 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 parts per million (ppm)																	
Amor	211	<DL	39.2	1.3	<DL	<DL	3.6	7.0	25.9	188	14	13	11	9	89.1%	6.6%	6.2%	5.2%	4.3%
Aurdal	205	<DL	36.0	0.3	<DL	<DL	<DL	0.3	4.9	200	4	2	1	1	97.6%	2.0%	1.0%	0.5%	0.5%
Bluffton	40	<DL	10.5	1.7	<DL	2.4	7.5	9.4	10.5	31	7	7	4	2	77.5%	17.5%	17.5%	10.0%	5.0%
Butler	23	<DL	28.2	1.8	<DL	0.1	4.5	14.0	28.2	20	2	2	1	1	87.0%	8.7%	8.7%	4.3%	4.3%
Clitherall	192	< DL	32.1	2.3	< DL	0.1	9.8	15.3	24.5	156	17	30	26	19	81.3%	8.9%	15.6%	13.5%	9.9%
Compton	85	<DL	35.8	3.9	<DL	3.8	15.1	25.9	32.8	62	10	20	14	13	72.9%	11.8%	23.5%	16.5%	15.3%
Corliss	123	<DL	36.4	1.4	<DL	<DL	0.4	6.5	34.1	114	4	7	6	5	92.7%	3.3%	5.7%	4.9%	4.1%
Dora	294	<DL	32.0	1.1	<DL	<DL	1.7	5.3	28.3	273	12	15	13	9	92.9%	4.1%	5.1%	4.4%	3.1%
Eagle Lake	130	<DL	17.8	1.0	<DL	0.04	2.6	6.4	17.1	119	6	10	6	5	91.5%	4.6%	7.7%	4.6%	3.8%
Eastern	38	<DL	19.4	1.3	<DL	0.03	4.8	9.9	19.4	34	2	4	3	2	89.5%	5.3%	10.5%	7.9%	5.3%
Edna	313	<DL	15.6	0.3	<DL	<DL	0.2	1.3	6.8	306	6	5	3	1	97.8%	1.9%	1.6%	1.0%	0.3%
Effington	34	<DL	4.6	0.2	<DL	<DL	<DL	3.0	4.6	32	2	0	0	0	94.1%	5.9%	0.0%	0.0%	0.0%
Elmo	44	<DL	30.1	3.5	<DL	4.8	12.6	17.0	30.1	31	7	11	9	6	70.5%	15.9%	25.0%	20.5%	13.6%
Everts	360	<DL	17.2	0.4	<DL	<DL	0.5	2.5	8.2	343	16	8	7	1	95.3%	4.4%	2.2%	1.9%	0.3%
Gorman	113	<DL	26.2	2.6	<DL	0.7	12.4	21.0	26.1	93	7	15	14	13	82.3%	6.2%	13.3%	12.4%	11.5%
Hobart	228	<DL	27.4	0.7	<DL	<DL	1.6	3.6	14.0	212	13	10	6	3	93.0%	5.7%	4.4%	2.6%	1.3%
Inman	36	<DL	21.3	2.4	0.0	2.8	8.8	11.4	21.3	27	7	7	4	2	75.0%	19.4%	19.4%	11.1%	5.6%

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 parts per million (ppm)																	
Leaf Lake	140	<DL	30.0	1.1	<DL	<DL	2.0	6.0	26.8	130	6	8	5	4	92.9%	4.3%	5.7%	3.6%	2.9%
Leaf Mountain	63	<DL	7.0	0.5	<DL	0.1	2.0	4.2	6.8	59	4	2	0	0	93.7%	6.3%	3.2%	0.0%	0.0%
Maine	201	< DL	26.3	1.5	< DL	0.1	5.8	9.3	21.9	172	20	24	16	9	85.6%	10.0%	11.9%	8.0%	4.5%
Newton	100	<DL	12.2	0.8	<DL	0.1	2.2	6.2	10.1	92	7	6	3	1	92.0%	7.0%	6.0%	3.0%	1.0%
Nidaros	128	<DL	14.9	0.7	<DL	0.1	1.8	3.9	13.8	120	5	4	4	3	93.8%	3.9%	3.1%	3.1%	2.3%
Oak Valley	42	<DL	15.3	2.6	<DL	3.5	11.0	12.4	15.3	30	6	9	7	6	71.4%	14.3%	21.4%	16.7%	14.3%
Otter Tail	250	< DL	44.0	2.3	< DL	0.04	4.9	18.7	38.6	219	12	24	23	19	87.6%	4.8%	9.6%	9.2%	7.6%
Otto	121	<DL	23.3	1.4	<DL	0.1	3.3	11.7	20.1	107	8	9	7	6	88.4%	6.6%	7.4%	5.8%	5.0%
Parkers Prairie	56	<DL	41.1	4.5	<DL	5.9	14.8	18.7	40.4	39	7	15	13	10	69.6%	12.5%	26.8%	23.2%	17.9%
Perham	152	<DL	35.9	3.0	<DL	3.6	10.9	15.7	24.1	110	24	31	26	18	72.4%	15.8%	20.4%	17.1%	11.8%
Pine Lake	192	<DL	14.0	0.5	<DL	<DL	0.6	2.6	11.7	183	5	7	5	4	95.3%	2.6%	3.6%	2.6%	2.1%
Rush Lake	267	<DL	15.2	0.6	<DL	<DL	0.7	4.0	13.2	252	8	10	8	7	94.4%	3.0%	3.7%	3.0%	2.6%
Scambler	178	<DL	16.7	0.3	<DL	<DL	0.2	1.6	6.7	173	4	4	1	1	97.2%	2.2%	2.2%	0.6%	0.6%
Tordenskjold	139	<DL	5.2	0.1	<DL	<DL	<DL	0.3	4.0	136	3	1	0	0	97.8%	2.2%	0.7%	0.0%	0.0%
Woodside	35	<DL	40.7	3.7	<DL	0.4	15.2	28.4	40.7	29	1	6	6	5	82.9%	2.9%	17.1%	17.1%	14.3%
Total	4,533	<DL	44.0	1.2	<DL	<DL	2.8	7.9	24.6	4092	256	326	252	185	90.3%	5.6%	7.2%	5.6%	4.1%

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

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 851 people in Otter Tail County's study area have drinking water over the nitrate HRL (Table 4). Additional public awareness and education programming will need to take place in several of the townships.

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

Township	Estimated Households on Private Wells (2012)*	Estimated Population on Private Wells (2012)*	Estimated Population ≥10 mg/L Nitrate-N**
Amor	195	501	21
Aurdal	543	1,447	7
Bluffton	171	478	24
Butler	101	281	12
Clitherall	207	461	45
Compton	280	811	124
Corliss	193	500	20
Dora	344	725	22
Eagle Lake	158	377	15
Eastern	94	226	12
Edna	353	886	3
Effington	100	254	0
Elmo	138	327	45
Everts	306	651	2
Gorman	181	460	53
Hobart	321	774	10
Inman	118	288	16
Leaf Lake	232	552	16
Leaf Mountain	123	319	0
Maine	276	642	32
Newton	297	742	7
Nidaros	139	326	8
Oak Valley	146	359	51
Otter Tail	240	494	37
Otto	226	556	28
Parkers Prairie	140	346	62
Perham	320	834	99

Township	Estimated Households on Private Wells (2012)*	Estimated Population on Private Wells (2012)*	Estimated Population ≥10 mg/L Nitrate-N**
Pine Lake	266	635	13
Rush Lake	404	971	25
Scambler	216	473	3
Tordenskjold	242	551	0
Woodside	110	275	39
Total	7,180	17,522	851

* Data collected from the Minnesota State Demographic Center, 2012

** Estimates based off of the 2012 estimated households per township gathered 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 drilled 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. 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 (MGS, 2013).

In some cases, well owners were able to provide Unique Well Identification Numbers for their wells. Additionally, MDA staff were able to find many Unique Well IDs online or on well tags during site visits. 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 1,345 documented wells (Table 5). Approximately 30 percent of the sampled wells had corresponding well logs. However, most of the well logs did not contain a defined aquifer. Only 140 wells (3 percent) had a defined aquifer, while the rest were undesignated. Thus, the data gathered on aquifers represents a small portion of the total sampled wells.

According to the well log data, the most commonly utilized aquifer in the sampled wells was from the Quaternary buried aquifers. This majority reflects the overall findings for all documented wells in the focus area (Appendix F, Table 20). The wells in these aquifers are relatively shallow, averaging 103 feet deep.

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

The Quaternary Water Table (QWTA) wells are defined as having less than ten feet of confining material (clay) between the land surface and the well screen (MPCA, 1999). 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 may be more susceptible to nitrate contamination.

The Quaternary Buried aquifer wells have more than ten feet of confining material (typically clay) between the land surface and the well screen (MPCA, 1999).

Most wells did not have an aquifer identified and therefore are labeled "undesignated". The MGS did not yet completed a County Geologic Atlas for Otter Tail County (MGS, 2013). Typically after an atlas is completed well information such as the aquifer designation and geologic formation codes are completed in the well logs.

Table 5. Nitrate Concentrations within Sampled Groundwater Aquifers

Aquifer	Total Wells	Average Depth (Feet)	Number of wells			Percent of wells		
			<3	3<10	≥10	<3	3<10	≥10
			Nitrate-N mg/L					
Quaternary Water Table	26	71	23	1	2	88%	4%	8%
Quaternary Buried	113	103	105	3	5	93%	3%	4%
Quaternary Undifferentiated	1	76	0	1	0	0%	100%	0%
Undesignated	1,205	94	1,121	47	37	93%	4%	3%
Total	1,345	94	1,249	52	44	93%	4%	3%

WELL OWNER SURVEY

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

The wells were mainly located on lake home or on rural properties. Otter Tail has many cabins and lake homes located in the central part of the county. Overall almost half of the homes are on lake property. In townships (Bluffton, Eastern, Newton, Oak Valley, Parkers Prairie and Woodside) located on the east side of Otter Tail County, the vast majority of the wells (over 75%) were located on rural properties also referred to as "country" properties.

Approximately 57 percent of sampled wells are of drilled construction and 17 percent are sand point wells. Sand point (drive-point) wells are typically completed at shallower depths than drilled wells. Sand point wells are also usually installed in areas where sand is the dominant geologic material and where there are no thick confining units such as clay. This makes sand point wells more vulnerable to contamination from the surface. There were only eight hand dug wells sampled in the townships. As mentioned previously, hand dug wells are shallow and more sensitive to local surface runoff contamination than deeper drilled wells.

Approximately half of the wells in the townships are less than 100 feet deep. Leaf Mountain has the lowest percentage of wells less than 100 feet deep (19 percent) and Oak Valley has the highest percent of wells less than 100 feet deep (79 percent).

Most of the wells had not been tested for nitrate within the last ten years or homeowners were unsure if they had been tested. Therefore, the results most homeowners receive from this study will provide new information.

It is important to note that in the follow-up site surveys MDA staff was able to gather more information on the construction type, and staff were able to find unique IDs so that an official well depth, and well age could be found. Therefore the information provided by the homeowner survey will not exactly match information provided later in the report for the final well dataset.

POTENTIAL NITRATE SOURCE DISTANCES

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

- On average, farming takes place on less than 12 percent of the properties.
- Agricultural fields are closer than 300 feet from wells at 19 percent of the properties.
- Less than four percent of the well owners across all the townships responded that they have livestock (greater than ten head of cattle or other equivalent) on their property.
- The majority of wells (more than 62 percent) are 300 feet or more from an active or inactive feedlot.
- Very few well owners (less than one percent) across all townships store more than 500 pounds of fertilizer on their property.
- A small minority of wells (less than five percent) are less than 50 feet away from septic systems. Most wells are between 50-299 feet from a septic system.

FINAL RESULTS

FINAL WELL DATASET

A total of 4,533 well water samples were collected by homeowners across 32 townships. The initial report shows 4,536 wells but three wells were found to be duplicates or extra kits and were removed for analysis. A total of 167 (4 percent) wells were found to be unsuitable and were removed to create the final well dataset. The final analysis was conducted on the remaining 4,366 wells (Table 6). The wells in the final well dataset represent drinking water wells potentially impacted by applied commercial agricultural fertilizer.

WELL WATER NITROGEN ANALYSIS

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

Table 6 shows the results for all townships sampled. The percent of wells at or over the HRL ranged from 0.0 to 13.5 percent.

Table 6. Initial and Final Well Dataset Results, Otter Tail County

Township	Initial Well Dataset	Final Well Dataset	Wells ≥10 mg/L Nitrate-N	
			Count	Percentage
Amor	211	203	4	2.0%
Aurdal	205	204	0	0.0%
Bluffton	40	36	1	2.8%
Butler	23	21	0	0.0%
Clitherall	192	182	14	7.7%
Compton	85	74	6	8.1%
Corliss	123	118	2	1.7%
Dora	294	288	6	2.1%
Eagle Lake	130	126	2	1.6%
Eastern	38	36	1	2.8%
Edna	313	309	0	0.0%
Effington	34	34	0	0.0%
Elmo	44	36	2	5.6%
Everts	360	357	0	0.0%
Gorman	113	102	5	4.9%
Hobart	228	226	3	1.3%
Inman	36	33	2	6.1%
Leaf Lake	140	134	3	2.2%
Leaf Mountain	63	62	0	0.0%
Maine	201	182	2	1.1%
Newton	100	97	1	1.0%
Nidaros	128	126	2	1.6%
Oak Valley	42	34	1	2.9%
Otter Tail	250	242	14	5.8%
Otto	121	114	2	1.8%
Parkers Prairie	56	52	7	13.5%
Perham	152	144	13	9.0%
Pine Lake	192	187	2	1.1%
Rush Lake	267	263	3	1.1%
Scambler	178	175	0	0.0%
Tordenskjold	139	138	0	0.0%
Woodside	35	31	2	6.5%
Total	4,533	4,366	100	2.3%

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

The final well dataset summary statistics are shown in Table 7. The minimum values were all below the detection limit. The maximum values ranged from 4.1 to 44.0 mg/L nitrate, with Otter Tail Township having the highest result. The 90th percentile ranged from <DL to 13.9 mg/L nitrate-N, with Parkers Prairie Township having the highest result.

