FINAL TOWNSHIP TESTING NITRATE REPORT: SHERBURNE COUNTY 2014-2016

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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 2014 and 2015, private wells in the Sherburne County study area (six 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 2,070 wells representing an average response rate of 27 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, 9.6 percent of private wells sampled were at or above the health standard of 10 mg/L for nitrate-N. Based on the initial results, it is estimated that over 1,800 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 418 wells in 2015 and 2016. 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 77 (4 percent) wells were determined to be unsuitable and were removed from the dataset. The final well dataset had a total of 1,993 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 5.3 to 13.8 percent. One third (2 of 6) of the townships sampled in Sherburne County are showing 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 January 2017, 167 townships in 19 counties have completed the initial sampling. A total of 20,042 wells have been sampled.

In 2014 and 2015, six townships in Sherburne County were selected to participate in the Township Testing Program (Figure 1). Areas were chosen based on several criteria. Criteria used includes: professional knowledge shared by the local soil and water conservation district (SWCD) or county environmental departments, past high nitrate as nitrogen (nitrate-N) results, vulnerable groundwater, and the amount of row crop production. Initial water samples were collected from private wells by homeowners and mailed to a laboratory. Sample results were mailed by the laboratory to the participating homeowners. The sampling, analysis, and results were provided at no cost to participating homeowners and paid for by the Clean Water Fund.

Well owners with detectable nitrate-N results were offered a no cost pesticide sample and a follow-up nitrate-N sample collected by MDA staff. The MDA began evaluating pesticide presence and concentrations in private water wells at the direction of the Minnesota Legislature. The follow-up pesticide and nitrate-N sampling in Sherburne County occurred during the summers of 2015 and 2016. 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, please visit the following webpages:
www.mda.state.mn.us/nfmp
www.mda.state.mn.us/townshiptesting

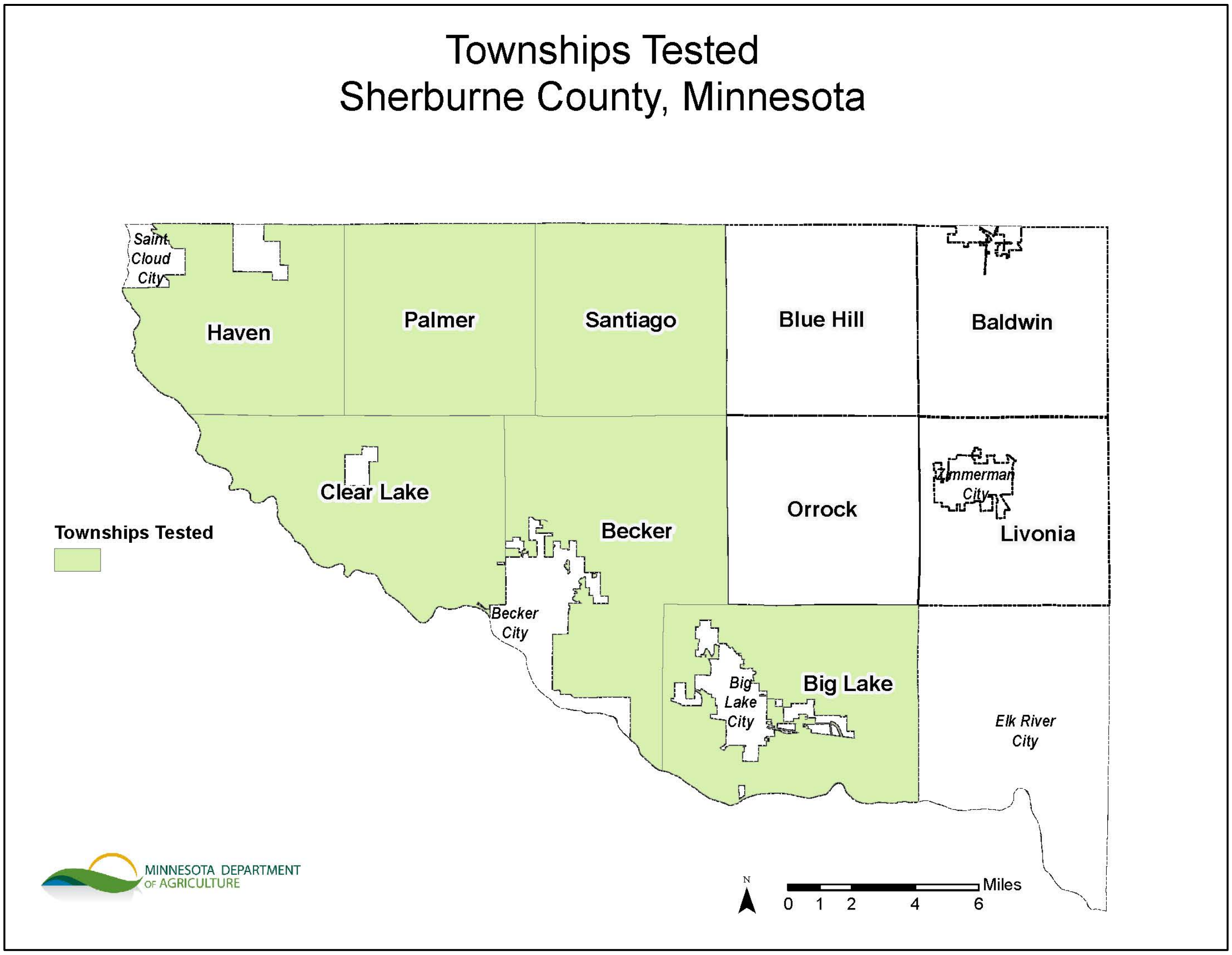

Figure 1. Townships Tested in Sherburne County

BACKGROUND

In many rural areas of Minnesota, nitrate is one of the most common contaminants in groundwater, and in some localized areas, a significant number of wells have high nitrate levels.

Nitrate is a naturally occurring, water soluble molecule that is made up of nitrogen and oxygen. Although nitrate occurs naturally, it can also originate from other sources such as fertilizer, animal manure, and human waste. Nitrate is a concern because it can have a negative effect on human health at elevated levels. The United States Environmental Protection Agency has established a drinking water Maximum Contaminant Level (MCL) of 10 mg/L for nitrate-N (US EPA, 2009) in municipal water systems. The Minnesota Department of Health (MDH) has also established a Health Risk Limit (HRL) of 10 mg/L nitrate-N for private drinking water wells in Minnesota.

Nitrogen present in groundwater can be found in the forms of nitrite and nitrate. In the environment, nitrite generally converts to nitrate, which means nitrite occurs very rarely in groundwater. The nitrite concentration is commonly less than the reporting level of 0.01 mg/L, resulting in a negligible contribution to the nitrate plus nitrite concentration (Nolan and Stoner, 2000). Therefore, analytical methods generally combine nitrate plus nitrite together. Measurements of nitrate plus nitrite as nitrogen and measurements of nitrate as nitrogen will hereafter be referred to as “nitrate”.

NITRATE FATE AND TRANSPORT

Nitrate is considered a conservative anion and is highly mobile in many shallow coarse-textured groundwater systems. Once in groundwater, nitrate is often considered very stable and can move large distances from its source. However, in some settings nitrate in groundwater may be converted to nitrogen gas in the absence of oxygen and the presence of organic carbon, through a natural process called denitrification. Denitrification occurs when oxygen levels are depleted and nitrate becomes the primary oxygen source for microorganisms. 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 Sherburne County with glacial outwash (Lusardi, 2013) and intensive row crop agriculture, are particularly vulnerable to elevated nitrate concentrations. However, geochemical conditions can be highly variable within an aquifer or region and can also change over-time (MPCA, 1998).

GEOLOGY AND HYDROGEOLOGY

The geology in Sherburne County is heavily influenced by outwash plains, terrace deposits, and lacustrine sediment.

Glacial outwash is relatively coarse-textured compared to other glacial deposits such as till and supraglacial drift deposits. Outwash is material consisting primarily of sand and gravel that was deposited by running water that flowed from melting ice during the last glacial period.

The terrace deposits extend from the northwest edge to the southeast corner of the county. When the glacial ice was melting, the Mississippi river extended well beyond its current banks. As the river retreated into its current location, sand and gravel were deposited along wide terraces (Lusardi, 2013). The coarse-textured deposits associated with glacial outwash and terrace deposits often allow contaminants from the surface to travel rapidly to the water table aquifers.

Across the eastern side of Sherburne County there are lacustrine sediments that were deposited by glacial Lake Anoka. As the lake retreated, primarily very fine to medium-grained sands were left behind on the landscape (Lusardi, 2013). These finer grained lacustrine sediments can impede the flow of contaminates into the aquifer.

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 Sherburne County as presented in Figure 2.

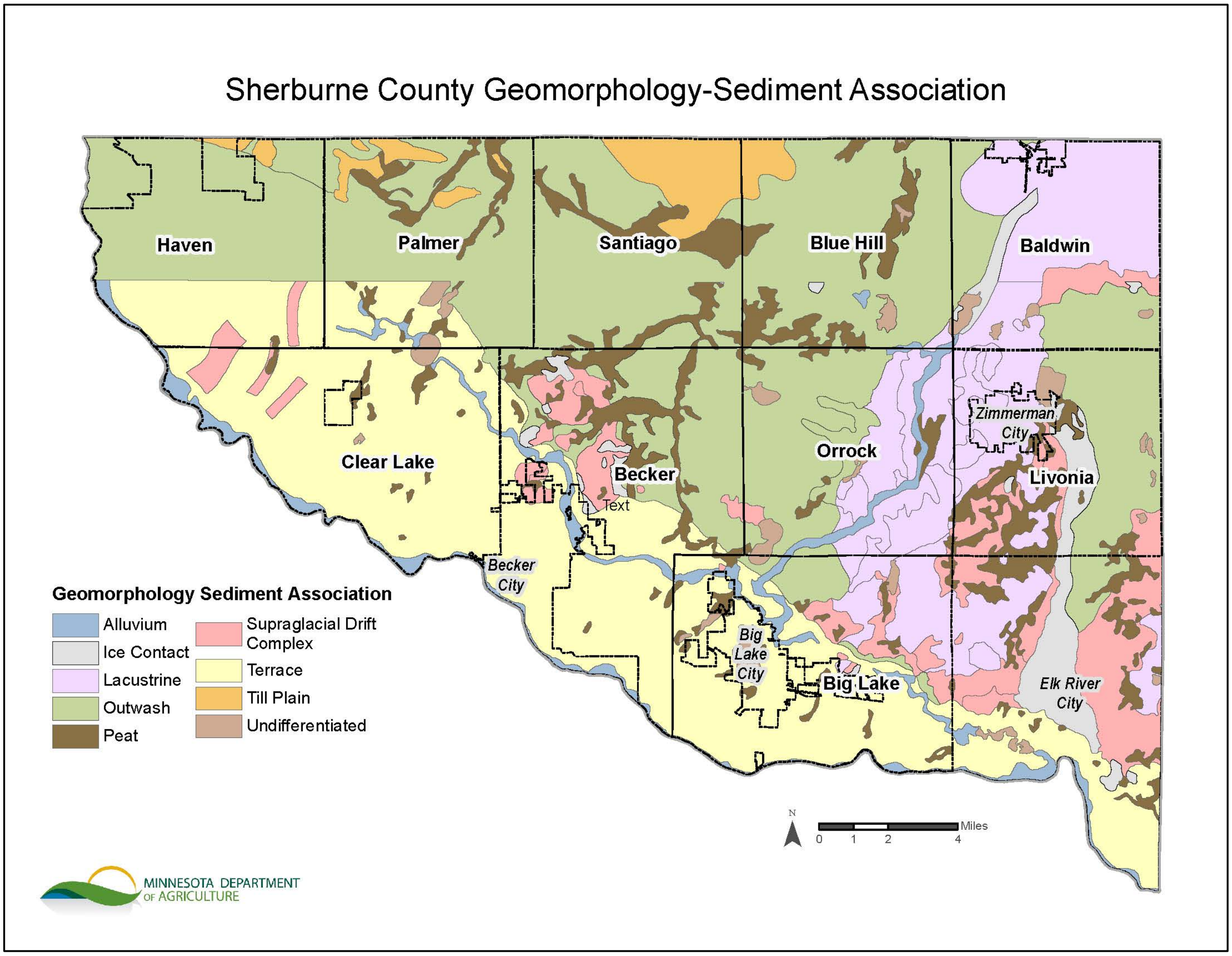

Figure 2. Statewide Geomorphology Layer, Sediment Association in Sherburne County (DNR, MGS, UMD, 1997)

NITROGEN POINT SOURCES

The focus of the Township Testing Program is to assess nitrogen contamination in groundwater as a result of commercial nitrogen fertilizer applied to cropland. Any wells potentially impacted by point sources were removed from the final well dataset. Potential point sources such as subsurface sewage treatment systems (more commonly known as septic systems), feedlots, fertilizer spills, and bulk storage of fertilizer are considered in this section. Below is a brief overview of these sources in Sherburne 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 13,960 SSTS were reported in Sherburne County for 2014. Over a recent 13 year period (2002-2014), 8,571 construction permits for new, replacement, or repairs for SSTS were issued. Of all the reported septic systems in Sherburne County, 62 percent are newer than 2002 or have been repaired since 2002 (MPCA, 2015a). When new SSTS's are installed they are required to be in compliance with the rules at the time of installation. Newer systems meet modern SSTS regulations and must comply with the current well code; which requires a 50 foot horizontal separation from the well (MDH, 2014).

FEEDLOT

Manure produced on a feedlot can be a potential source of nitrogen pollution if improperly stored or spread. In the Sherburne County study area there are a total of 27 active feedlots. The majority of the feedlots are permitted to house less than 300 animal units (AU) (Appendix B; Figure 7). Clear Lake Township has the most feedlots, houses the largest feedlots, and has the most permitted AU per square mile (Appendix B; Table 11).

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 Sherburne County study area has a total of 139 fertilizer storage licenses with majority located in Becker and Clear Lake Townships (Appendix B; Table 12).

FERTILIZER SPILLS AND INVESTIGATIONS

A total of 9 historic fertilizer spills and investigations occurred in the Sherburne County study area. The majority of these were old emergency incidents (Appendix B; Table 13).