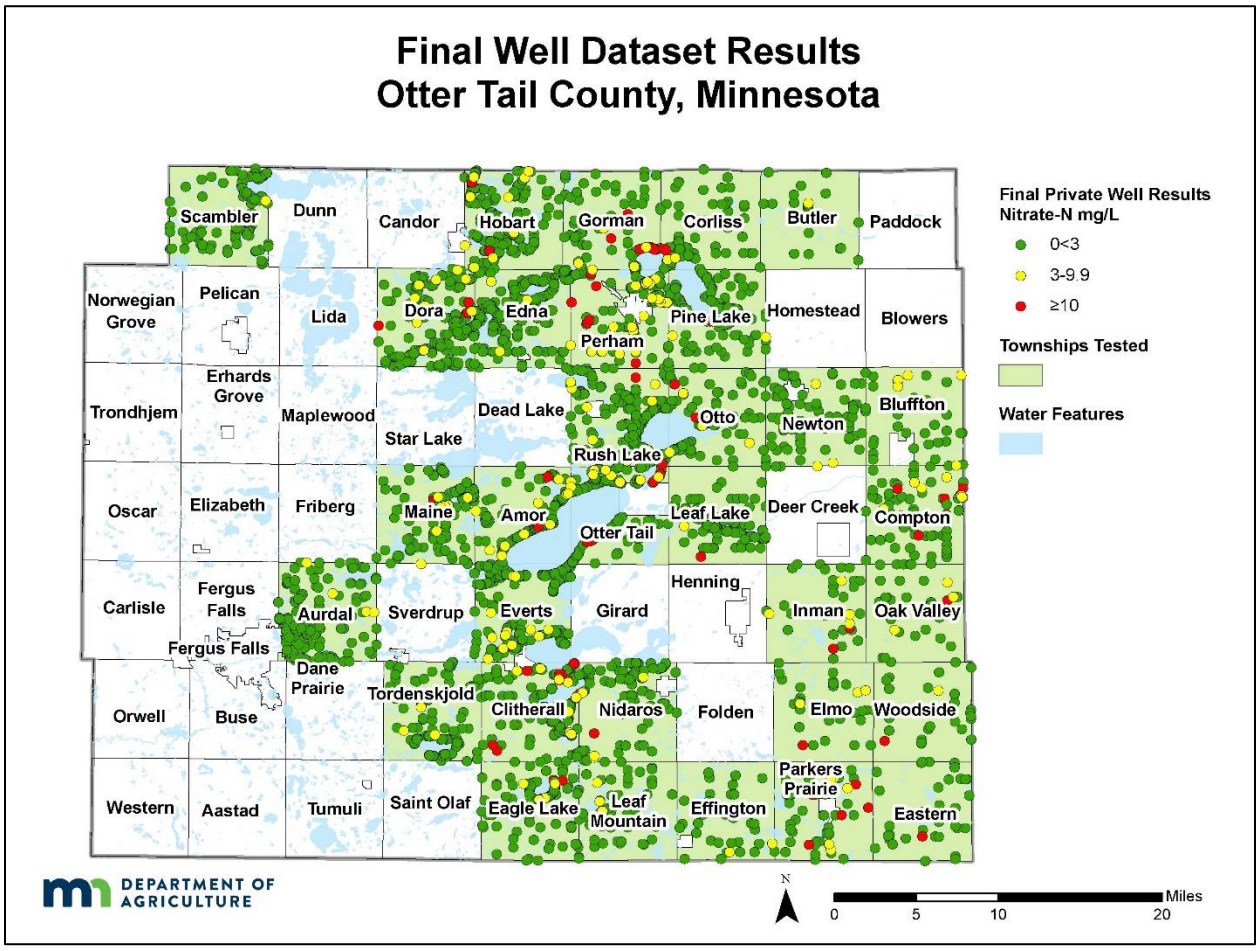


Figure 6. Well Locations and Nitrate Results from Final Well Dataset in Otter Tail County

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

Township	Total Wells	Values			Percentiles					Number of Wells					Percent				
		Min	Max	Mean	(50th) 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 parts per million (ppm)																	
Amor	203	<DL	28.3	0.7	<DL	<DL	1.2	4.1	18.2	188	11	5	4	4	92.6%	5.4%	2.5%	2.0%	2.0%
Aurdal	204	<DL	6.0	0.1	<DL	<DL	<DL	0.2	3.9	200	4	1	0	0	98.0%	2.0%	0.5%	0.0%	0.0%
Bluffton	36	<DL	10.4	1.2	<DL	0.3	5.8	8.0	10.4	30	5	4	2	1	83.3%	13.9%	11.1%	5.6%	2.8%
Butler	21	<DL	4.1	0.3	<DL	<DL	1.4	2.7	4.1	20	1	0	0	0	95.2%	4.8%	0.0%	0.0%	0.0%
Clitherall	182	<DL	32.1	1.8	<DL	<DL	6.0	11.9	24.7	156	12	21	17	14	85.7%	6.6%	11.5%	9.3%	7.7%
Compton	74	<DL	27.2	2.0	<DL	0.9	5.8	15.3	26.1	62	6	9	6	6	83.8%	8.1%	12.2%	8.1%	8.1%
Corliss	118	<DL	36.4	0.7	<DL	<DL	0.1	0.9	34.3	114	2	2	2	2	96.6%	1.7%	1.7%	1.7%	1.7%
Dora	288	<DL	32.0	0.8	<DL	<DL	1.2	3.3	23.9	273	9	9	8	6	94.8%	3.1%	3.1%	2.8%	2.1%
Eagle Lake	126	<DL	17.8	0.6	<DL	<DL	1.8	4.9	12.0	119	5	6	2	2	94.4%	4.0%	4.8%	1.6%	1.6%
Eastern	36	<DL	10.4	0.6	<DL	<DL	1.8	4.8	10.4	34	1	2	1	1	94.4%	2.8%	5.6%	2.8%	2.8%
Edna	309	<DL	8.9	0.2	<DL	<DL	0.1	0.9	3.4	306	3	1	1	0	99.0%	1.0%	0.3%	0.3%	0.0%
Effington	34	<DL	4.6	0.2	<DL	<DL	<DL	3.0	4.6	32	2	0	0	0	94.1%	5.9%	0.0%	0.0%	0.0%
Elmo	36	<DL	30.1	1.8	<DL	0.4	3.5	11.3	30.1	31	3	3	3	2	86.1%	8.3%	8.3%	8.3%	5.6%
Everts	357	<DL	9.8	0.3	<DL	<DL	0.3	2.0	6.9	343	14	5	4	0	96.1%	3.9%	1.4%	1.1%	0.0%
Gorman	102	<DL	24.6	1.2	<DL	<DL	2.7	7.1	22.8	92	5	5	5	5	90.2%	4.9%	4.9%	4.9%	4.9%
Hobart	226	<DL	27.4	0.7	<DL	<DL	1.5	3.5	14.0	212	11	8	4	3	93.8%	4.9%	3.5%	1.8%	1.3%
Inman	33	<DL	21.3	2.0	<DL	1.8	6.0	11.8	21.3	27	4	4	3	2	81.8%	12.1%	12.1%	9.1%	6.1%
Leaf Lake	134	<DL	30.0	0.8	<DL	<DL	0.4	2.6	27.0	129	2	3	3	3	96.3%	1.5%	2.2%	2.2%	2.2%

Township	Total Wells	Values			Percentiles					Number of Wells					Percent				
		Min	Max	Mean	(50th) 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 parts per million (ppm)																	
Leaf Mountain	62	<DL	7.0	0.5	<DL	<DL	1.7	2.8	6.7	59	3	1	0	0	95.2%	4.8%	1.6%	0.0%	0.0%
Maine	182	<DL	16.2	0.6	<DL	<DL	1.6	3.7	9.9	171	9	6	5	2	94.0%	4.9%	3.3%	2.7%	1.1%
Newton	97	<DL	12.2	0.6	<DL	<DL	1.9	3.5	9.8	92	4	3	2	1	94.8%	4.1%	3.1%	2.1%	1.0%
Nidaros	126	<DL	14.9	0.5	<DL	0.03	1.5	3.0	11.4	120	4	2	2	2	95.2%	3.2%	1.6%	1.6%	1.6%
Oak Valley	34	<DL	10.2	0.8	<DL	0.4	3.1	4.0	10.2	30	3	1	1	1	88.2%	8.8%	2.9%	2.9%	2.9%
Otter Tail	242	<DL	44.0	1.8	<DL	<DL	2.9	16.2	38.7	218	10	17	16	14	90.1%	4.1%	7.0%	6.6%	5.8%
Otto	114	<DL	17.5	0.7	<DL	<DL	1.9	3.4	16.1	107	5	3	3	2	93.9%	4.4%	2.6%	2.6%	1.8%
Parkers Prairie	52	<DL	18.8	3.0	<DL	3.3	13.9	17.2	18.8	39	6	11	9	7	75.0%	11.5%	21.2%	17.3%	13.5%
Perham	144	<DL	35.9	2.6	<DL	2.2	9.1	15.2	24.9	110	21	23	19	13	76.4%	14.6%	16.0%	13.2%	9.0%
Pine Lake	187	<DL	11.9	0.3	<DL	<DL	0.2	1.6	8.6	182	3	3	2	2	97.3%	1.6%	1.6%	1.1%	1.1%
Rush Lake	263	<DL	13.2	0.4	<DL	<DL	0.5	2.1	10.5	252	8	6	4	3	95.8%	3.0%	2.3%	1.5%	1.1%
Scambler	175	<DL	5.8	0.1	<DL	<DL	0.2	1.0	3.2	173	2	1	0	0	98.9%	1.1%	0.6%	0.0%	0.0%
Tordenskjold	138	<DL	5.2	0.1	<DL	<DL	<DL	0.2	4.0	135	3	1	0	0	97.8%	2.2%	0.7%	0.0%	0.0%
Woodside	31	<DL	32.7	1.9	<DL	<DL	4.3	14.8	32.7	28	1	3	3	2	90.3%	3.2%	9.7%	9.7%	6.5%
Total	4,366	<DL	44.0	0.8	<DL	<DL	1.5	4.0	17.4	4084	182	169	131	100	93.5%	4.2%	3.9%	3.0%	2.3%

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

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

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

Township	Final Well Dataset	Percent Vulnerable Geology	Percent Row Crop Production (2013)*	Percent ≥7 Nitrate-N mg/L or parts per million (ppm)	Percent ≥10 Nitrate-N mg/L or parts per million (ppm)
Amor	203	47%	19%	2.0%	2.0%
Aurdal	204	38%	34%	0.0%	0.0%
Bluffton	36	69%	10%	5.6%	2.8%
Butler	21	34%	14%	0.0%	0.0%
Clitherall	182	77%	23%	9.3%	7.7%
Compton	74	77%	28%	8.1%	8.1%
Corliss	118	42%	19%	1.7%	1.7%
Dora	288	89%	11%	2.8%	2.1%
Eagle Lake	126	68%	18%	1.6%	1.6%
Eastern	36	61%	19%	2.8%	2.8%
Edna	309	99%	18%	0.3%	0.0%
Effington	34	50%	22%	0.0%	0.0%
Elmo	36	70%	21%	8.3%	5.6%
Everts	357	53%	15%	1.1%	0.0%
Gorman	102	83%	23%	4.9%	4.9%
Hobart	226	94%	12%	1.8%	1.3%
Inman	33	57%	16%	9.1%	6.1%
Leaf Lake	134	31%	29%	2.2%	2.2%

Township	Final Well Dataset	Percent Vulnerable Geology	Percent Row Crop Production (2013)*	Percent ≥7 Nitrate-N mg/L or parts per million (ppm)	Percent ≥10 Nitrate-N mg/L or parts per million (ppm)
Leaf Mountain	62	36%	14%	0.0%	0.0%
Maine	182	73%	20%	2.7%	1.1%
Newton	97	31%	16%	2.1%	1.0%
Nidaros	126	62%	21%	1.6%	1.6%
Oak Valley	34	51%	15%	2.9%	2.9%
Otter Tail	242	43%	15%	6.6%	5.8%
Otto	114	57%	19%	2.6%	1.8%
Parkers Prairie	52	83%	36%	17.3%	13.5%
Perham	144	98%	28%	13.2%	9.0%
Pine Lake	187	85%	13%	1.1%	1.1%
Rush Lake	263	83%	10%	1.5%	1.1%
Scambler	175	37%	29%	0.0%	0.0%
Tordenskjold	138	61%	24%	0.0%	0.0%
Woodside	31	52%	16%	9.7%	6.5%
Total	4,366	62%**	20%**	3.0%	2.3%

* Data retrieved from USDA NASS Cropland Data Layer, 2013 and grouped into broader categories by MDA

**Represents an average

WELL AND WATER CHARACTERISTICS

WELL CONSTRUCTION

Unique identification numbers from well logs were compiled for the wells in the Otter Tail 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 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 (63 percent) and 17 percent were sand point wells
- The median depth of wells was 81 feet, and the shallowest was 18 feet
- The median year the wells were constructed in was 2004

WELL WATER PARAMETERS

MDA staff conducted the follow-up sampling. 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 are described below and a more comprehensive view is available in Appendix K (Table 38-41).

- The temperatures ranged from 7.62 °C to 21.43 °C, the average was 10.08 °C
- The median specific conductivity was 627 µS/cm, and was as high as 1,530 µS/cm
- The water from the wells had a median pH of 7.41
- The dissolved oxygen readings ranged from 0.09 mg/L to 10.92 mg/L, the average was 2.43 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 Otter Tail County. In order to prioritize testing, the MDA looked at townships with significant row crop production and vulnerable geology. Approximately 20 percent of the land cover is row crop agriculture and there are over 92,000 acres of groundwater irrigation in the study area. In total the Otter Tail study area covers 723,236 acres.

The initial (homeowner collected) nitrate sampling resulted in 4,533 samples. The 4,533 households that participated represent approximately 36 percent of the population on private wells. Well owners with measureable nitrate results were offered a follow-up nitrate sample and a pesticide sample. The MDA resampled and visited 427 wells.

The MDA conducted a nitrogen source assessment and identified wells near potential point sources and wells with poor construction. A total of 167 (4 percent) wells were found to be unsuitable and were removed to create the final well dataset of 4,366 wells. The remaining 4,366 wells were wells believed to be impacted by commercial nitrogen fertilizer.

A majority of wells (63 percent) were drilled and 17 percent were sand points. The median depth of the wells was 81 and depths ranged from 18 to 477 feet.

In the final well dataset only one of the 32 townships (Parkers Prairie) tested in Otter Tail County had more than 10 percent of the 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 13.5 percent.

REFERENCES

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

Harris, K.L.. (1999). Quaternary geology-Otter Tail area, west-central Minnesota [Part A]. Minnesota Geological Survey] Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/59783.

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, M.A. (2012). *Manure Management in Minnesota* (WW-03553). Retrieved from www.extension.umn.edu/agriculture/manure-management-and-air-quality/manure-management-basics/manure-management-in-minnesota/doc/manure-management-in-minnesota.pdf.

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

Minnesota Department of Agriculture [MDA]. (2016a). *Agricultural Chemical Incidents* [Data file]. Retrieved from gisdata.mn.gov/dataset/env-agchem-incidents.

Minnesota Department of Agriculture [MDA]. (2016b). Township Testing Program Sampling and Analysis Plan. Available Upon Request.

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

Minnesota Department of Health [MDH]. (2017). *Minnesota Well Index.* Retrieved from www.health.state.mn.us/divs/eh/cwi/.

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]. (2016a). *DNR Water Permits*. Retrieved from www.dnr.state.mn.us/permits/water/index.html.

Minnesota Department of Natural Resources [MDNR]. (2016b). *Minnesota Water Use Data* [Data File]. Retrieved from dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html.

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]. (2013). *County Atlas Website*. St. Paul, MN: Minnesota Geologic Survey. Retrieved from www.mngs.umn.edu/county_atlas/countyatlas.htm.

Minnesota Geologic Survey [MGS]. (1997). *Minnesota at a Glance – Quaternary Glacial Geology*, Retrieved from http://www.d.umn.edu/~mille066/Teaching/4100/MaG-Quaternary.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 December 16, 2015, from /www.pca.state.mn.us/sites/default/files/wq-f8-11.pdf.