TOWNSHIP TESTING METHODS

VULNERABLE TOWNSHIPS

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

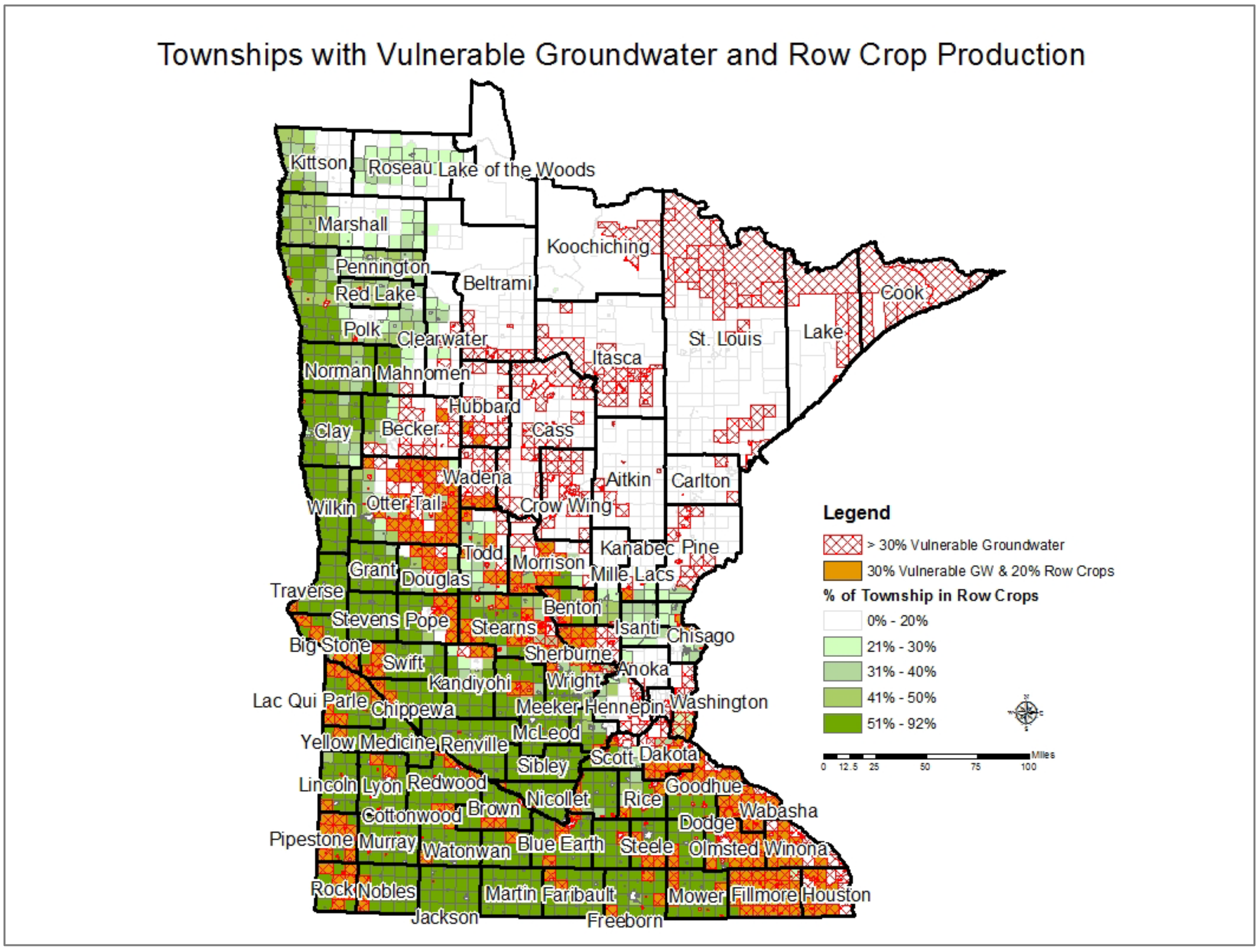

Figure 3. Minnesota Townships with Vulnerable Groundwater and Row Crop Production

Aquifer sensitivity ratings from the Minnesota Department of Natural Resources were used to estimate the percentage of geology vulnerable to groundwater contamination. The same geologic mapping project presented in Figure 2 was used to classify the state into aquifer sensitivity ratings. There are three ratings for aquifer sensitivity: low, medium and high.

Sensitivity ratings are described in Table 1.The ratings are based upon guidance from the Geologic Sensitivity Project Workshop's report "Criteria and Guidelines for Assessing Geologic Sensitivity in Ground Water Resources in Minnesota" (MDNR, 1991). A map of Sherburne 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

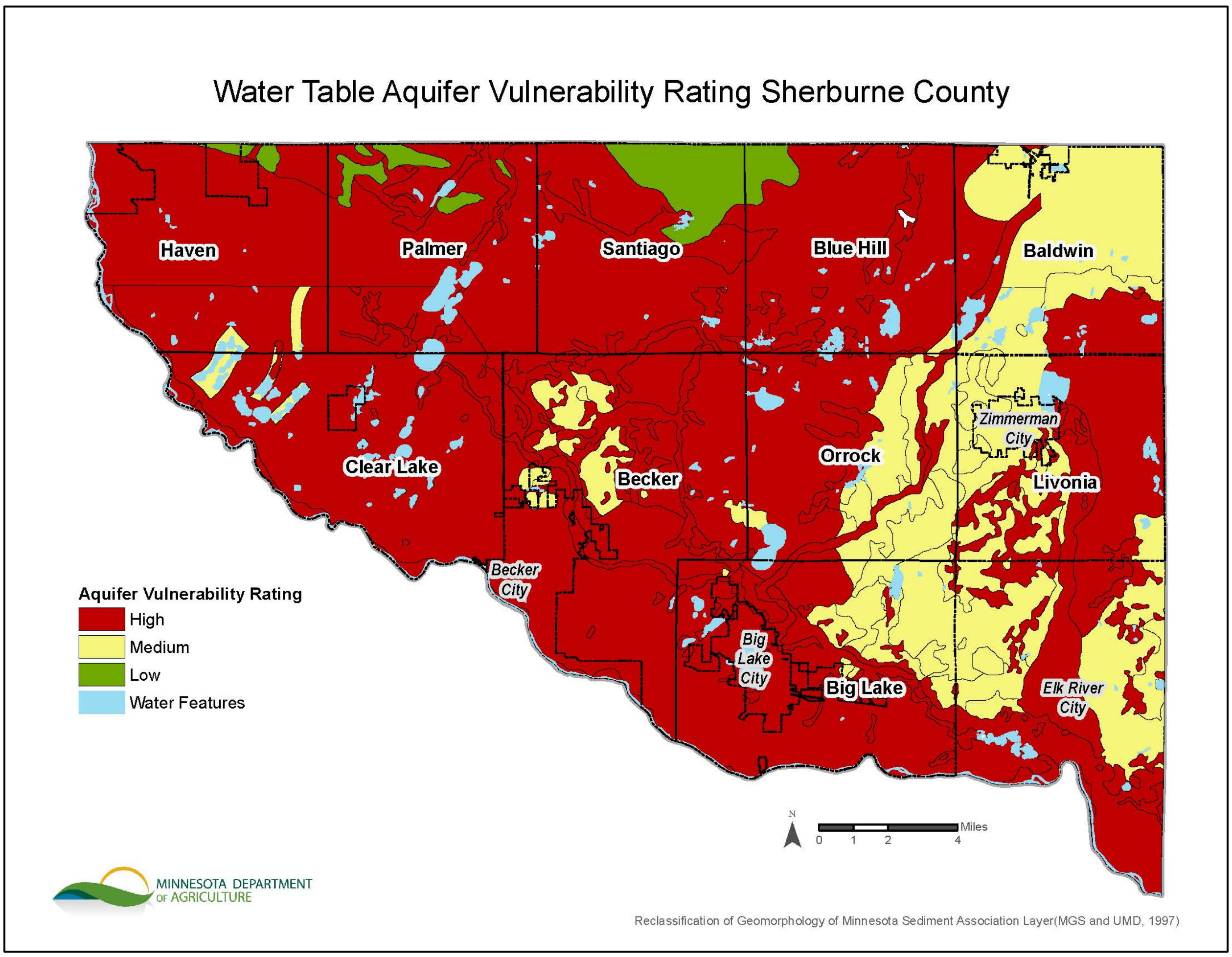

Figure 4. Water Table Aquifer Vulnerability Rating in Sherburne County

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 Sherburne County can be found in Appendix C (Figure 9, Table 15). On average 29 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 2014 and 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 2,070 homeowners using the mail-in kit (Table 2). These 2,070 samples are considered the "initial well dataset". On average, 27 percent of the homeowners in these townships responded to the free nitrate test offered by MDA.