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

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

Minnesota Pollution Control Agency [MPCA]. (2015a). Feedlot Registration Form. Online PDF retrieved December 7, 2015 from www.pca.state.mn.us/sites/default/files/wq-f4-12.pdf

Minnesota Pollution Control Agency [MPCA]. (2015b). State of Minnesota General Animal Feedlots NPDES Permit. Online PDF retrieved December 8, 2015, from www.pca.state.mn.us/sites/default/files/wq-f3-53.pdf

Minnesota Pollution Control Agency [MPCA]. (2016). *Feedlots in Minnesota* [Data file]. St. Paul, MN: Minnesota Pollution Control Agency. Retrieved from: gisdata.mn.gov/dataset/env-feedlots

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

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]. (1999). Baseline Water Quality of Minnesota's Principal Aquifers, Region 3, Northwest Minnesota.

Minnesota Rules, part 4725.4450 (2014)

Minnesota State Demographic Center. (2012). *Latest annual estimates of Minnesota and its cities and townships' population and households, 2012* [Data file]. Retrieved from https://mn.gov/admin/assets/mn_cities_townships_estimates_sdc_2016_tcm36-303998.xlsx.

Minnesota Statutes 2015, section 115.55, subdivision 5

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

Nelson, T., & Heger, S. (2017). Otter Tail Water Management District Septic System Use and Maintenance Evaluation. Retrieved from, https://septic.umn.edu/sites/septic.umn.edu/files/ottertail_maintenance_use_report_final_1.pdf

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. https://doi.org/10.1021/es9907663.

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

United States Environmental Protection Agency [US EPA]. (2009). *National primary drinking water regulations list* (EPA 816-F-09-004). Retrieved from, https://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 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

Private Well Field Log and Survey Form

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

MDA -Private Well Field Log & Well Survey Form

Water Treatment and Testing Information

1. Is this well the primary water supply for the residence? ☐ Yes ☐ No
2. Is this well used for drinking/cooking water? ☐ Yes ☐ No
3. Is there an indoor water treatment system? ☐ Yes ☐ No

   If yes, check system: ☐ Softened ☐ Distilled ☐ Reverse Osmosis

   ☐ Activated Carbon ☐ Other_____
4. Is there water treatment on the outdoor spigot? ☐ Yes ☐ No

   If yes, what type?_____
5. List additional samples taken at this site independent of the study_____

Well Construction Information

	HO Survey	HO Verbal	CWI
Construction Type			
Construction Date			
Well Depth			
Well Diameter			
Pump Installer			
Service			

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

   If yes, what type? ☐ Filtration System ☐ Raised Well ☐ Replaced Pump

   ☐ Upgraded Well Casing ☐ 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?_____

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

MDA -Private Well Field Log & Well Survey Form

DIRECTIONS

Stand at the well, find north and describe the type, position and distance to potential nitrate sources within 300 feet of the well. Put a dot where nitrate source is relative to the well. Label the dot with the appropriate code and label the distance. Codes are given below.

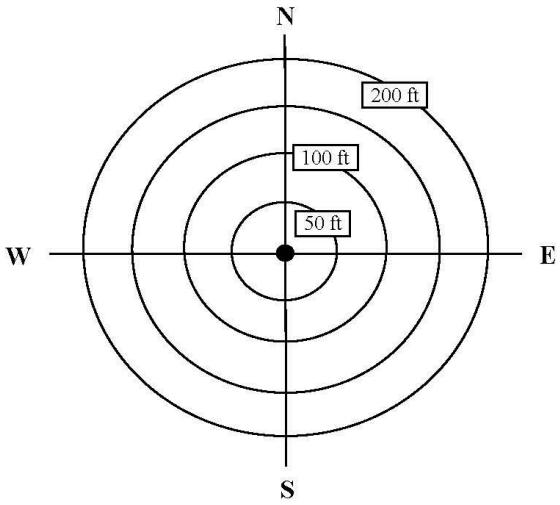
CODES

AFL: Animal Feedlot
APB: Animal/Poultry Building
MSA: Manure Storage Area
FSA: Fertilizer Storage Area
LAP: Land Application of Manure, Septage, Sewage Sludge, Waste
FWP: Feeding or Watering Area
DRA: Drain field - Above or Below Grade
PRV: Privy (Old Outhouse)
SET: Septic Tank
AGG: Dry Well, Leaching Pit, Seepage Pit, Injection Well, Agricultural Drainage Well
FIELD: Agricultural Field
HOME: House

5. Does water drain toward the well? ☐ Yes ☐ No
6. Which direction does the landscape slope?(Draw arrow across bull's eye, through well, and label)
7. Is the slope: ☐ Steep ☐ Shallow ☐ Flat
8. Are there any *obvious* problems with the well? ☐ Yes ☐ No
   If yes, describe the problem_____
9. Source codes, distances, and direction_____

_____

10. Are there potential nitrate sources nearby that are >300 ft. away from the well? If yes, list type direction and approximate distance_____



ADDITIONAL NOTES:

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 (Minnesota Rules, part 4725.4450; MDH, 2014).

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

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

Otter Tail County inspects SSTS for most areas in the county except areas within the Otter Tail Water Management District (OTWMD). The OTWMD includes Amor, Otter Tail, Everts and Girard Townships. This management district was established in 1981 and manages septic systems rigorously. With the help of EPA funding 850 of the existing 1,250 SSTS were replaced with two compartment tanks in 1985. Also, OTWMD inspects SSTS every two or three years and will pay for repairs or maintenance at properties in "active" management. All SSTS constructed since 2012 are required to be in active management (Nelson and Heger, 2017).

Inspections at the time of a property transfer are not required by the state, but some local government units like Otter Tail County elect to require this inspection. In 2016, Otter Tail County (including the OTWMD) reported a total of 23,888 SSTS and 977 systems (4.1 percent) were inspected for compliance. Otter Tail County had the 2rd highest number of compliance inspections for Minnesota (MPCA, 2017a).

FEEDLOT

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

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

Government agencies regulate feedlots to reduce the risk of contamination to water resources. Rules pertaining to feedlots have been in place since the 1970's; they were revised in 2000 and 2014 (MPCA, 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, 2015b).

As part of new feedlot construction, an environmental assessment must be completed for feedlots with a proposed capacity of greater than 1,000 AU. If the feedlot is located in a sensitive area the requirement for an environmental assessment is 500 AU (MPCA, 2017b).

Farmers must register their feedlot if it is in active status. Feedlots are considered active until no animals have been present on the feedlot for five years. To register, farmers fill out paperwork which includes a chart with the type and maximum number of animals on the feedlot (MPCA, 2015a). Registration is required to be completed at least once during a set four year period, the most recent period was from 2014 to 2017. Currently, approximately 24,000 feedlots are registered in Minnesota (MPCA, 2017b). A map and table of the feedlots located in the Otter Tail County study area can be found below (Figure 7; Table 10).

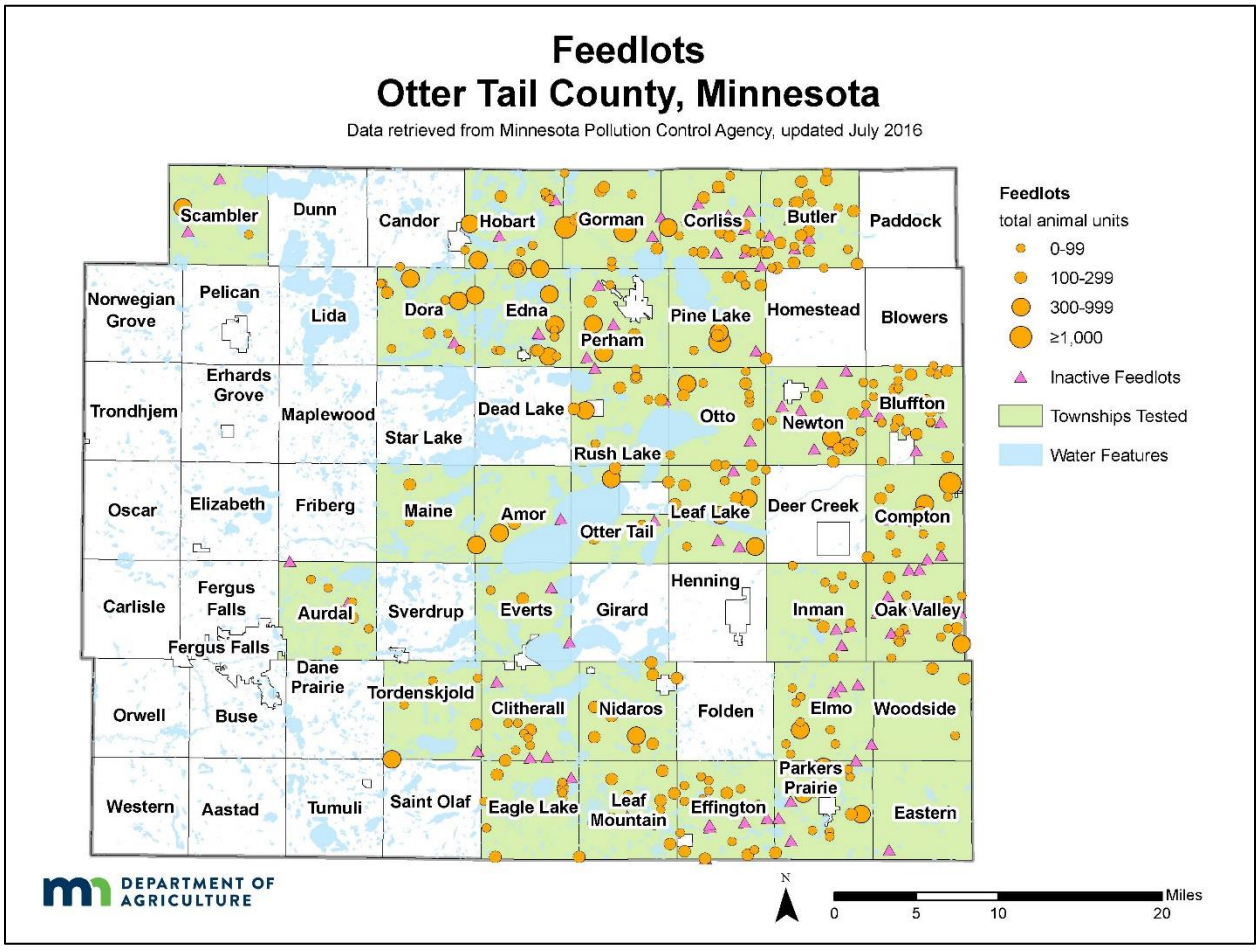


Figure 7. Feedlot Locations in Otter Tail County (MPCA, 2016)

On average there are 45 AU per square mile (0.071 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 Otter Tail County study area livestock densities average 0.363 AU per acre of row crops (MPCA, 2016 ; USDA NASS, 2013).

Table 10. Feedlots and Permitted Animal Unit Capacity, Otter Tail County

Township	Total Feedlots	Active Feedlots	Inactive feedlots	Average AU Permitted* Per Feedlot	Total Permitted* AU	Total Square Miles	Permitted* AU per Square Mile
Amor	4	3	1	300	899	35	26
Aurdal	9	7	2	54	381	35	11
Bluffton	29	25	4	85	2,124	33	64
Butler	31	26	5	141	3,663	36	102
Clitherall	11	8	3	126	1,007	35	29
Compton	15	11	4	247	2,712	36	75
Corliss	24	16	8	135	2,163	37	58
Dora	13	12	1	107	1,279	36	36
Eagle Lake	10	9	1	100	900	36	25
Eastern	2	0	2	0	0	37	0
Edna	16	14	2	265	3,708	35	106
Effington	23	18	5	93	1,665	35	48
Elmo	14	10	4	101	1,012	37	27
Everts	5	2	3	103	206	35	6
Gorman	13	11	2	348	3,832	36	106
Hobart	11	9	2	268	2,412	36	67
Inman	12	9	3	126	1,131	37	31
Leaf Lake	17	14	3	199	2,790	36	78
Leaf Mountain	11	10	1	153	1,527	36	42
Maine	4	4	0	82	328	36	9
Newton	21	14	7	137	1,917	35	55
Nidaros	9	9	0	223	2,008	35	57
Oak Valley	22	15	7	94	1,416	36	39
Otter Tail	5	4	1	229	917	30	31
Otto	14	13	1	155	2,012	36	56
Parkers Prairie	15	11	4	208	2,292	35	65
Perham	12	8	4	139	1,109	32	35
Pine Lake	11	10	1	281	2,814	36	78
Rush Lake	11	9	2	158	1,423	35	41
Scambler	4	2	2	265	530	36	15
Tordenskjold	8	6	2	108	649	36	18
Woodside	3	3	0	199	598	36	17
Total	409	322	87	160	51,424	1,133	45

*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.

FERTILIZER STORAGE LOCATION

MDA tracks licenses for bulk fertilizer storage facilities, anhydrous ammonia, and chemigation sites. A total of 588 sites are found in the Otter Tail study area and 581 of these are 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, Otter Tail County

Township	*Bulk Fertilizer Facility	*Anhydrous Ammonia	*Chemigation Sites	*Abandoned Sites	Total
Amor	0	0	33	0	33
Aurdal	0	0	0	0	0
Bluffton	0	0	2	0	2
Butler	0	0	0	0	0
Clitherall	0	0	2	0	2
Compton	1	0	47	0	48
Corliss	0	0	6	0	6
Dora	0	0	2	0	2
Eagle Lake	0	0	0	0	0
Eastern	0	0	18	0	18
Edna	0	0	10	0	10
Effington	0	0	1	0	1
Elmo	0	0	28	0	28
Everts	0	0	13	0	13
Gorman	0	0	65	0	65
Hobart	0	0	2	0	2
Inman	0	0	11	0	11
Leaf Lake	0	0	17	0	17
Leaf Mountain	0	0	1	0	1
Maine	0	0	18	0	18
Newton	0	0	0	0	0
Nidaros	0	0	19	0	19
Oak Valley	0	0	19	0	19
Otter Tail	0	0	22	0	22
Otto	0	1	33	0	34
Parkers Prairie	1	0	40	0	41
Perham	4	0	89	0	93
Pine Lake	0	0	32	0	32
Rush Lake	0	0	13	0	13

Township	*Bulk Fertilizer Facility	*Anhydrous Ammonia	*Chemigation Sites	*Abandoned Sites	Total
Scambler	0	0	26	0	26
Tordenskjold	0	0	1	0	1
Woodside	0	0	11	0	11
Total	6	1	581	0	588

* Data retrieved from MDA Pesticide and Fertilizer Management Division, 2015; updated December 2015

SPILLS AND INVESTIGATIONS

The MDA is responsible for investigating any fertilizer spills within Minnesota. Figure 8 shows the locations of mapped historic fertilizer spills within the Otter Tail 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, 2016a).

The MDA tracks several types of incidents. Incident investigations are typically for larger spills. There are two in the study area. Contingency areas are locations that have not been remediated because they were inaccessible or the contaminant could not be removed for some other reason. They are often a part of an incident investigation. There is one contingency area in this study area which is part of the incident investigation in Perham. Old emergency incidents were closed prior to March 1st, 2004 (MDA, 2016a), but they can still be a point source. At most of these older sites, the contaminants are unknown and their location may not be precise. Small spills and investigations are typically smaller emergency spills such as a truck spilling chemicals. It is important to note that while the locations of the incidents described are as accurate as possible, it is an incomplete dataset (MDA, 2016a). A breakdown of chemical type of these incidents can be found in Table 12. A breakdown of the fertilizer specific spills and investigations, by township, can be found in Table 13.

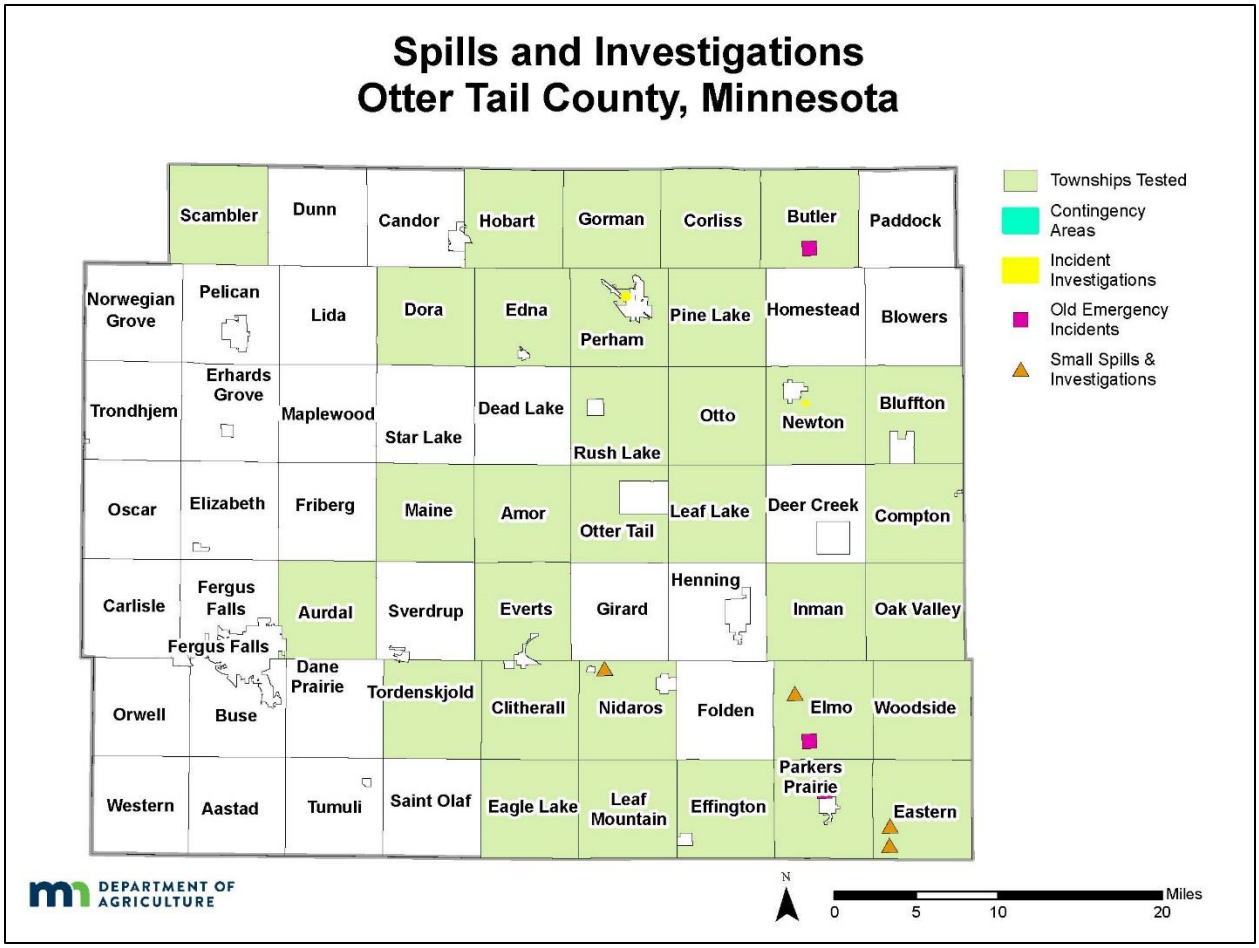


Figure 8. Fertilizer Spills and Investigations in Otter Tail County

Table 12. Spills and Investigations by Chemical Type, Otter Tail County

Contaminant	Incident Investigations	Contingency Areas	Small Spills and Investigations	Old Emergency Incidents	Total
Fertilizer	2	1	3	3	9
Pesticides & Fertilizer	0	0	0	0	0
Anhydrous Ammonia	0	0	1	0	1
Total	2	1	4	3	10

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

Township	Incidents and Spills
Amor	0
Aurdal	0
Bluffton	0
Butler	1
Clitherall	0
Compton	0
Corliss	0
Dora	0
Eagle Lake	0
Eastern	2
Edna	0
Effington	0
Elmo	2
Everts	0
Gorman	0
Hobart	0
Inman	0
Leaf Lake	0
Leaf Mountain	0
Maine	0
Newton	1
Nidaros	1
Oak Valley	0
Otter Tail	0
Otto	0
Parkers Prairie	1
Perham	2
Pine Lake	0
Rush Lake	0
Scambler	0
Tordenskjold	0
Woodside	0
Total	10

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 (Figure 9; Table 14). Row crops can include: corn, sweet corn, soybeans, alfalfa, sugar beets, potatoes, dry beans and double crops involving corn and soybeans. Overall the Otter Tail study area has 20% row crops.

Otter Tail is located in the northwestern region of Minnesota. In this area lakes and forests are a prominent landscape feature. In Otter Tail, Armor and Everts townships over 25 percent of the land cover is open water. In all of the study area townships at least 14 percent of the land cover is classified as forest (Figure 9 and Table 15).

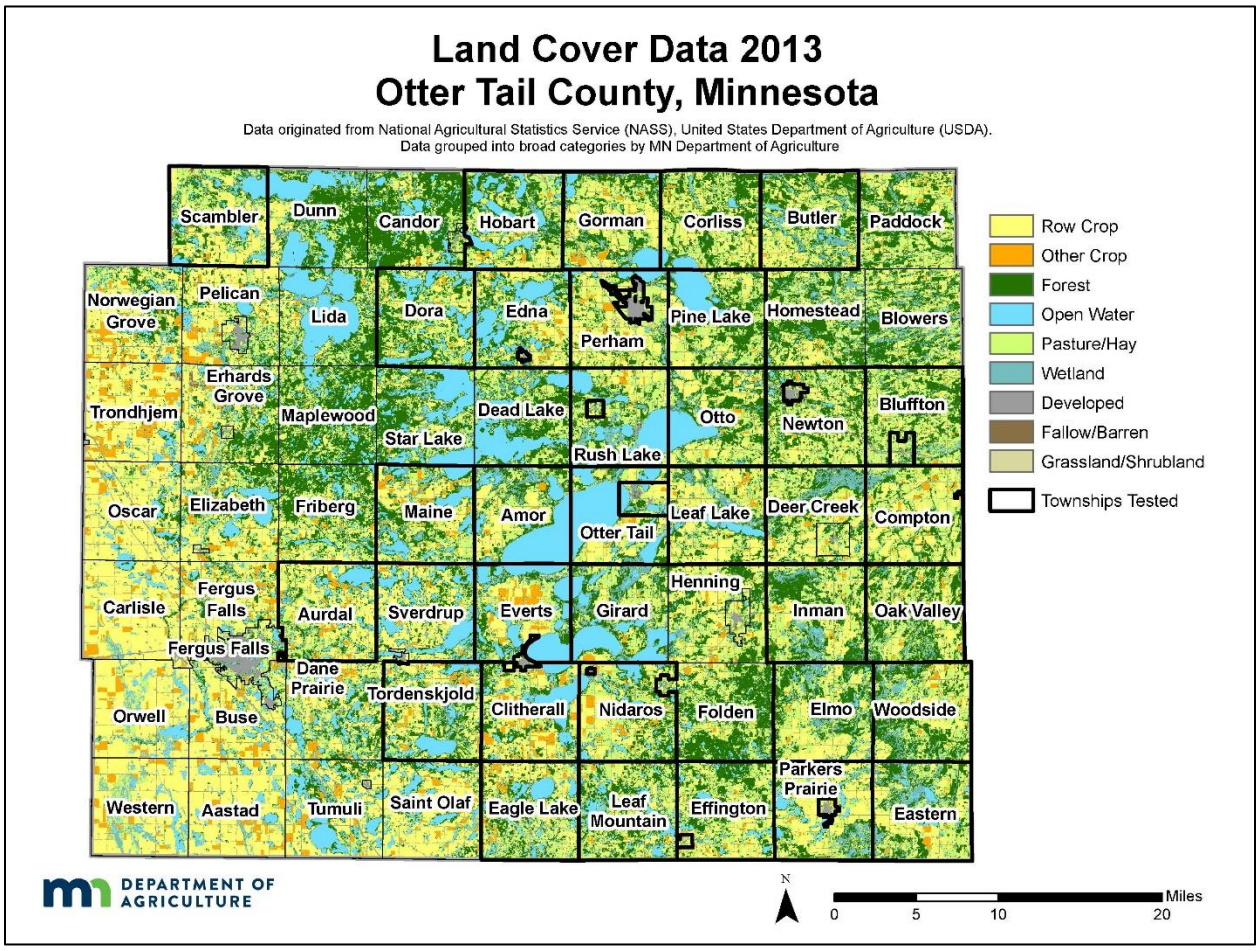


Figure 9. Land Cover in Otter Tail County

Table 14. Land Cover Data (2013) by Township, Otter Tail County

Township	Total Acres	Row Crops	Other Crops	Forest	Open Water	Pasture/Hay	Wetland	Developed	Fallow/ Barren	Grassland/ Shrubland
Amor	22,434	19%	2%	17%	34%	15%	9%	3%	0%	2%
Aurdal	22,643	34%	6%	17%	11%	22%	5%	5%	0%	1%
Bluffton	21,116	10%	2%	32%	0%	43%	7%	4%	0%	2%
Butler	22,955	14%	3%	33%	2%	31%	14%	3%	0%	1%
Clitherall	22,587	23%	11%	18%	18%	18%	5%	4%	0%	2%
Compton	22,819	28%	5%	20%	0%	36%	5%	5%	0%	1%
Corliss	23,637	19%	3%	35%	5%	31%	4%	3%	0%	1%
Dora	22,917	11%	2%	33%	19%	28%	2%	4%	0%	1%
Eagle Lake	23,033	18%	5%	20%	14%	27%	5%	4%	0%	7%
Eastern	23,361	19%	3%	25%	4%	30%	14%	3%	0%	2%
Edna	22,240	18%	4%	24%	24%	21%	4%	4%	0%	1%
Effington	22,361	22%	3%	27%	6%	33%	3%	4%	0%	1%
Elmo	23,516	21%	2%	30%	2%	29%	12%	3%	0%	1%
Everts	22,139	14%	9%	17%	33%	15%	5%	4%	0%	3%
Gorman	22,797	23%	6%	26%	9%	26%	6%	4%	0%	1%
Hobart	22,969	12%	3%	30%	21%	25%	4%	5%	0%	1%
Inman	23,371	16%	3%	33%	1%	30%	13%	3%	0%	1%

Township	Total Acres	Row Crops	Other Crops	Forest	Open Water	Pasture/Hay	Wetland	Developed	Fallow/ Barren	Grassland/ Shrubland
Leaf Lake	22,771	29%	4%	19%	8%	25%	11%	4%	0%	2%
Leaf Mountain	23,005	14%	2%	30%	11%	30%	5%	4%	0%	4%
Maine	22,984	20%	7%	23%	16%	21%	7%	4%	0%	1%
Newton	22,551	16%	3%	32%	1%	36%	5%	6%	0%	1%
Nidaros	22,170	21%	6%	22%	11%	28%	4%	4%	0%	3%
Oak Valley	22,879	15%	3%	37%	0%	31%	9%	3%	0%	2%
Otter Tail	18,954	15%	2%	14%	45%	15%	5%	3%	0%	1%
Otto	22,791	18%	3%	28%	13%	26%	7%	4%	0%	1%
Parkers Prairie	22,464	36%	2%	16%	8%	24%	8%	4%	0%	1%
Perham	21,193	28%	5%	16%	6%	33%	3%	7%	0%	1%
Pine Lake	22,834	12%	2%	31%	19%	27%	5%	4%	0%	1%
Rush Lake	22,262	10%	3%	21%	23%	28%	10%	4%	0%	1%
Scambler	23,258	29%	1%	22%	14%	23%	5%	5%	0%	1%
Tordenskjold	23,051	23%	6%	22%	15%	20%	6%	5%	0%	2%
Woodside	23,173	16%	3%	31%	0%	33%	11%	3%	0%	2%
Total	723,236	20%*	4%*	25%*	12%*	27%*	7%*	4%*	0%*	2%*

*Represents an average

Data originated from National Agriculture Statistics Service (NASS), USDA United States Department of Agriculture (USDA NASS, 2013). Data grouped into broad categories by MDA.

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, 2016a). There are a total of 841 active groundwater well permits in the study area and 828 are used for irrigating major crops (Tables 15-16; Figure 10). Over 90,000 acres of cropland is permitted for groundwater irrigation in this area (Table 15). Most permitted wells are withdrawing groundwater from the quaternary aquifer (Table 16; MDNR, 2016b).

Table 15. Active Groundwater Use Permits by Township, Otter Tail County

Township	Major Crop Irrigation Well Permits	Average Depth (feet)	Irrigated Acres
Amor	47	140	4,973
Aurdal	8	149	1,281
Bluffton	5	114	821
Butler	6	158	683
Clitherall	11	88	1,076
Compton	57	85	6,529
Corliss	18	153	2,005
Dora	8	91	976
Eagle Lake	0	0	0
Eastern	25	96	2,935
Edna	31	119	3,555
Effington	3	168	105
Elmo	43	83	4,844
Everts	23	148	2,684
Gorman	71	95	7,022
Hobart	12	102	1,382
Inman	15	80	1,281
Leaf Lake	33	120	4,283
Leaf Mountain	0	0	0
Maine	29	116	3,088
Newton	1	80	134
Nidaros	28	122	3,736
Oak Valley	33	59	2,947
Otter Tail	40	98	4,991
Otto	38	88	4,011
Parkers Prairie	65	107	6,988
Perham	69	120	7,688
Pine Lake	35	108	3,873
Rush Lake	29	108	3,838
Scambler	19	177	2,173
Tordenskjold	4	102	296
Woodside	22	61	2,557
Total	828	107	92,755

Table 16. Active Groundwater Use Permits by Aquifer, Otter Tail County

Water Use Well Permit	Total	Average Depth (feet)	Aquifer			
			Quaternary (Water Table)	Quaternary (Buried)	Paleozoic	Not Classified
Major Crop Irrigation	828	107	241	448	0	139
Non-Crop Irrigation	6	73	2	4	0	0
Heating/Cooling	1	52	1	0	0	0
Industrial Processing	2	119	1	1	0	0
Special Categories	4	158	0	4	0	0
Total	841	107	245	457	0	139