All of the homeowners with a nitrate detection from the initial sampling were asked to participate in a follow-up well site visit and sampling. The well site visit and follow-up sampling was conducted in 2015 and 2016 by MDA staff. A total of 418 follow-up samples were analyzed (Table 2).

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

Township	Kits Sent	Initial Well Dataset	Well Site Visits & Follow-Up Sampling Conducted
Becker	1,792	386	72
Big Lake	2,814	781	118
Clear Lake	655	207	63
Haven	722	254	89
Palmer	1,017	315	58
Santiago	564	127	18
Total	7,564	2,070	418

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

The well site visit was used to collect information on potential nitrogen point sources, well characteristics (construction type, depth, and age) and the integrity of the well construction. Well site visit information was recorded on the Well Information and Potential Nitrate Source Inventory Form (Appendix A).

WELL ASSESSMENT

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

Using the following criteria, a total of 77 wells were removed to create the final well dataset. See Appendix E (Table 18 and 19) 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. High nitrate-N wells 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.

IRRIGATION WELL

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

UNSURE OF WATER SOURCE

Also, if the water source of the sample was uncertain, then data pertaining to this sample was removed.

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.

DUPLICATE / EXTRA KIT

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

INITIAL RESULTS

INITIAL WELL DATASET

Approximately 2,070 well owners returned water samples for analysis across the six townships (Figure 5). These wells represent the initial well dataset.

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

The minimum values of nitrate for all townships were less than the detection limit (<DL) which is 0.03 mg/L. The maximum values ranged from 28.0 to 48.0 mg/L, with Santiago Township having the highest result. Median values range from <DL to 0.4 mg/L, with Haven Township having the highest median value. The 90th percentiles range from 5.1 to 22.0 mg/L, with Haven Township having the highest 90th percentile.

Initial results from the sampling showed that in Clear Lake, Haven, and Palmer Townships, ten percent or more of the wells were at or over 10 mg/L nitrate. The township testing results contrast findings from a 2010 USGS report on nitrate concentrations in private wells in the glacial aquifer systems across the upper United States (US) in which less than five percent of sampled private wells had nitrate concentrations greater than 10 mg/L (Warner and Arnold, 2010). Data from the township testing program suggests that private well water in Clear Lake, Haven, and Palmer Townships are 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.

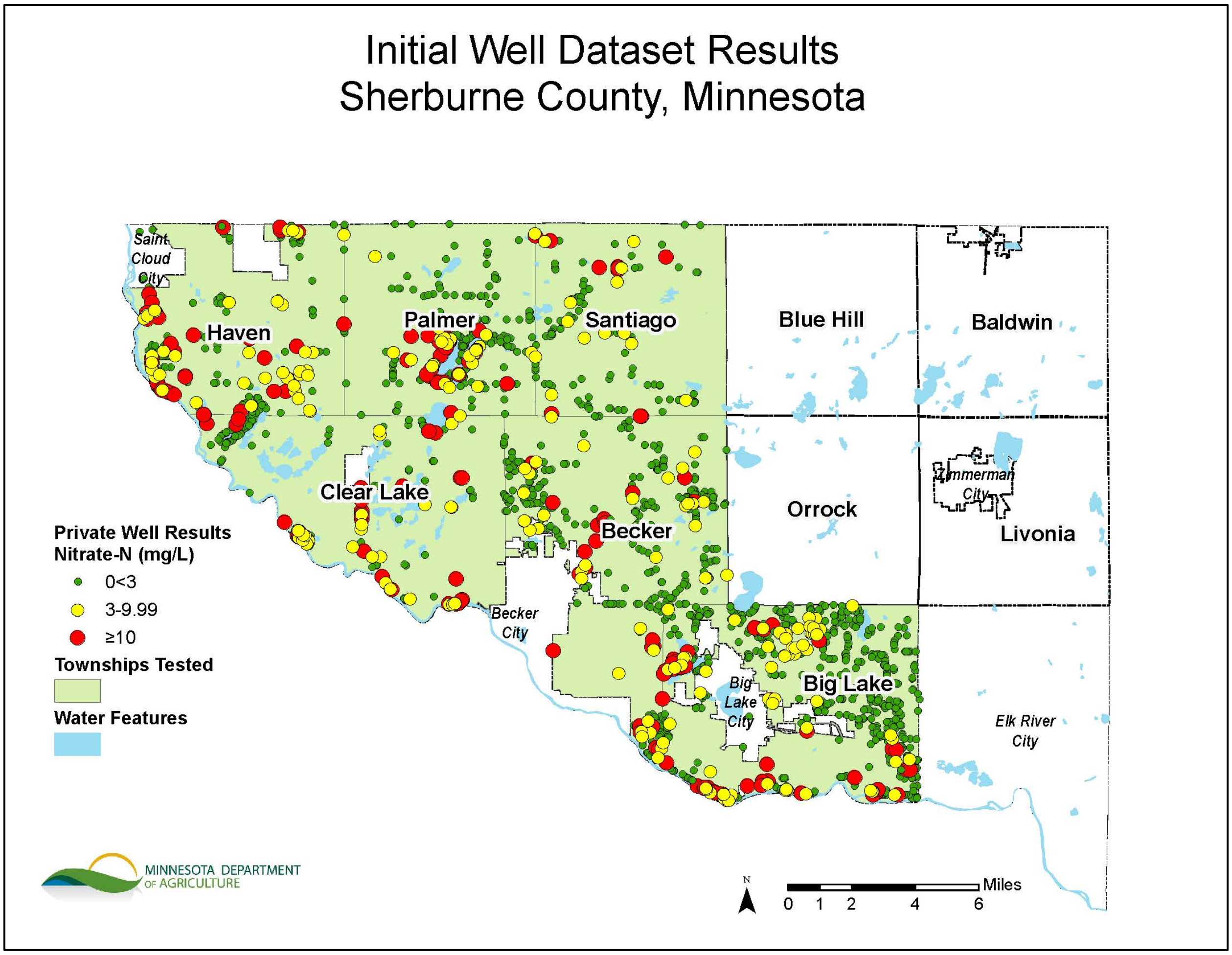

Figure 5. Well Locations and Nitrate Results from Initial Dataset in Sherburne County

Table 3. Sherburne 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)																	
Becker	386	<DL	37.7	1.8	<DL	0.7	5.7	11.4	23.4	325	36	47	31	25	84.2%	9.3%	12.2%	8.0%	6.5%
Big Lake	781	<DL	35.8	1.7	<DL	0.4	5.1	12.2	23.7	665	68	80	56	48	85.1%	8.7%	10.2%	7.2%	6.1%
Clear Lake	207	<DL	36.8	3.7	0.05	5.0	14.2	18.6	27.9	147	30	52	42	30	71.0%	14.5%	25.1%	20.3%	14.5%
Haven	254	<DL	36.7	5.3	0.4	7.2	22.0	24.6	32.6	163	40	71	65	51	64.2%	15.7%	28.0%	25.6%	20.1%
Palmer	315	<DL	28.0	2.4	<DL	1.8	10.6	14.4	19.2	249	32	52	47	34	79.0%	10.2%	16.5%	14.9%	10.8%
Santiago	127	<DL	48.0	2.6	<DL	0.7	8.9	19.8	33.4	103	13	21	15	11	81.1%	10.2%	16.5%	11.8%	8.7%
Total	2,070	<DL	48.0	2.5*	<DL*	1.4*	9.5*	16.3*	26.8*	1,652	219	323	256	199	79.8%	10.6%	15.6%	12.4%	9.6%

* Represents an average value

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

ESTIMATES OF POPULATION AT RISK

The human population at risk of consuming well water at or over the HRL of 10 mg/L nitrate was estimated based on the sampled wells. An estimated 1,846 people in Sherburne County's study area have drinking water over the nitrate HRL (Table 4). Nitrate contamination is a significant problem across much of Sherburne County. Additional public awareness and education programming will need to take place in many of the townships.