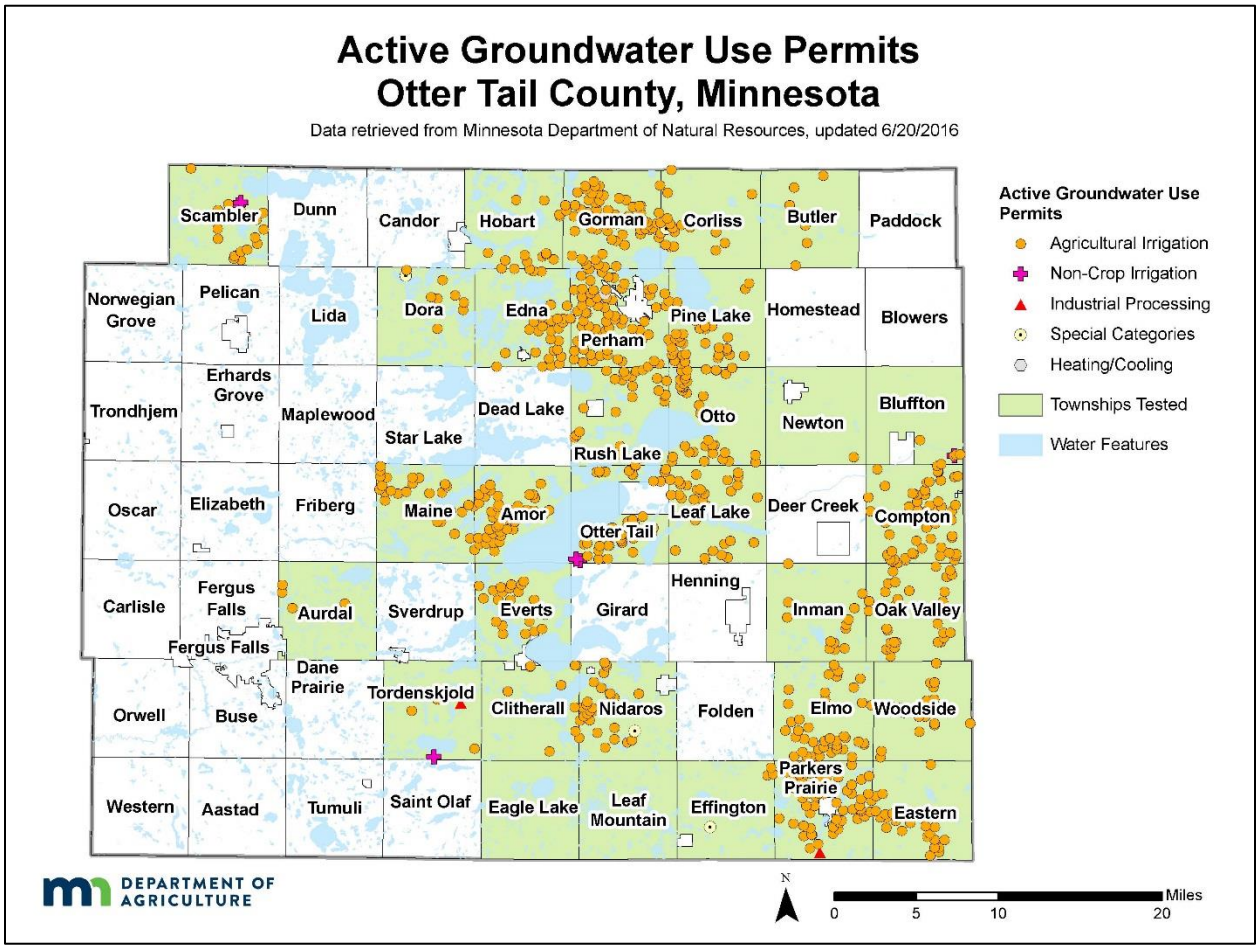


Figure 10. Active Groundwater Use Permits in Otter Tail County

APPENDIX D

Nitrate Brochure

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

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

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

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

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

If the Nitrate result is above 10 mg/L:

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

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

---

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

APPENDIX E

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

Township	Point Source	Well Construction Problem	Hand Dug well	Unsure of water source	Site Visit Completed - Well Not Found & Constructed before 1975 & No Well ID	No Site Visit & Constructed before 1975 & No Well ID	No Site Visit & Insufficient Data & No Well ID	Total
Amor	2	1	0	0	1	4	0	8
Aurdal	0	0	0	0	0	0	1	1
Bluffton	0	0	3	0	0	1	0	4
Butler	1	0	0	0	0	1	0	2
Clitherall	0	0	1	0	3	2	4	10
Compton	4	1	0	0	1	4	1	11
Corliss	0	1	0	0	0	2	2	5
Dora	2	0	0	0	0	3	1	6
Eagle Lake	2	0	0	0	1	0	1	4
Eastern	1	0	0	0	0	1	0	2
Edna	0	0	0	0	0	3	1	4
Effington	0	0	0	0	0	0	0	0
Elmo	1	2	0	0	0	3	2	8
Everts	0	0	0	0	1	1	1	3
Gorman	5	0	0	1	1	3	1	11
Hobart	0	0	0	1	0	0	1	2

Township	Point Source	Well Construction Problem	Hand Dug well	Unsure of water source	Site Visit Completed - Well Not Found & Constructed before 1975 & No Well ID	No Site Visit & Constructed before 1975 & No Well ID	No Site Visit & Insufficient Data & No Well ID	Total
Inman	2	0	0	1	0	0	0	3
Leaf Lake	0	1	1	0	1	2	1	6
Leaf Mountain	1	0	0	0	0	0	0	1
Maine	6	0	1	3	2	5	2	19
Newton	0	0	0	0	2	1	0	3
Nidaros	1	0	0	0	0	0	1	2
Oak Valley	2	0	0	1	1	2	2	8
Otter Tail	2	0	0	2	0	3	1	8
Otto	2	0	0	2	0	1	2	7
Parkers Prairie	0	0	0	0	1	3	0	4
Perham	3	1	0	0	0	4	0	8
Pine Lake	2	0	1	0	1	0	1	5
Rush Lake	1	0	0	1	0	2	0	4
Scambler	1	0	0	1	0	0	1	3
Tordenskjold	0	0	1	0	0	0	0	1
Woodside	1	0	0	2	0	0	1	4
Total	42	7	8	15	16	51	28	167

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

Township	Site Visit	No Site Visit	Total Wells Removed
Amor	2	6	8
Aurdal	0	1	1
Bluffton	1	3	4
Butler	0	2	2
Clitherall	3	7	10
Compton	4	7	11
Corliss	1	4	5
Dora	1	5	6
Eagle Lake	2	2	4
Eastern	0	2	2
Edna	0	4	4
Effington	0	0	0
Elmo	3	5	8
Everts	1	2	3
Gorman	4	7	11
Hobart	1	1	2
Inman	3	0	3
Leaf Lake	2	4	6
Leaf Mountain	1	0	1
Maine	7	12	19
Newton	2	1	3
Nidaros	0	2	2
Oak Valley	2	6	8
Otter Tail	4	4	8
Otto	4	3	7
Parkers Prairie	1	3	4
Perham	3	5	8
Pine Lake	2	3	5
Rush Lake	1	3	4
Scambler	2	1	3
Tordenskjold	0	1	1
Woodside	2	2	4
Total	59	108	167

APPENDIX F

MINNESOTA WELL INDEX

The MWI was used to gather information about the 32 townships in Otter Tail County included in the study. This section includes all domestic drinking water wells in the study area, not just wells MDA sampled. Table 19 summarizes the general aquifer types, while the following is a brief summary of the major aquifer types with the average well depth. According to the information from the MWI (MDH, 2017):

In these townships, there are 2,179 documented (have a verified location in the MWI) active, drinking water wells:

- Most wells are listed as "undesignated" with an average depth of 100 feet deep. Otter Tail County does not have a County Geologic Atlas yet. Typically after an atlas is completed well information such as the aquifer designation and geologic formations codes are completed in the well logs.
- Thirteen percent are completed in the shallow Quaternary Water Table Aquifer (QWTA) and are 71 feet deep on average.
- At 67 percent, the vast majority, are completed in a Quaternary buried aquifer and are 104 feet deep on average.

Table 19. Aquifer Type Distribution of Wells in Minnesota Well Index

Township	Total Wells	Quaternary Water Table	Quaternary Buried	Quaternary Undifferentiated	Undesignated
Amor	83	18%	41%	0%	41%
Aurdal	118	9%	76%	0%	14%
Bluffton	47	2%	98%	0%	0%
Butler	34	0%	97%	0%	3%
Clitherall	92	33%	41%	1%	25%
Compton	58	12%	74%	0%	14%
Corliss	59	2%	83%	0%	15%
Dora	152	12%	74%	1%	14%
Eagle Lake	64	6%	59%	0%	34%
Eastern	16	19%	81%	0%	0%
Edna	118	17%	75%	0%	8%
Effington	32	0%	88%	0%	13%
Elmo	31	6%	77%	0%	16%
Everts	137	15%	36%	0%	48%
Gorman	42	12%	79%	0%	10%
Hobart	131	8%	84%	0%	8%
Inman	23	22%	65%	0%	13%
Leaf Lake	57	18%	75%	0%	7%
Leaf Mountain	43	5%	65%	0%	30%

Township	Total Wells	Quaternary Water Table	Quaternary Buried	Quaternary Undifferentiated	Undesignated
Maine	67	34%	36%	0%	30%
Newton	99	0%	89%	1%	10%
Nidaros	53	30%	42%	2%	26%
Oak Valley	15	27%	73%	0%	0%
Otter Tail	75	21%	61%	0%	17%
Otto	58	10%	72%	0%	17%
Parkers Prairie	26	15%	81%	0%	4%
Perham	130	18%	48%	0%	34%
Pine Lake	68	3%	85%	0%	12%
Rush Lake	98	15%	69%	0%	15%
Scambler	37	19%	54%	3%	24%
Tordenskjold	95	6%	81%	1%	12%
Woodside	21	24%	57%	5%	14%
Total	2,179	13%	67%	0%	19%

APPENDIX G

Private Well Survey Questions

1. What setting did the water sample come from? Please choose only one.
   Answers choices: Sub-division, Lake Home, River Home, Country, Municipal/city, or Other.

2. Are there livestock on this property? Yes or No

3. Do you mix or store fertilizer (500lbs or more) on this property? Yes or No

4. Does farming take place on this property? Yes or No

Well Information Section

5. Does your well have a Unique Well ID number? Yes or No

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

7. Type of well construction?
   Answer choices: Drilled, Sand point, Hand dug, Other, and Don't Know.

8. Approximate age (years) of your well?
   Answer choices: 0-10 years, 11-20 years, 21-40 years, and over 40 years old.

9. Approximate depth of your well
   Answer choices: 0-49 feet, 50-99 feet, 100-299 feet, and 300 or more feet.

10. Distance to an active or inactive feedlot
    Answer choices: 0-49 feet, 50-99 feet, 100-299 feet, and 300 or more feet.

11. Distance to a septic system
    Answer choices: 0-49 feet, 50-99 feet, 100-299 feet, and 300 or more feet.

12. Distance to an agricultural field
    Answer choices: 0-49 feet, 50-99 feet, 100-299 feet, and 300 or more feet.

13. Is this well currently used for human consumption? Yes or No

14. Please check any water treatment you have other than a water softener.
    Answer choices: None, Reverse Osmosis, Distillation, Filtering System and Other.

15. When did you last have your well tested for nitrates?
    Answer choices: Never, within the last year, within the last 3 years, the last 10, or 10 or more.

16. What was the result of your last nitrate test?
    Answer choices: 0<3, 3<10, 10 or greater, or Don't Know.

APPENDIX H

Table 20. Property Setting for Well Location

Township	Total	Country	Lake	River Home	Sub-division	Municipality/ City	Other	Not available
Amor	211	16.1%	67.3%	1.4%	0.0%	0.0%	0.0%	15.2%
Aurdal	205	40.0%	15.6%	21.0%	2.4%	0.0%	0.0%	21.0%
Bluffton	40	87.5%	0.0%	0.0%	0.0%	0.0%	0.0%	12.5%
Butler	23	73.9%	0.0%	0.0%	0.0%	0.0%	0.0%	26.1%
Clitherall	192	21.4%	54.2%	0.0%	1.0%	0.0%	0.5%	22.9%
Compton	85	74.1%	0.0%	3.5%	4.7%	0.0%	0.0%	17.6%
Corliss	123	35.8%	41.5%	4.1%	0.0%	0.0%	0.0%	18.7%
Dora	294	11.6%	68.0%	0.0%	0.0%	0.0%	0.3%	20.1%
Eagle Lake	130	30.0%	55.4%	0.0%	0.0%	0.0%	0.0%	14.6%
Eastern	38	78.9%	5.3%	0.0%	0.0%	0.0%	2.6%	13.2%
Edna	313	14.4%	68.4%	0.0%	0.0%	0.0%	0.3%	16.9%
Effington	34	70.6%	8.8%	0.0%	0.0%	0.0%	0.0%	20.6%
Elmo	44	68.2%	2.3%	0.0%	0.0%	0.0%	0.0%	29.5%
Everts	360	7.8%	68.6%	1.7%	0.0%	0.0%	0.3%	21.7%
Gorman	113	43.4%	36.3%	1.8%	0.0%	0.0%	0.9%	17.7%
Hobart	228	18.4%	59.2%	0.4%	0.0%	0.0%	0.0%	21.9%
Inman	36	72.2%	0.0%	0.0%	0.0%	0.0%	2.8%	25.0%
Leaf Lake	140	24.3%	57.1%	0.0%	0.0%	0.0%	0.7%	17.9%
Leaf Mountain	63	57.1%	25.4%	0.0%	0.0%	0.0%	0.0%	17.5%
Maine	201	17.9%	55.7%	5.5%	0.0%	0.0%	1.0%	19.9%
Newton	100	76.0%	0.0%	0.0%	1.0%	0.0%	0.0%	23.0%
Nidaros	128	20.3%	60.2%	0.0%	0.8%	0.0%	0.8%	18.0%
Oak Valley	42	90.5%	0.0%	0.0%	0.0%	0.0%	0.0%	9.5%
Otter Tail	250	6.4%	69.2%	6.0%	0.4%	0.0%	0.4%	17.6%
Otto	121	35.5%	34.7%	3.3%	0.0%	0.0%	2.5%	24.0%
Parkers Prairie	56	76.8%	7.1%	0.0%	1.8%	0.0%	0.0%	14.3%
Perham	152	49.3%	23.7%	2.6%	4.6%	0.0%	0.0%	19.7%
Pine Lake	192	27.6%	52.6%	1.0%	0.5%	0.0%	0.5%	17.7%
Rush Lake	267	19.1%	52.4%	4.1%	0.7%	0.4%	0.0%	23.2%
Scambler	178	16.3%	59.0%	0.0%	0.0%	0.0%	1.1%	23.6%
Tordenskjold	139	28.1%	55.4%	0.0%	0.0%	0.0%	0.7%	15.8%
Woodside	35	88.6%	0.0%	0.0%	0.0%	0.0%	0.0%	11.4%
Total	4,533	28.4%	48.7%	2.4%	0.6%	0.0%	0.4%	19.5%