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

Township	Estimated Households on Private Wells*	Estimated Population on Private Wells*	Estimated Population ≥10 mg/L Nitrate-N**
Becker	1,561	5,054	327
Big Lake	2,519	7,468	459
Clear Lake	600	1,574	228
Haven	719	2,016	405
Palmer	910	2,399	259
Santiago	590	1,937	168
Total	6,899	20,448	1,846

* Data collected from the Minnesota State Demographic Center, 2013

** Estimates based off of the 2013 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, 2016).

In some cases, well owners were able to provide Unique Well Identification Numbers for their wells. When the correct Unique IDs are provided, a well log can be used to identify the aquifer that the well withdraws water from. The well logs were obtained from the MWI for 1,178 documented wells (Table 5). Approximately 57 percent of the sampled wells had corresponding well logs. Thus, the data gathered on aquifers represents a 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 85 feet deep.

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

The Quaternary aquifers represent the youngest geological aquifer formation identified in Sherburne County. 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, 1998). When there is less than ten feet of clay, it allows surface contaminants to travel more quickly to the water table aquifers. In general, shallower wells completed in the QWTA 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, 1998).

The sedimentary rocks from the Cretaceous aquifers have been eroded by glacial events and therefore can be distributed unevenly. Cretaceous aquifers are more prevalent in south and southwestern Minnesota and only scattered in western Sherburne (Lusardi, 2013).

The Paleozoic (Pre-Cretaceous) aquifer is dominated by sandstone and shale. Upper parts of this formation were eroded during the later Quaternary glaciation (Lusardi, 2013).

Precambrian aquifers are the deepest and geologically oldest depicted in this report. Concentrations of chemicals in these aquifers are defined by the rock parent material. Thus chemicals such as boron and beryllium are more common in this aquifer than in others (MPCA, 1998).

Table 5. Nitrate Concentrations within Sampled Groundwater Aquifers

Aquifer	Total Wells	Ave Depth (Feet)	Number of wells <3	3<10	≥10	Percent of wells <3	3<10	≥10
			Nitrate-N mg/L					
Quaternary Water Table	142	64	92	33	17	65%	23%	12%
Quaternary Buried	710	85	587	73	49	83%	10%	7%
Quaternary Undifferentiated	5	71	4	0	1	80%	0%	20%
Cretaceous	19	154	18	1	0	95%	5%	0%
Paleozoic	195	150	173	13	9	89%	7%	5%
Precambrian	52	171	36	8	8	69%	15%	15%
Undesignated	49	90	38	6	5	78%	12%	10%
Other**	6	91	5	0	1	83%	0%	17%
Total	1,178	98*	953	134	90	81%*	11%*	8%*

* Represents an average value.

** “Other” aquifers include wells that are in multiple or intermediate aquifers.

WELL OWNER SURVEY

The private well owner survey, sent out with the sampling kit, provided additional information about private wells that were sampled. The survey included questions about the well construction, depth and age, and questions about nearby land use. A blank survey can be found in Appendix G. It is important to note that well information was provided by the well owners and may be approximate or potentially erroneous. The following section is a summary of information gathered from the well owner survey (complete well survey results are located in Appendix H at the end of this document, Tables 21-35).

The majority of wells in each township are located on “rural” property. In Townships of Clear Lake and Palmer a significant number of wells (28 and 38 percent, respectively) were located on lake home properties.

Approximately 71 percent of sampled wells are of drilled construction and seven 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 two 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. Big Lake has the lowest percentage of wells less than 100 feet deep (26 percent) and Clear Lake has the highest percent of wells less than 100 feet deep (73 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.

POTENTIAL NITRATE SOURCE DISTANCES

The following response summary relates to isolation distances of potential point sources of nitrate that may contaminate wells. This information was obtained from the well surveys completed by the homeowner (complete well survey results are located in Appendix H at the end of this document, Tables 21-35).

- On average, farming takes place on less than five percent of the properties.
- Agricultural fields are greater than 300 feet from wells at 70 percent of the properties.
- One 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 71 percent) are over 300 feet 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.

FINAL RESULTS

FINAL WELL DATASET

A total of 2,070 well water samples were collected by homeowners across six townships. A total of 77 (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 1,923 wells (Table 6). The wells in the final well dataset represent drinking water wells potentially impacted by applied commercial agricultural fertilizer.

WELL WATER NITROGEN ANALYSIS

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

Table 6 shows the results for all townships sampled. The percent of wells at or over the HRL ranged from 5.3 to 13.8 percent.

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

Township	Initial Well Dataset	Final well Dataset	Final Wells ≥10 mg/L Nitrate-N	
			Count	Percentage
Becker	386	379	20	5.3%
Big Lake	781	775	43	5.5%
Clear Lake	207	195	22	11.3%
Haven	254	224	31	13.8%
Palmer	315	302	26	8.6%
Santiago	127	118	7	5.9%
Total	2,070	1,993	149	7.5%*

* Represents an average value

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 20.3 to 37.7 mg/L nitrate, with Becker Township having the highest result. The 90th percentile ranged from 4.8 to 15.4 mg/L nitrate-N, with Big Lake Township having the lowest result and Haven Township having the highest result.