Table 21. Well Construction Type

Township	Total	Drilled	Sand point	Hand Dug	Other	Not Available
Amor	211	55.9%	23.7%	0.0%	0.0%	20.4%
Aurdal	205	70.2%	2.4%	0.0%	0.0%	27.3%
Bluffton	40	65.0%	7.5%	7.5%	0.0%	20.0%
Butler	23	60.9%	13.0%	0.0%	0.0%	26.1%
Clitherall	192	51.0%	16.7%	0.5%	0.5%	31.3%
Compton	85	47.1%	31.8%	0.0%	0.0%	21.2%
Corliss	123	58.5%	13.0%	0.0%	0.0%	28.5%
Dora	294	54.4%	20.1%	0.0%	0.0%	25.5%
Eagle Lake	130	67.7%	12.3%	0.0%	0.8%	19.2%
Eastern	38	65.8%	15.8%	0.0%	0.0%	18.4%
Edna	313	60.7%	16.3%	0.0%	0.3%	22.7%
Effington	34	64.7%	8.8%	0.0%	0.0%	26.5%
Elmo	44	43.2%	22.7%	0.0%	0.0%	34.1%
Everts	360	49.4%	22.2%	0.0%	0.3%	28.1%
Gorman	113	51.3%	26.5%	0.0%	0.0%	22.1%
Hobart	228	60.1%	11.8%	0.0%	0.0%	28.1%
Inman	36	44.4%	22.2%	0.0%	0.0%	33.3%
Leaf Lake	140	63.6%	12.1%	0.7%	0.0%	23.6%
Leaf Mountain	63	68.3%	4.8%	0.0%	0.0%	27.0%
Maine	201	49.3%	26.9%	0.5%	0.0%	23.4%
Newton	100	70.0%	5.0%	0.0%	1.0%	24.0%
Nidaros	128	63.3%	10.2%	0.0%	0.0%	26.6%
Oak Valley	42	35.7%	54.8%	0.0%	0.0%	9.5%
Otter Tail	250	55.6%	17.2%	0.0%	0.0%	27.2%
Otto	121	47.9%	21.5%	0.0%	0.0%	30.6%
Parkers Prairie	56	62.5%	16.1%	0.0%	1.8%	19.6%
Perham	152	64.5%	13.8%	0.0%	0.0%	21.7%
Pine Lake	192	62.0%	14.6%	0.5%	0.0%	22.9%
Rush Lake	267	50.9%	21.3%	0.0%	0.0%	27.7%
Scambler	178	56.2%	14.6%	0.0%	0.0%	29.2%
Tordenskjold	139	69.1%	7.2%	0.7%	0.7%	22.3%
Woodside	35	48.6%	31.4%	0.0%	0.0%	20.0%
Total	4,533	57.4%	17.0%	0.2%	0.2%	25.3%

Table 22. Age of Well

Township	Total	0-10 years	11-20 years	21-40 years	Over 40 years	Not available
Amor	211	24.2%	19.9%	22.7%	13.7%	19.4%
Aurdal	205	11.7%	31.7%	31.2%	3.4%	22.0%
Bluffton	40	25.0%	20.0%	15.0%	25.0%	15.0%
Butler	23	21.7%	8.7%	34.8%	8.7%	26.1%
Clitherall	192	16.7%	27.1%	23.4%	7.3%	25.5%
Compton	85	18.8%	15.3%	28.2%	17.6%	20.0%
Corliss	123	22.0%	26.8%	16.3%	14.6%	20.3%
Dora	294	15.6%	27.2%	26.2%	8.5%	22.4%
Eagle Lake	130	23.1%	21.5%	29.2%	9.2%	16.9%
Eastern	38	18.4%	18.4%	31.6%	18.4%	13.2%
Edna	313	17.6%	29.4%	24.6%	8.6%	19.8%
Effington	34	14.7%	26.5%	26.5%	11.8%	20.6%
Elmo	44	15.9%	22.7%	15.9%	13.6%	31.8%
Everts	360	22.5%	21.9%	20.3%	11.4%	23.9%
Gorman	113	23.0%	24.8%	21.2%	10.6%	20.4%
Hobart	228	22.8%	29.8%	20.2%	4.8%	22.4%
Inman	36	16.7%	16.7%	22.2%	16.7%	27.8%
Leaf Lake	140	17.9%	23.6%	23.6%	12.9%	22.1%
Leaf Mountain	63	9.5%	27.0%	28.6%	12.7%	22.2%
Maine	201	18.9%	20.9%	28.9%	8.5%	22.9%
Newton	100	19.0%	18.0%	28.0%	14.0%	21.0%
Nidaros	128	24.2%	19.5%	28.1%	7.8%	20.3%
Oak Valley	42	21.4%	31.0%	21.4%	14.3%	11.9%
Otter Tail	250	24.8%	24.0%	23.6%	7.2%	20.4%
Otto	121	20.7%	23.1%	19.8%	12.4%	24.0%
Parkers Prairie	56	26.8%	21.4%	14.3%	19.6%	17.9%
Perham	152	15.8%	24.3%	31.6%	9.2%	19.1%
Pine Lake	192	18.2%	25.0%	29.7%	5.2%	21.9%
Rush Lake	267	22.1%	25.1%	22.5%	4.5%	25.8%
Scambler	178	31.5%	21.9%	17.4%	7.3%	21.9%
Tordenskjold	139	19.4%	29.5%	28.8%	4.3%	18.0%
Woodside	35	22.9%	25.7%	20.0%	14.3%	17.1%
Total	4,533	20.3%	24.5%	24.3%	9.3%	21.6%

Table 23. Depth of Well

Township	Total	0-50 ft	51-100 ft	101-300 ft	Over 300 ft	NA
Amor	211	21.8%	24.2%	25.1%	0.5%	28.4%
Aurdal	205	1.0%	36.6%	29.8%	1.0%	31.7%
Bluffton	40	15.0%	25.0%	32.5%	2.5%	25.0%
Butler	23	13.0%	21.7%	39.1%	0.0%	26.1%
Clitherall	192	17.2%	31.3%	17.7%	0.5%	33.3%
Compton	85	29.4%	34.1%	12.9%	0.0%	23.5%
Corliss	123	13.8%	25.2%	28.5%	4.9%	27.6%
Dora	294	21.1%	34.7%	15.0%	1.0%	28.2%
Eagle Lake	130	10.0%	39.2%	24.6%	0.8%	25.4%
Eastern	38	34.2%	23.7%	23.7%	2.6%	15.8%
Edna	313	14.4%	37.4%	20.8%	0.0%	27.5%
Effington	34	8.8%	11.8%	50.0%	0.0%	29.4%
Elmo	44	25.0%	22.7%	20.5%	0.0%	31.8%
Everts	360	19.4%	29.4%	16.9%	0.3%	33.9%
Gorman	113	23.9%	23.0%	30.1%	0.0%	23.0%
Hobart	228	11.8%	38.6%	19.3%	0.4%	29.8%
Inman	36	22.2%	27.8%	13.9%	0.0%	36.1%
Leaf Lake	140	17.1%	26.4%	30.0%	0.0%	26.4%
Leaf Mountain	63	7.9%	11.1%	49.2%	7.9%	23.8%
Maine	201	22.9%	35.8%	10.9%	0.5%	29.9%
Newton	100	7.0%	32.0%	35.0%	0.0%	26.0%
Nidaros	128	13.3%	33.6%	19.5%	3.9%	29.7%
Oak Valley	42	59.5%	19.0%	9.5%	0.0%	11.9%
Otter Tail	250	18.4%	32.0%	20.0%	0.0%	29.6%
Otto	121	23.1%	31.4%	17.4%	0.0%	28.1%
Parkers Prairie	56	21.4%	16.1%	41.1%	0.0%	21.4%
Perham	152	10.5%	29.6%	32.2%	0.7%	27.0%
Pine Lake	192	16.7%	26.6%	30.7%	1.0%	25.0%
Rush Lake	267	18.4%	40.8%	9.0%	0.0%	31.8%
Scambler	178	12.9%	32.6%	26.4%	0.0%	28.1%
Tordenskjold	139	7.9%	28.8%	36.0%	0.7%	26.6%
Woodside	35	34.3%	20.0%	20.0%	5.7%	20.0%
Total	4,533	16.9%	31.3%	22.6%	0.8%	28.4%

Table 24. Unique Well ID Known

Township	Total	No Unique Well ID	Yes Unique Well ID	Not Available
Amor	211	29.4%	19.4%	51.2%
Aurdal	205	20.0%	24.4%	55.6%
Bluffton	40	30.0%	22.5%	47.5%
Butler	23	34.8%	13.0%	52.2%
Clitherall	192	16.1%	20.8%	63.0%
Compton	85	30.6%	10.6%	58.8%
Corliss	123	13.0%	29.3%	57.7%
Dora	294	19.4%	17.7%	62.9%
Eagle Lake	130	23.8%	26.9%	49.2%
Eastern	38	34.2%	21.1%	44.7%
Edna	313	18.8%	25.9%	55.3%
Effington	34	23.5%	17.6%	58.8%
Elmo	44	27.3%	18.2%	54.5%
Everts	360	19.7%	23.6%	56.7%
Gorman	113	24.8%	23.9%	51.3%
Hobart	228	22.8%	27.6%	49.6%
Inman	36	30.6%	19.4%	50.0%
Leaf Lake	140	17.9%	27.1%	55.0%
Leaf Mountain	63	25.4%	17.5%	57.1%
Maine	201	20.9%	21.9%	57.2%
Newton	100	16.0%	18.0%	66.0%
Nidaros	128	15.6%	28.1%	56.3%
Oak Valley	42	57.1%	9.5%	33.3%
Otter Tail	250	20.4%	27.2%	52.4%
Otto	121	23.1%	22.3%	54.5%
Parkers Prairie	56	25.0%	28.6%	46.4%
Perham	152	21.1%	24.3%	54.6%
Pine Lake	192	27.1%	20.3%	52.6%
Rush Lake	267	18.0%	25.5%	56.6%
Scambler	178	17.4%	28.1%	54.5%
Tordenskjold	139	19.4%	25.9%	54.7%
Woodside	35	28.6%	8.6%	62.9%
Total	4,533	21.5%	23.3%	55.2%

Table 25. Livestock Located on Property

Township	Total	No Livestock	Yes Livestock	Not Available
Amor	211	84.8%	0.0%	15.2%
Aurdal	205	80.0%	0.0%	20.0%
Bluffton	40	65.0%	22.5%	12.5%
Butler	23	52.2%	21.7%	26.1%
Clitherall	192	72.9%	3.6%	23.4%
Compton	85	72.9%	9.4%	17.6%
Corliss	123	74.0%	7.3%	18.7%
Dora	294	77.6%	2.0%	20.4%
Eagle Lake	130	77.7%	4.6%	17.7%
Eastern	38	71.1%	15.8%	13.2%
Edna	313	80.8%	1.6%	17.6%
Effington	34	64.7%	11.8%	23.5%
Elmo	44	63.6%	9.1%	27.3%
Everts	360	77.8%	1.4%	20.8%
Gorman	113	76.1%	7.1%	16.8%
Hobart	228	76.8%	1.8%	21.5%
Inman	36	63.9%	13.9%	22.2%
Leaf Lake	140	78.6%	2.9%	18.6%
Leaf Mountain	63	66.7%	17.5%	15.9%
Maine	201	79.1%	1.0%	19.9%
Newton	100	70.0%	8.0%	22.0%
Nidaros	128	76.6%	3.9%	19.5%
Oak Valley	42	64.3%	23.8%	11.9%
Otter Tail	250	81.6%	0.0%	18.4%
Otto	121	75.2%	4.1%	20.7%
Parkers Prairie	56	78.6%	5.4%	16.1%
Perham	152	77.0%	3.3%	19.7%
Pine Lake	192	80.7%	1.6%	17.7%
Rush Lake	267	73.0%	3.7%	23.2%
Scambler	178	74.2%	2.8%	23.0%
Tordenskjold	139	80.6%	2.9%	16.5%
Woodside	35	77.1%	8.6%	14.3%
Total	4,533	76.8%	3.7%	19.5%

Table 26. Fertilizer Stored on Property

Township	Total	No Fertilizer Stored	Yes Fertilizer Stored	Not Available
Amor	211	84.8%	0.0%	15.2%
Aurdal	205	80.0%	0.0%	20.0%
Bluffton	40	85.0%	2.5%	12.5%
Butler	23	73.9%	0.0%	26.1%
Clitherall	192	76.0%	0.0%	24.0%
Compton	85	82.4%	0.0%	17.6%
Corliss	123	78.0%	0.8%	21.1%
Dora	294	78.9%	0.0%	21.1%
Eagle Lake	130	82.3%	0.0%	17.7%
Eastern	38	86.8%	0.0%	13.2%
Edna	313	81.8%	0.6%	17.6%
Effington	34	76.5%	0.0%	23.5%
Elmo	44	70.5%	0.0%	29.5%
Everts	360	78.9%	0.0%	21.1%
Gorman	113	80.5%	1.8%	17.7%
Hobart	228	78.5%	0.0%	21.5%
Inman	36	77.8%	0.0%	22.2%
Leaf Lake	140	80.0%	1.4%	18.6%
Leaf Mountain	63	81.0%	3.2%	15.9%
Maine	201	79.1%	0.0%	20.9%
Newton	100	76.0%	1.0%	23.0%
Nidaros	128	80.5%	0.0%	19.5%
Oak Valley	42	88.1%	2.4%	9.5%
Otter Tail	250	81.2%	0.0%	18.8%
Otto	121	78.5%	0.8%	20.7%
Parkers Prairie	56	83.9%	0.0%	16.1%
Perham	152	80.3%	0.0%	19.7%
Pine Lake	192	80.7%	0.0%	19.3%
Rush Lake	267	75.7%	0.7%	23.6%
Scambler	178	75.8%	0.6%	23.6%
Tordenskjold	139	84.2%	0.0%	15.8%
Woodside	35	85.7%	0.0%	14.3%
Total	4,533	79.8%	0.4%	19.9%

Table 27. Farming on Property

Township	Total	No Farming	Yes Farming	Not Available
Amor	211	79.1%	5.2%	15.6%
Aurdal	205	67.3%	12.7%	20.0%
Bluffton	40	47.5%	40.0%	12.5%
Butler	23	30.4%	43.5%	26.1%
Clitherall	192	67.7%	8.3%	24.0%
Compton	85	52.9%	29.4%	17.6%
Corliss	123	56.1%	23.6%	20.3%
Dora	294	75.2%	4.4%	20.4%
Eagle Lake	130	66.9%	15.4%	17.7%
Eastern	38	23.7%	63.2%	13.2%
Edna	313	76.4%	5.8%	17.9%
Effington	34	35.3%	38.2%	26.5%
Elmo	44	50.0%	22.7%	27.3%
Everts	360	75.3%	3.3%	21.4%
Gorman	113	56.6%	25.7%	17.7%
Hobart	228	70.2%	8.3%	21.5%
Inman	36	30.6%	47.2%	22.2%
Leaf Lake	140	70.7%	10.0%	19.3%
Leaf Mountain	63	58.7%	25.4%	15.9%
Maine	201	71.1%	8.0%	20.9%
Newton	100	43.0%	34.0%	23.0%
Nidaros	128	68.0%	12.5%	19.5%
Oak Valley	42	28.6%	61.9%	9.5%
Otter Tail	250	79.6%	1.6%	18.8%
Otto	121	66.1%	13.2%	20.7%
Parkers Prairie	56	58.9%	25.0%	16.1%
Perham	152	71.1%	9.2%	19.7%
Pine Lake	192	75.5%	5.7%	18.8%
Rush Lake	267	72.3%	4.5%	23.2%
Scambler	178	71.9%	5.1%	23.0%
Tordenskjold	139	71.9%	11.5%	16.5%
Woodside	35	45.7%	37.1%	17.1%
Total	4,533	68.3%	11.9%	19.9%