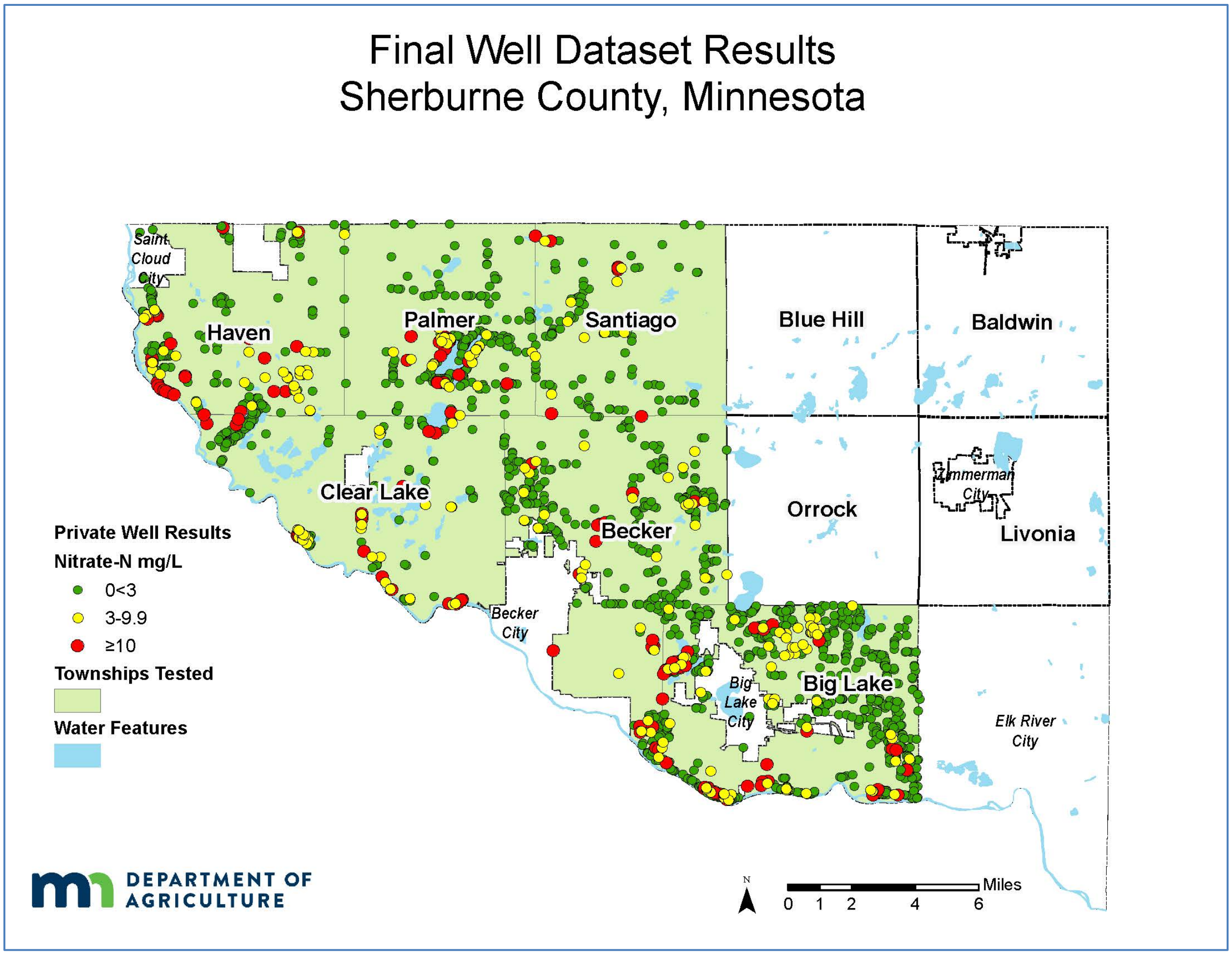

Figure 6. Well Locations and Nitrate Results from Final Well Dataset in Sherburne County

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

Township	Total Wells	Values			Percentiles					Number of Wells					Percent of Wells				
		Min	Max	Mean	(50^{th}) Median	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)																	
Becker	379	<DL	37.7	1.6	<DL	0.6	5.3	10.5	23.1	325	34	40	25	20	85.8%	9.0%	10.6%	6.6%	5.3%
Big Lake	775	<DL	35.8	1.6	<DL	0.3	4.8	10.7	23.8	664	68	75	51	43	85.7%	8.8%	9.7%	6.6%	5.5%
Clear Lake	195	<DL	36.8	3.1	<DL	3.5	12.8	15.9	28.2	145	28	42	33	22	74.4%	14.4%	21.5%	16.9%	11.3%
Haven	224	<DL	36.7	3.9	0.1	3.5	15.4	23.3	33.0	163	30	44	41	31	72.8%	13.4%	19.6%	18.3%	13.8%
Palmer	302	<DL	20.3	2.0	<DL	1.3	9.3	13.6	17.4	248	28	41	38	26	82.1%	9.3%	13.6%	12.6%	8.6%
Santiago	118	<DL	29.0	1.7	<DL	0.1	5.1	11.1	25.9	102	9	13	9	7	86.4%	7.6%	11.0%	7.6%	5.9%
Total	1,993	<DL	37.7	2.1	<DL	0.9	6.9	14.0	25.2	1,647	197	255	197	149	82.6%	9.9%	12.8%	9.9%	7.5%

* Represents an average value

<DL stands for less than detectable limit. The detectable limit ranges from <0.03 to <0.5 mg/L nitrate-N. The 50^{th} percentile (75^{th}, 90^{th}, 95^{th}, and 99^{th}, respectively) is the value below which 50 percent (75%, 90%, 95% and 99%) of the observed values fall

As discussed previously, the areas selected were deemed most vulnerable to nitrate contamination of groundwater. Table 8 compares the final results to the percent of vulnerable geology (MDNR, 1991) and row crop production (USDA NASS Cropland Data Layer, 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, Sherburne County

Township	Final Well Dataset	Percent Vulnerable Geology	Percent Row Crop Production (2013)**	Percent ≥7 mg/L	Percent ≥10 mg/L
				Nitrate-N mg/L or parts per million (ppm)	
Becker	379		29%	6.6%	5.3%
Big Lake	775	69%	19%	6.6%	5.5%
Clear Lake	195	93%	47%	16.9%	11.3%
Haven	224	95%	37%	18.3%	13.8%
Palmer	302	81%	24%	12.6%	8.6%
Santiago	118	65%	17%	7.6%	5.9%
Total	1,993	80%	29%	9.9%	7.5%*

* Represents an average value

** Data retrieved from USDA NASS Cropland Data Layer, 2013

WELL AND WATER CHARACTERISTICS

WELL CONSTRUCTION

Unique identification numbers from well logs were compiled for the wells in the Sherburne 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 36-38).

- The majority of wells were drilled (75 percent), and only 118 (6 percent) were sand point wells
- The median depth of wells was 85 feet, and the shallowest was 15 feet
- The median year the wells were constructed in was 1997

WELL WATER PARAMETERS

MDA staff conducted the follow-up sampling. Field measurements of the well water parameters were recorded on a field log (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 39-42).

- The temperatures ranged from 8.88 °C to 19.02 °C
- The median specific conductivity was 544 µS/cm, and was as high as 1,355 µS/cm
- The water from the wells had a median pH of 7.67
- The dissolved oxygen readings ranged from 0.02 mg/L to 17.26 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, 2015).

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 Sherburne County. In order to prioritize testing, the MDA looked at townships with significant row crop production and vulnerable geology. Approximately 29 percent of the land cover is row crop agriculture and there are over 50,000 acres of groundwater irrigation in the study area.

Six townships were sampled covering over 152,000 acres. The initial (homeowner collected) nitrate sampling resulted in 2,070 samples. The 2,070 households that participated represent approximately 27 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 418 wells.

The MDA conducted a nitrogen source assessment and identified wells near potential point sources and wells with poor construction. A total of 77 (4 percent) wells were found to be unsuitable and were removed from the final well dataset of 1,993 wells. The remaining 1,993 wells were wells believed to be impacted by nitrogen fertilizer and were included in the final well dataset.

A majority of wells (75 percent) were drilled; less than 6 percent were sand points. The median depth of the wells was 85 and depths ranged from 15 to 413 feet.

In two of the six townships tested in Sherburne County, more than 10 percent of the wells were at or over the nitrate Health Risk Limit of 10 mg/L. The percent of wells at or over the nitrate Health Risk Limit in each township ranged from 5.3 to 13.8 percent.

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APPENDIX A

Well information and Potential Nitrate Source Inventory Form

UNIQUE NUMBER:________________ or SITE ID:______________________

Well Information and Potential Nitrate Source Inventory Form

General Information

Date of Visit: ________________County: ____________________ Township_______________

Well Unique Number (6 digits): ______________ Parcel Number: _____________________

Site ID (from township sampling if no Unique ID):_____________________________________

GPS location of well: Latitude:_________________ Longitude:________________________

Owner Name: ____

Owner Phone: ____

Owner Address: ____

e-mail:________________________________

Inspector Name:____________________________Inspector Phone: ____________________

Well Construction Information

1. Is this well used for drinking water? (Circle One) a) YES or b) NO
2. Is the outdoor water raw or filtered? (softened, distilled, reverse osmosis, activated carbon, etc.)

   ____
3. Well Information collected from (Circle One):
   - a) Well Log (**Attach**) or b) Verbal (Indicate Person): _________________
4. Well Construction Type: _______________________ (Drilled, Sand point, Hand-dug, other)
5. Well Construction Date: __________________________
6. Well Depth (Feet): __________________
7. Well Diameter (Inches): _________
8. Pump Installer (Sticker):___________________________
9. Who services the well (if available)? _______________________________
10. Is there more than one well on this property?_______________________________________
    - If yes, list well type and Unique No. if available:____________________________

1

UNIQUE NUMBER:________________ or SITE ID:_______________________

11. Is Fertilizer stored on this property(Circle One) a) YES or b) NO
    - If yes, what is the distance to the well?_______________________
12. Historical fertilizer storage? a) YES or b) NO
    - If yes, what is the distance to the well? _______________________
13. Historic/Abandoned septic system? a) YES or b) NO
    - If yes, what is the distance to the well?_______________________
14. List sample types collected at this site:____
15. Have you made any changes to your well in the last year? _____________________________

    (added filtration system, raised well, replaced pump, upgraded well casing, replaced well, etc.)