Table 28. Distance to an Active or Inactive Feedlot

Township	Total	0-50 feet	51-100 feet	101-300 feet	Over 300 feet	Not Available
Amor	211	0.9%	0.0%	0.5%	73.9%	24.6%
Aurdal	205	3.4%	0.5%	2.0%	63.4%	30.7%
Bluffton	40	2.5%	7.5%	10.0%	55.0%	25.0%
Butler	23	0.0%	4.3%	13.0%	43.5%	39.1%
Clitherall	192	2.6%	0.5%	2.1%	64.1%	30.7%
Compton	85	1.2%	4.7%	9.4%	50.6%	34.1%
Corliss	123	4.1%	0.8%	4.9%	64.2%	26.0%
Dora	294	4.8%	0.0%	1.4%	65.0%	28.9%
Eagle Lake	130	1.5%	0.8%	1.5%	67.7%	28.5%
Eastern	38	7.9%	2.6%	7.9%	52.6%	28.9%
Edna	313	4.2%	0.6%	1.0%	65.8%	28.4%
Effington	34	2.9%	5.9%	11.8%	47.1%	32.4%
Elmo	44	6.8%	4.5%	6.8%	34.1%	47.7%
Everts	360	1.1%	0.3%	0.6%	63.9%	34.2%
Gorman	113	2.7%	1.8%	11.5%	57.5%	26.5%
Hobart	228	3.1%	1.3%	3.9%	64.0%	27.6%
Inman	36	5.6%	5.6%	11.1%	27.8%	50.0%
Leaf Lake	140	3.6%	0.0%	2.9%	67.1%	26.4%
Leaf Mountain	63	3.2%	1.6%	4.8%	57.1%	33.3%
Maine	201	4.5%	1.0%	1.0%	63.2%	30.3%
Newton	100	5.0%	4.0%	6.0%	46.0%	39.0%
Nidaros	128	3.1%	0.8%	0.0%	64.1%	32.0%
Oak Valley	42	4.8%	7.1%	16.7%	40.5%	31.0%
Otter Tail	250	1.2%	0.4%	0.4%	68.0%	30.0%
Otto	121	5.0%	1.7%	2.5%	58.7%	32.2%
Parkers Prairie	56	8.9%	1.8%	10.7%	51.8%	26.8%
Perham	152	2.6%	2.0%	2.0%	62.5%	30.9%
Pine Lake	192	2.1%	0.5%	3.6%	61.5%	32.3%
Rush Lake	267	1.5%	1.5%	1.5%	59.6%	36.0%
Scambler	178	3.9%	0.0%	1.1%	66.3%	28.7%
Tordenskjold	139	4.3%	2.2%	2.9%	68.3%	22.3%
Woodside	35	2.9%	0.0%	11.4%	51.4%	34.3%
Total	4,533	3.1%	1.2%	2.9%	62.3%	30.5%

Table 29. Distance to Septic System

Township	Total	0-50 feet	51-100 feet	101-300 feet	Over 300 feet	Not Available
Amor	211	8.5%	35.5%	26.5%	7.1%	22.3%
Aurdal	205	1.5%	32.7%	38.5%	5.9%	21.5%
Bluffton	40	2.5%	37.5%	42.5%	2.5%	15.0%
Butler	23	0.0%	34.8%	34.8%	4.3%	26.1%
Clitherall	192	5.7%	38.0%	26.0%	4.7%	25.5%
Compton	85	7.1%	31.8%	35.3%	3.5%	22.4%
Corliss	123	3.3%	30.1%	37.4%	7.3%	22.0%
Dora	294	2.4%	38.1%	30.6%	6.5%	22.4%
Eagle Lake	130	6.2%	29.2%	39.2%	6.2%	19.2%
Eastern	38	2.6%	23.7%	47.4%	13.2%	13.2%
Edna	313	5.1%	41.9%	26.5%	6.7%	19.8%
Effington	34	2.9%	29.4%	20.6%	23.5%	23.5%
Elmo	44	4.5%	36.4%	20.5%	9.1%	29.5%
Everts	360	5.8%	43.3%	20.8%	3.1%	26.9%
Gorman	113	8.8%	34.5%	31.0%	8.0%	17.7%
Hobart	228	2.2%	33.8%	36.4%	3.9%	23.7%
Inman	36	0.0%	13.9%	44.4%	11.1%	30.6%
Leaf Lake	140	2.1%	41.4%	31.4%	5.0%	20.0%
Leaf Mountain	63	4.8%	25.4%	38.1%	11.1%	20.6%
Maine	201	6.0%	35.8%	30.8%	6.0%	21.4%
Newton	100	1.0%	33.0%	39.0%	4.0%	23.0%
Nidaros	128	7.8%	29.7%	29.7%	7.8%	25.0%
Oak Valley	42	19.0%	35.7%	23.8%	11.9%	9.5%
Otter Tail	250	4.0%	36.0%	29.6%	6.0%	24.4%
Otto	121	11.6%	33.9%	23.1%	6.6%	24.8%
Parkers Prairie	56	3.6%	39.3%	32.1%	5.4%	19.6%
Perham	152	4.6%	30.9%	40.8%	2.6%	21.1%
Pine Lake	192	3.1%	43.8%	26.6%	6.3%	20.3%
Rush Lake	267	3.7%	40.8%	24.7%	3.0%	27.7%
Scambler	178	3.4%	33.1%	33.1%	3.9%	26.4%
Tordenskjold	139	5.0%	36.7%	33.1%	6.5%	18.7%
Woodside	35	5.7%	28.6%	31.4%	8.6%	25.7%
Total	4,533	4.7%	36.2%	30.6%	5.8%	22.7%

Table 30. Distance to an Agricultural Field

Township	Total	0-50 feet	51-100 feet	101-300 feet	Over 300 feet	Not Available
Amor	211	0.9%	3.3%	6.6%	68.7%	20.4%
Aurdal	205	1.5%	3.9%	18.0%	54.6%	22.0%
Bluffton	40	2.5%	2.5%	35.0%	40.0%	20.0%
Butler	23	0.0%	4.3%	30.4%	39.1%	26.1%
Clitherall	192	2.6%	3.1%	10.9%	56.8%	26.6%
Compton	85	5.9%	11.8%	24.7%	36.5%	21.2%
Corliss	123	4.1%	1.6%	17.1%	54.5%	22.8%
Dora	294	2.7%	2.0%	5.8%	65.6%	23.8%
Eagle Lake	130	2.3%	3.1%	16.2%	52.3%	26.2%
Eastern	38	7.9%	10.5%	21.1%	44.7%	15.8%
Edna	313	2.6%	3.8%	10.9%	58.8%	24.0%
Effington	34	5.9%	14.7%	14.7%	35.3%	29.4%
Elmo	44	2.3%	0.0%	27.3%	36.4%	34.1%
Everts	360	1.9%	1.1%	9.7%	57.8%	29.4%
Gorman	113	1.8%	7.1%	20.4%	50.4%	20.4%
Hobart	228	2.6%	3.1%	14.9%	54.4%	25.0%
Inman	36	2.8%	5.6%	27.8%	36.1%	27.8%
Leaf Lake	140	1.4%	4.3%	16.4%	56.4%	21.4%
Leaf Mountain	63	1.6%	9.5%	9.5%	54.0%	25.4%
Maine	201	3.5%	1.5%	13.4%	59.2%	22.4%
Newton	100	4.0%	11.0%	17.0%	43.0%	25.0%
Nidaros	128	0.8%	2.3%	7.0%	64.1%	25.8%
Oak Valley	42	9.5%	16.7%	14.3%	50.0%	9.5%
Otter Tail	250	1.6%	1.6%	6.8%	67.2%	22.8%
Otto	121	1.7%	5.8%	10.7%	54.5%	27.3%
Parkers Prairie	56	1.8%	7.1%	25.0%	46.4%	19.6%
Perham	152	0.7%	3.3%	14.5%	57.9%	23.7%
Pine Lake	192	1.6%	0.0%	5.2%	66.1%	27.1%
Rush Lake	267	1.5%	1.1%	10.5%	57.3%	29.6%
Scambler	178	2.2%	3.4%	10.7%	56.7%	27.0%
Tordenskjold	139	0.7%	2.2%	20.1%	59.0%	18.0%
Woodside	35	0.0%	8.6%	25.7%	45.7%	20.0%
Total	4,533	2.2%	3.5%	12.8%	57.0%	24.4%

Table 31. Drinking Water Well

Township	Total	Not used for drinking	Yes used for drinking	Not available
Amor	211	3.3%	81.5%	15.2%
Aurdal	205	2.0%	79.0%	19.0%
Bluffton	40	0.0%	85.0%	15.0%
Butler	23	8.7%	60.9%	30.4%
Clitherall	192	2.6%	74.0%	23.4%
Compton	85	2.4%	77.6%	20.0%
Corliss	123	2.4%	76.4%	21.1%
Dora	294	5.1%	73.5%	21.4%
Eagle Lake	130	2.3%	82.3%	15.4%
Eastern	38	2.6%	84.2%	13.2%
Edna	313	3.5%	77.3%	19.2%
Effington	34	5.9%	73.5%	20.6%
Elmo	44	0.0%	72.7%	27.3%
Everts	360	4.7%	73.3%	21.9%
Gorman	113	8.0%	75.2%	16.8%
Hobart	228	3.1%	75.9%	21.1%
Inman	36	2.8%	75.0%	22.2%
Leaf Lake	140	1.4%	78.6%	20.0%
Leaf Mountain	63	1.6%	82.5%	15.9%
Maine	201	4.5%	76.1%	19.4%
Newton	100	3.0%	76.0%	21.0%
Nidaros	128	6.3%	73.4%	20.3%
Oak Valley	42	7.1%	83.3%	9.5%
Otter Tail	250	4.4%	76.8%	18.8%
Otto	121	3.3%	75.2%	21.5%
Parkers Prairie	56	1.8%	83.9%	14.3%
Perham	152	4.6%	76.3%	19.1%
Pine Lake	192	4.2%	77.6%	18.2%
Rush Lake	267	3.4%	72.3%	24.3%
Scambler	178	6.2%	70.8%	23.0%
Tordenskjold	139	4.3%	79.9%	15.8%
Woodside	35	8.6%	71.4%	20.0%
Total	4,533	3.9%	76.3%	19.9%

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

Township	Total	None	Filtering System	Reverse Osmosis	Distillation	Other	Not Available
Amor	211	58.3%	12.3%	7.1%	0.0%	1.4%	20.9%
Aurdal	205	52.7%	16.1%	6.8%	0.5%	0.0%	23.9%
Bluffton	40	47.5%	17.5%	7.5%	0.0%	2.5%	25.0%
Butler	23	47.8%	4.3%	4.3%	0.0%	4.3%	39.1%
Clitherall	192	54.7%	9.9%	7.3%	0.0%	1.0%	27.1%
Compton	85	52.9%	10.6%	10.6%	0.0%	2.4%	23.5%
Corliss	123	53.7%	13.8%	8.1%	0.0%	0.8%	23.6%
Dora	294	57.1%	11.9%	6.8%	0.0%	1.0%	23.1%
Eagle Lake	130	64.6%	12.3%	2.3%	0.0%	0.0%	20.8%
Eastern	38	55.3%	21.1%	7.9%	0.0%	0.0%	15.8%
Edna	313	53.7%	13.4%	8.3%	0.3%	1.3%	23.0%
Effington	34	38.2%	23.5%	8.8%	2.9%	0.0%	26.5%
Elmo	44	54.5%	9.1%	9.1%	0.0%	0.0%	27.3%
Everts	360	55.0%	11.4%	6.4%	0.3%	1.4%	25.6%
Gorman	113	61.1%	9.7%	8.0%	1.8%	0.0%	19.5%
Hobart	228	53.1%	13.6%	5.3%	0.0%	0.4%	27.6%
Inman	36	44.4%	22.2%	5.6%	0.0%	0.0%	27.8%
Leaf Lake	140	59.3%	12.9%	5.0%	0.7%	0.0%	22.1%
Leaf Mountain	63	58.7%	14.3%	3.2%	0.0%	1.6%	22.2%
Maine	201	55.2%	12.4%	5.5%	0.5%	0.5%	25.9%
Newton	100	50.0%	16.0%	7.0%	0.0%	5.0%	22.0%
Nidaros	128	62.5%	7.8%	4.7%	0.0%	3.1%	21.9%
Oak Valley	42	59.5%	14.3%	7.1%	0.0%	0.0%	19.0%
Otter Tail	250	55.2%	12.0%	10.0%	0.0%	0.8%	22.0%
Otto	121	52.1%	17.4%	8.3%	0.0%	0.0%	22.3%
Parkers Prairie	56	55.4%	12.5%	10.7%	0.0%	1.8%	19.6%
Perham	152	54.6%	10.5%	11.2%	0.7%	0.0%	23.0%
Pine Lake	192	58.3%	11.5%	7.3%	0.0%	0.5%	22.4%
Rush Lake	267	53.2%	10.9%	5.6%	0.4%	0.4%	29.6%
Scambler	178	51.7%	9.6%	7.9%	1.7%	0.6%	28.7%
Tordenskjold	139	60.4%	10.8%	6.5%	0.0%	2.9%	19.4%
Woodside	35	54.3%	8.6%	2.9%	0.0%	0.0%	34.3%
Total	4,533	55.3%	12.4%	7.0%	0.3%	1.0%	24.0%

Table 33. Well Last Tested for Nitrate

Township	Total	Within the past year	Within the last 3 years	Within the last 10 years	Greater than 10 years	Never Tested	Not Sure	Not Available
Amor	211	2.4%	5.7%	18.5%	11.8%	26.5%	20.4%	14.7%
Aurdal	205	2.0%	6.3%	10.2%	11.2%	26.8%	23.9%	19.5%
Bluffton	40	7.5%	12.5%	7.5%	10.0%	25.0%	25.0%	12.5%
Butler	23	4.3%	4.3%	13.0%	4.3%	30.4%	17.4%	26.1%
Clitherall	192	5.2%	12.5%	21.9%	8.3%	13.5%	16.1%	22.4%
Compton	85	8.2%	4.7%	17.6%	14.1%	25.9%	8.2%	21.2%
Corliss	123	2.4%	6.5%	13.8%	13.8%	22.8%	21.1%	19.5%
Dora	294	3.4%	5.1%	9.2%	11.9%	28.9%	22.1%	19.4%
Eagle Lake	130	0.0%	7.7%	13.8%	19.2%	24.6%	20.0%	14.6%
Eastern	38	7.9%	5.3%	21.1%	18.4%	26.3%	7.9%	13.2%
Edna	313	2.6%	7.7%	17.9%	13.1%	24.3%	16.6%	17.9%
Effington	34	0.0%	5.9%	11.8%	11.8%	23.5%	26.5%	20.6%
Elmo	44	2.3%	4.5%	6.8%	11.4%	31.8%	15.9%	27.3%
Everts	360	3.3%	4.2%	14.2%	11.1%	23.3%	23.3%	20.6%
Gorman	113	3.5%	8.0%	19.5%	13.3%	19.5%	19.5%	16.8%
Hobart	228	3.5%	5.7%	12.3%	14.0%	25.0%	19.3%	20.2%
Inman	36	2.8%	8.3%	2.8%	13.9%	25.0%	25.0%	22.2%
Leaf Lake	140	2.9%	10.0%	12.9%	10.7%	20.0%	25.7%	17.9%
Leaf Mountain	63	1.6%	4.8%	6.3%	11.1%	39.7%	20.6%	15.9%
Maine	201	3.5%	3.5%	15.4%	10.4%	22.9%	24.4%	19.9%
Newton	100	2.0%	4.0%	13.0%	24.0%	17.0%	19.0%	21.0%
Nidaros	128	3.9%	9.4%	19.5%	5.5%	17.2%	25.8%	18.8%
Oak Valley	42	4.8%	9.5%	14.3%	19.0%	38.1%	4.8%	9.5%
Otter Tail	250	7.6%	7.6%	15.2%	10.4%	23.6%	18.0%	17.6%
Otto	121	4.1%	7.4%	19.0%	7.4%	20.7%	19.8%	21.5%
Parkers Prairie	56	1.8%	3.6%	19.6%	17.9%	25.0%	17.9%	14.3%
Perham	152	13.2%	12.5%	15.1%	11.2%	12.5%	15.8%	19.7%
Pine Lake	192	4.2%	7.3%	17.7%	13.5%	19.8%	19.8%	17.7%
Rush Lake	267	7.5%	9.0%	13.1%	13.9%	19.1%	14.6%	22.8%
Scambler	178	0.6%	4.5%	15.2%	9.6%	30.9%	17.4%	21.9%
Tordenskjold	139	0.0%	4.3%	10.1%	9.4%	36.7%	23.7%	15.8%
Woodside	35	2.9%	2.9%	8.6%	8.6%	40.0%	22.9%	14.3%
Total	4,533	3.9%	6.8%	14.6%	12.1%	23.8%	19.7%	19.0%