16. Are there potential nitrate sources nearby that are >300 ft. away from the well, if so list type and

    approximate distance____

Go to last page for Source Codes and well drawing.

ADDITIONAL NOTES:

____
____
____
____

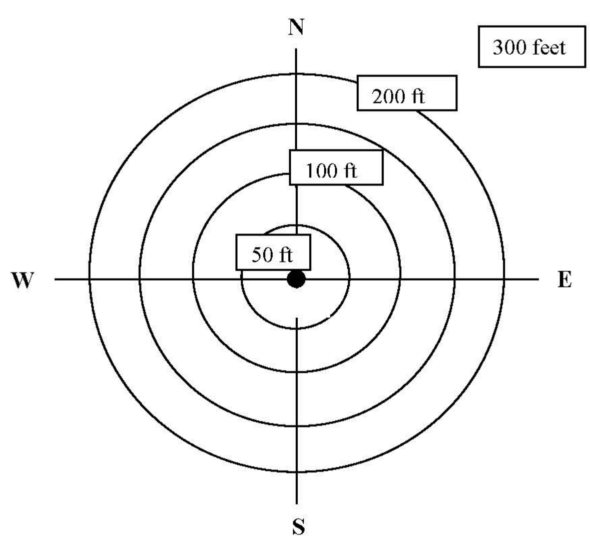
UNIQUE NUMBER:________________ or SITE ID:_______________________

DIRECTIONS: Stand at the well, find north and describe the type, position and distance to potential nitrate sources with 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

17. Does water drain toward the well? a) YES or b) NO
18. Which direction does the landscape slope? (Draw arrow across bull's eye, through well, and label)
19. Is the slope: a) Steep or b) Shallow
20. Are there any *obvious* problems with the well? a) YES or b) NO
21. If yes, describe the problem:____
20. Source Codes and Distances:____



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APPENDIX B

SUBSURFACE SEWAGE TREATMENT SYSTEM

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

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

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

Sherburne County has the authority to inspect SSTS for all townships in Sherburne County except Becker Township. In 2014 Sherburne County reported a total of 13,960 SSTS and 3.1 percent were inspected for compliance. Compliance inspections are conducted in Sherburne County during property transfers, when building permits are applied for, upon completion of new or replacement SSTS, and anytime the county deems appropriate (MPCA, 2015a). Sherburne County reported that an estimated 4 percent of SSTS are non-compliant (Sherburne County, 2014; Table 9)

Table 9. Subsurface Sewage Treatment System Compliance Rates in Sherburne County

Description	Number or Rate
Inspections of Existing SSTS’s	436
Estimated Complaint	96%
Estimated Non-Compliant FTPGW	3%
Estimated Non-Compliant ITPHS	1%
Total Estimated Non-Compliant	4%

FEEDLOT

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

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

Government agencies regulate feedlots to reduce the risk of contamination to water resources. Rules pertaining to feedlots have been in place since the 1970's; they were revised in 2000 and 2014 (MPCA, 2014). 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 10) (MPCA, 2014).

Table 10. Animal Unit Calculations (MPCA, 2014)

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, 2015c).

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, 2014).

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, 2015b). Registration is required to be completed at least once during a set four year period, the current period runs from January 2014 to December 2017. From 2010 to 2014, approximately 18,000 feedlots were registered in Minnesota (MPCA, 2014). A map and table of the feedlots located in the Sherburne County study area can be found below (Figure 7; Table 11).

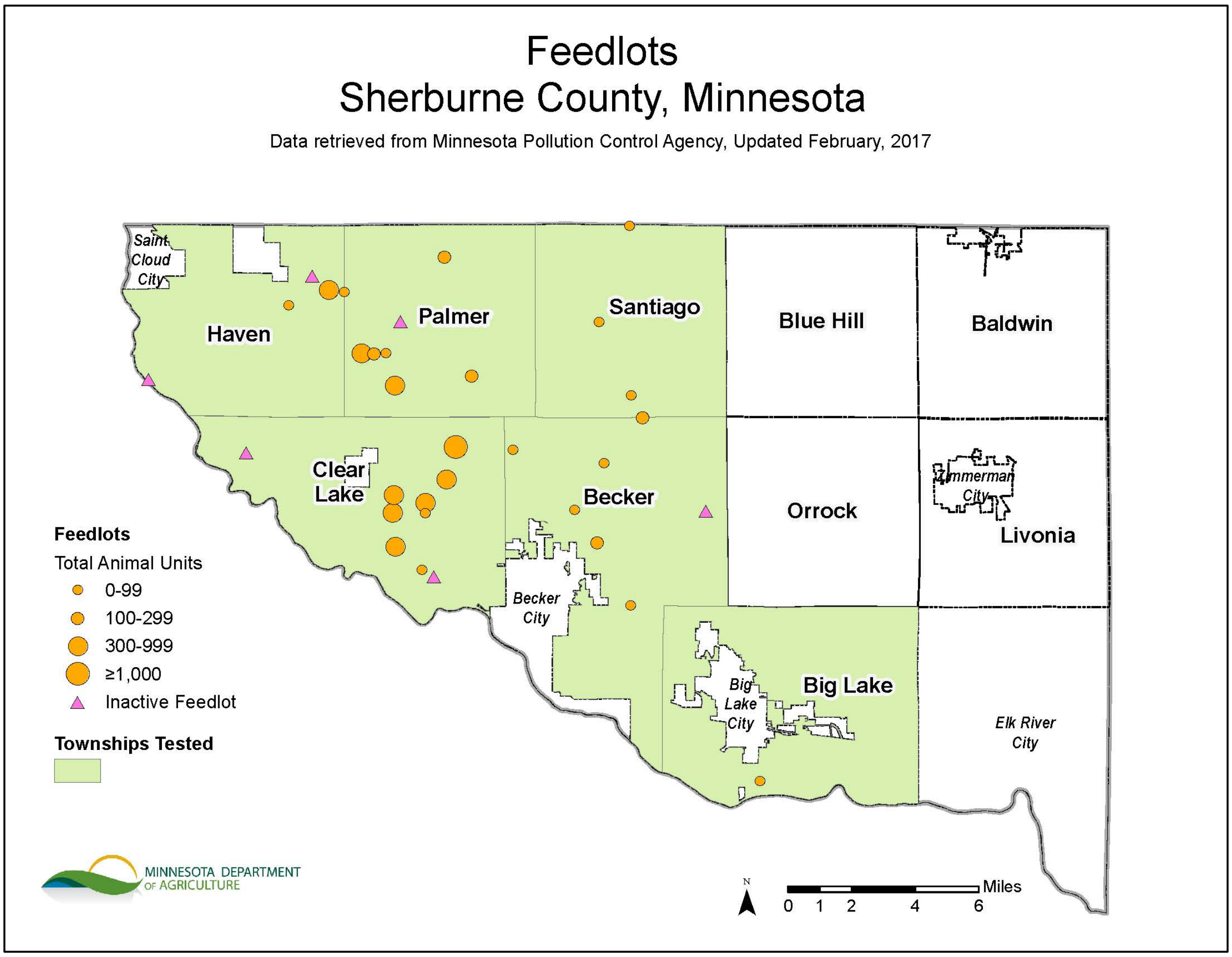

Figure 7. Feedlot Locations in Sherburne County (MPCA, 2017)

Table 11. Feedlots and Permitted Animal Unit Capacity, Sherburne County

Township	Total Feedlots	Active Feedlots	Inactive Feedlots	Average AU Permitted** Per Feedlot	Total Permitted** AU	Total Square Miles	Permitted** AU per Square Mile
Becker	7	6	1	76	457	48	10
Big Lake	1	1	0	97	97	41	2
Clear Lake	10	8	2	545	4,357	43	102
Haven	4	2	2	331	662	34	20
Palmer	8	7	1	236	1,652	36	45
Santiago	3	3	0	28	84	36	2
Total	33	27	6	219*	7,309	238	31*

* Represents an average value

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

On average there are 31 AU per square mile (0.048 AU/acre) over the entire study area (Table 11). Manure is often applied to cropland so it is pertinent to look at the AU per cropland acre. In the Sherburne County study area livestock densities average 0.144 AU per acre of row crops (MPCA, 2017; USDA NASS, 2013).