Table 34. Last Nitrate Test Result

Township	Total	<3 mg/L	3<10 mg/L	≥10 mg/L	Not available
Amor	211	5.2%	1.9%	0.0%	92.9%
Aurdal	205	6.8%	0.5%	0.0%	92.7%
Bluffton	40	17.5%	2.5%	0.0%	80.0%
Butler	23	4.3%	8.7%	0.0%	87.0%
Clitherall	192	10.9%	5.7%	1.6%	81.8%
Compton	85	3.5%	5.9%	2.4%	88.2%
Corliss	123	13.0%	0.8%	0.0%	86.2%
Dora	294	6.8%	0.3%	0.0%	92.9%
Eagle Lake	130	7.7%	3.8%	0.0%	88.5%
Eastern	38	10.5%	2.6%	0.0%	86.8%
Edna	313	10.5%	1.6%	0.0%	87.9%
Effington	34	8.8%	2.9%	0.0%	88.2%
Elmo	44	0.0%	4.5%	2.3%	93.2%
Everts	360	8.1%	0.6%	0.0%	91.4%
Gorman	113	12.4%	5.3%	0.9%	81.4%
Hobart	228	9.2%	0.0%	0.0%	90.8%
Inman	36	8.3%	2.8%	0.0%	88.9%
Leaf Lake	140	12.1%	2.9%	0.7%	84.3%
Leaf Mountain	63	6.3%	0.0%	0.0%	93.7%
Maine	201	6.0%	1.5%	1.5%	91.0%
Newton	100	7.0%	2.0%	0.0%	91.0%
Nidaros	128	18.8%	1.6%	0.0%	79.7%
Oak Valley	42	4.8%	4.8%	0.0%	90.5%
Otter Tail	250	9.6%	2.8%	3.2%	84.4%
Otto	121	8.3%	9.1%	0.0%	82.6%
Parkers Prairie	56	3.6%	3.6%	1.8%	91.1%
Perham	152	15.8%	10.5%	7.2%	66.4%
Pine Lake	192	12.0%	2.6%	0.0%	85.4%
Rush Lake	267	13.9%	1.5%	0.4%	84.3%
Scambler	178	7.9%	0.0%	0.0%	92.1%
Tordenskjold	139	5.0%	0.7%	0.0%	94.2%
Woodside	35	2.9%	0.0%	2.9%	94.3%
Total	4,533	9.2%	2.4%	0.7%	87.7%

APPENDIX I

Table 35. Well Construction Type for Final Well Dataset

Township	Samples	Drilled	Sand Point	Other	Not Available
Amor	203	116	42	0	45
Aurdal	204	135	18	0	51
Bluffton	36	26	5	0	5
Butler	21	13	1	0	7
Clitherall	182	116	26	1	39
Compton	74	44	15	0	15
Corliss	118	75	23	0	20
Dora	288	183	46	0	59
Eagle Lake	126	86	18	1	21
Eastern	36	23	7	0	6
Edna	309	190	56	0	63
Effington	34	22	5	0	7
Elmo	36	19	6	0	11
Everts	357	207	63	1	86
Gorman	102	65	21	0	16
Hobart	226	136	35	0	55
Inman	33	21	7	0	5
Leaf Lake	134	88	21	0	25
Leaf Mountain	62	45	8	0	9
Maine	182	120	28	0	34
Newton	97	55	20	1	21
Nidaros	126	85	21	0	20
Oak Valley	34	17	11	0	6
Otter Tail	242	146	43	0	53
Otto	114	72	18	0	24
Parkers Prairie	52	32	9	1	10
Perham	144	99	28	0	17
Pine Lake	187	125	29	0	33
Rush Lake	263	157	45	0	61
Scambler	175	117	25	0	33
Tordenskjold	138	89	19	1	29
Woodside	31	22	6	0	3
Total	4,366	2,746	725	6	889

Data compiled from well logs and homeowner responses.

Table 36. Well Depth (feet) for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Amor	51	41	245	88	108
Aurdal	57	55	170	80	88
Bluffton	10	41	216	115	112
Butler	4	94	196	127	136
Clitherall	59	54	190	70	78
Compton	16	18	135	76	76
Corliss	37	38	303	97	120
Dora	75	54	180	80	82
Eagle Lake	44	21	220	82	97
Eastern	10	35	124	65	76
Edna	94	53	155	85	89
Effington	8	65	190	100	118
Elmo	9	43	130	94	87
Everts	114	21	230	76	82
Gorman	37	46	231	85	98
Hobart	78	54	203	81	89
Inman	10	23	218	64	79
Leaf Lake	41	64	292	106	120
Leaf Mountain	16	58	239	138	144
Maine	57	21	160	64	71
Newton	23	67	150	93	99
Nidaros	45	45	477	84	118
Oak Valley	6	55	157	67	82
Otter Tail	84	26	273	69	77
Otto	32	18	192	81	89
Parkers Prairie	20	46	205	118	112
Perham	55	58	189	100	106
Pine Lake	52	34	270	107	125
Rush Lake	80	24	178	70	75
Scambler	67	35	240	80	105
Tordenskjold	35	46	260	104	118
Woodside	6	55	215	88	109
Total	1,332	18	477	81	94

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

Table 37. Year of Well Construction for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Amor	51	1991	2014	2004	2004
Aurdal	57	1991	2014	2000	2001
Bluffton	10	1999	2014	2006	2006
Butler	4	1976	2012	2008	2001
Clitherall	59	1991	2014	2004	2003
Compton	16	1978	2016	2005	2003
Corliss	37	1997	2014	2006	2005
Dora	75	1978	2014	2005	2004
Eagle Lake	44	1930	2012	2004	2002
Eastern	10	1989	2013	2005	2002
Edna	94	1987	2014	2003	2002
Effington	8	1992	2010	2000	2001
Elmo	9	1997	2012	2003	2003
Everts	114	1992	2016	2005	2004
Gorman	37	1996	2015	2003	2004
Hobart	78	1976	2015	2003	2002
Inman	10	1975	2010	2002	2001
Leaf Lake	41	1992	2015	2003	2002
Leaf Mountain	16	1985	2014	2002	2002
Maine	57	1991	2014	2004	2003
Newton	23	1980	2014	2005	2002
Nidaros	45	1993	2014	2005	2004
Oak Valley	6	1995	2015	2000	2001
Otter Tail	84	1990	2015	2004	2003
Otto	32	1978	2014	2004	2003
Parkers Prairie	20	1984	2012	2005	2003
Perham	55	1978	2015	2002	2001
Pine Lake	52	1986	2013	2004	2003
Rush Lake	80	1983	2015	2005	2004
Scambler	67	1994	2015	2006	2005
Tordenskjold	35	1990	2013	2002	2001
Woodside	6	1995	2012	2005	2004
Total	1,332	1930	2016	2004	2003

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#**_____ **Lab QA/QC#**_____

Well Owner Contact Information

Name_____

Address_____

Phone #_____ Township _____ County_____

Sampling Information

Sampler_____ Time Arrived_____

Pump Start Time_____ Discharge Rate_____ Time Collected_____

Sample Point Location/Notes_____

Well Location/Notes_____

GPS Location_____ UTM Easting (X)_____ UTM Northing (Y)_____

Weather_____ Wind Speed/Direction (mph)_____ Air Temp (°F)_____

Nearest Possible Pesticide Source (type, direction, distance)_____

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

Sample Comments/Notes:

APPENDIX K

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

Township	Samples	Min	Max	Median	Mean
Amor	13	8.78	14.82	9.67	10.30
Aurdal	4	9.29	11.71	9.40	9.95
Bluffton	6	9.32	12.57	11.83	11.55
Butler	1	9.67	9.67	9.67	9.67
Clitherall	29	8.20	14.47	9.81	9.94
Compton	9	8.80	10.60	9.87	9.87
Corliss	6	7.77	11.90	10.53	10.27
Dora	19	7.62	13.00	9.44	9.75
Eagle Lake	17	8.73	10.88	9.57	9.58
Eastern	3	8.14	11.59	8.92	9.55
Edna	13	8.76	12.37	10.79	10.79
Effington	0	.	.	.	.
Elmo	2	9.59	12.14	10.87	10.87
Everts	26	8.06	14.78	9.87	10.35
Gorman	9	8.44	12.81	10.27	10.47
Hobart	15	7.99	12.90	9.52	9.77
Inman	10	8.80	12.73	10.12	10.15
Leaf Lake	9	8.54	15.56	10.44	10.61
Leaf Mountain	8	8.67	16.10	10.46	11.13
Maine	15	8.66	21.43	9.50	10.78
Newton	5	9.10	10.23	9.65	9.64
Nidaros	12	8.73	13.32	9.46	9.97
Oak Valley	2	11.66	11.96	11.81	11.81
Otter Tail	20	8.57	13.25	9.65	9.95
Otto	10	8.32	13.49	9.90	10.46
Parkers Prairie	13	8.53	11.25	9.87	9.93
Perham	34	7.86	11.39	9.80	9.74
Pine Lake	13	8.41	11.84	9.36	9.53
Rush Lake	12	8.10	10.97	9.48	9.34
Scambler	5	8.44	14.66	9.47	10.29
Tordenskjold	6	8.85	10.20	9.08	9.24
Woodside	5	8.51	12.50	10.20	10.19
Total	351	7.62	21.43	9.68	10.08

Table 39. pH of Well Water for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Amor	13	7.22	7.69	7.46	7.45
Aurdal	4	7.20	7.74	7.40	7.44
Bluffton	6	7.13	7.47	7.29	7.28
Butler	1	7.22	7.22	7.22	7.22
Clitherall	29	7.08	8.03	7.54	7.56
Compton	9	7.24	7.55	7.38	7.39
Corliss	6	6.89	7.56	7.27	7.25
Dora	19	7.22	7.59	7.36	7.37
Eagle Lake	17	7.06	7.74	7.35	7.34
Eastern	3	7.31	7.43	7.37	7.37
Edna	13	7.16	7.88	7.38	7.41
Effington	0	NA	NA	NA	NA
Elmo	2	7.38	7.41	7.40	7.40
Everts	26	7.17	7.87	7.49	7.51
Gorman	9	7.16	7.57	7.46	7.39
Hobart	15	7.07	7.73	7.45	7.43
Inman	10	7.04	7.44	7.28	7.26
Leaf Lake	9	7.00	7.58	7.29	7.27
Leaf Mountain	8	7.25	8.10	7.42	7.57
Maine	15	7.32	7.90	7.46	7.50
Newton	5	7.18	7.37	7.27	7.28
Nidaros	12	7.24	7.60	7.53	7.48
Oak Valley	2	7.30	7.48	7.39	7.39
Otter Tail	20	7.29	7.63	7.42	7.44
Otto	10	7.08	7.78	7.37	7.38
Parkers Prairie	13	7.21	7.56	7.42	7.43
Perham	34	7.08	7.69	7.47	7.44
Pine Lake	13	7.17	7.90	7.38	7.39
Rush Lake	12	7.07	7.53	7.35	7.33
Scambler	5	7.31	7.65	7.40	7.44
Tordenskjold	6	7.02	7.43	7.34	7.30
Woodside	5	7.31	8.40	7.41	7.58
Total	351	6.89	8.40	7.41	7.42

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

Township	Samples	Min	Max	Median	Mean
Amor	13	360	715	509	532
Aurdal	4	743	821	767	775
Bluffton	6	429	666	590	572
Butler	1	592	592	592	592
Clitherall	29	328	1,152	633	655
Compton	9	510	804	659	655
Corliss	6	497	1,280	847	892
Dora	19	516	895	694	695
Eagle Lake	17	504	895	674	682
Eastern	3	538	736	571	615
Edna	13	415	1,314	605	630
Effington	0	NA	NA	NA	NA
Elmo	2	652	696	674	674
Everts	26	422	792	585	590
Gorman	9	476	989	642	683
Hobart	15	364	1,530	564	624
Inman	10	621	995	658	702
Leaf Lake	9	551	903	815	747
Leaf Mountain	8	483	853	651	655
Maine	15	350	829	600	587
Newton	5	522	703	660	627
Nidaros	12	376	738	602	580
Oak Valley	2	550	566	558	558
Otter Tail	20	456	896	610	632
Otto	10	418	760	609	613
Parkers Prairie	13	459	753	617	631
Perham	34	337	1,436	600	625
Pine Lake	13	487	844	659	646
Rush Lake	12	472	841	603	634
Scambler	5	446	589	568	539
Tordenskjold	6	505	870	652	662
Woodside	5	550	724	599	619
Total	351	328	1,530	627	639

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

Township	Samples	Min	Max	Median	Mean
Amor	13	0.19	6.26	0.79	1.62
Aurdal	4	0.14	7.68	0.21	2.06
Bluffton	6	0.20	3.38	1.91	1.99
Butler	1	1.08	1.08	1.08	1.08
Clitherall	29	0.09	8.73	2.70	3.02
Compton	9	0.42	6.44	1.01	2.25
Corliss	6	0.19	5.60	0.73	1.45
Dora	19	0.14	7.22	1.80	2.60
Eagle Lake	17	0.10	7.21	0.22	1.46
Eastern	3	0.19	5.15	1.76	2.37
Edna	13	0.10	3.34	0.41	1.23
Effington	0	NA	NA	NA	NA
Elmo	2	1.85	5.85	3.85	3.85
Everts	25	0.11	7.89	0.86	2.72
Gorman	9	0.09	4.17	0.24	1.11
Hobart	15	0.19	8.30	2.40	3.00
Inman	10	0.24	8.20	1.63	2.65
Leaf Lake	9	0.53	8.52	1.69	3.54
Leaf Mountain	6	0.13	7.28	1.28	2.43
Maine	15	0.12	9.17	2.85	3.25
Newton	5	0.28	7.08	3.37	3.33
Nidaros	12	0.29	10.15	4.47	4.66
Oak Valley	2	0.34	2.15	1.25	1.25
Otter Tail	20	0.13	9.80	0.83	2.03
Otto	10	0.11	1.39	0.37	0.49
Parkers Prairie	13	0.16	8.36	3.60	4.15
Perham	34	0.18	10.92	1.94	3.01
Pine Lake	13	0.12	4.98	0.30	0.80
Rush Lake	12	0.14	7.42	1.80	2.04
Scambler	5	0.12	4.94	0.94	2.19
Tordenskjold	6	0.12	1.91	0.16	0.50
Woodside	4	0.51	6.95	1.62	2.67
Total	347	0.09	10.92	1.18	2.43