FERTILIZER STORAGE LOCATION

MDA tracks licenses for bulk fertilizer storage facilities, anhydrous ammonia, and chemigation sites (Table 12). 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 12. Fertilizer Storage Facility Licenses and Abandoned Sites, Sherburne County

Township	*Bulk Fertilizer Storage	*Anhydrous Ammonia	*Chemigation Sites	*Abandoned Sites	Total
Becker	1	0	44	0	45
Big Lake	1	0	22	0	23
Clear Lake	2	1	29	0	32
Haven	0	0	12	0	12
Palmer	0	0	13	0	13
Santiago	1	1	12	0	14
Total	5	2	132	0	139

* 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 spills within the Sherburne County study area from fertilizer. While other types of spills are recorded, only sites that are potential point sources of nitrogen to the groundwater are reported here (MDA, 2017).

The MDA tracks several types of incidents. Incident investigations are typically for larger spills. There is only one in the study area. Contingency areas are locations that have not been remediated because they were inaccessible or the contaminant could not be removed for some other reason. They are often a part of an incident investigation. There are no contingency areas in this study area. Old emergency incidents were closed prior to March 1st, 2004 (MDA, 2017), but they can still be a point source. At most of these older sites, the contaminants are unknown and their location may not be precise. 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, 2017). Many types of spills are reported to the MDA, however only spills that potentially contain nitrogen are reported here. A breakdown of chemical type of these incidents can be found in Table 13. A breakdown of the fertilizer specific spills and investigations, by township, can be found in Table 14.

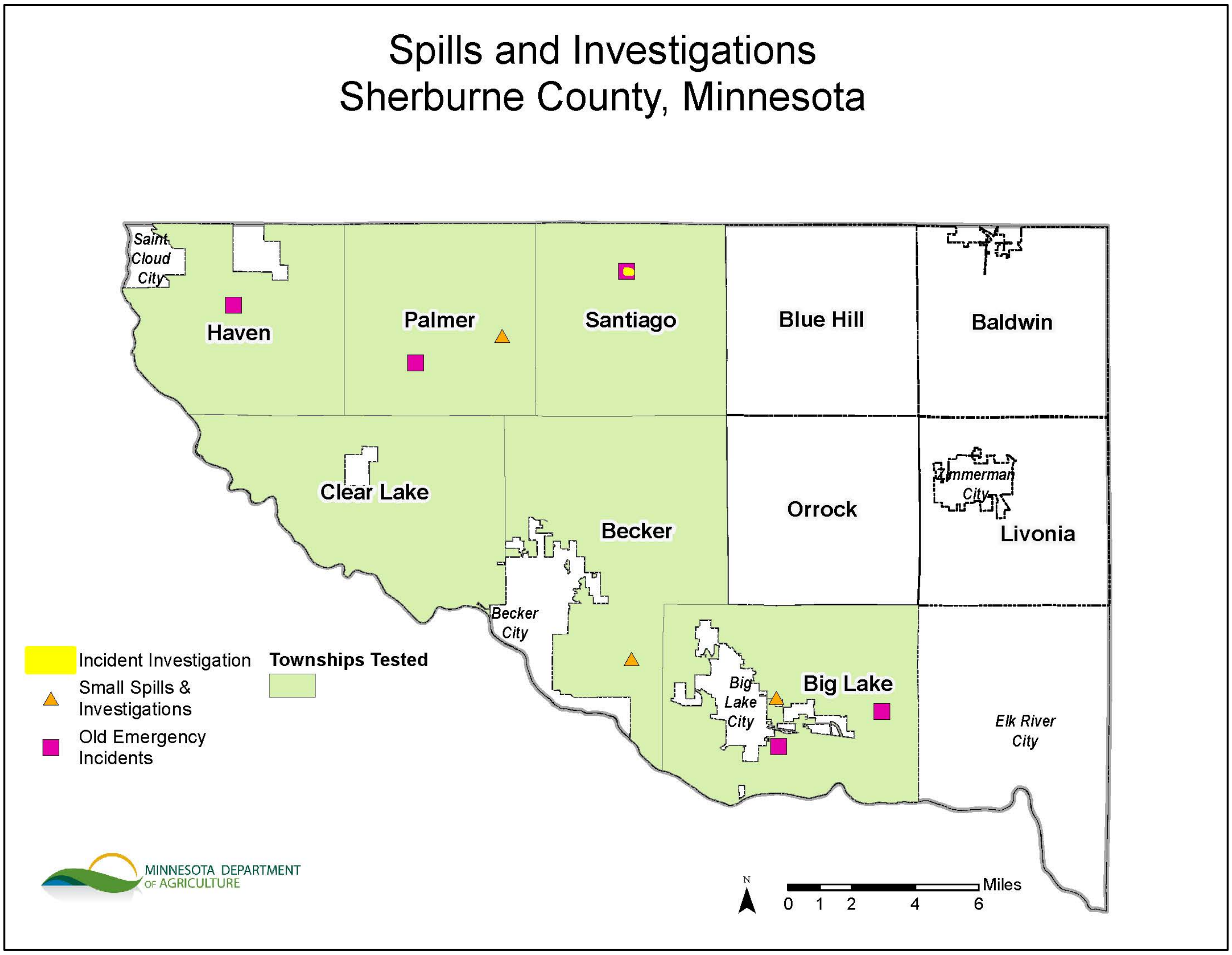

Figure 8. Fertilizer Spills and Investigations in Sherburne County (MDA, 2017)

Table 13. Spills and Investigations by Chemical Type, Sherburne County

Contaminant	Incident Investigations	Contingency Areas	Small Spills and Investigations	Old Emergency Incidents	Total
Fertilizer	1	0	2	2	5
Pesticides & Fertilizer	0	0	0	0	0
Anhydrous Ammonia	0	0	1	3	4
Total	1	0	3	5	9

Table 14. Fertilizer Related Spills and Investigations by Township, Sherburne County

Township	Incidents and Spills
Becker	1
Big Lake	3
Clear Lake	0
Haven	1
Palmer	2
Santiago	2
Total	9

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. Despite its close proximity to the Twin Cities, much of Sherburne County remains dominated by agricultural activities (Figure 9; Table 15). Row crops can include: corn, sweet corn, soybeans, alfalfa, sugar beets, potatoes, durum wheat, dry beans and double crops involving corn and soybeans.

Sherburne County is situated northwest of the Twin Cities and southeast of St. Cloud, and abuts the Mississippi River on the south and west boundaries. At 16 percent of the land area Santiago has the most wetland coverage in the study area. More than 35 percent of the land area in the townships of Clear Lake and Haven is considered row crops (Figure 9; Table 15).

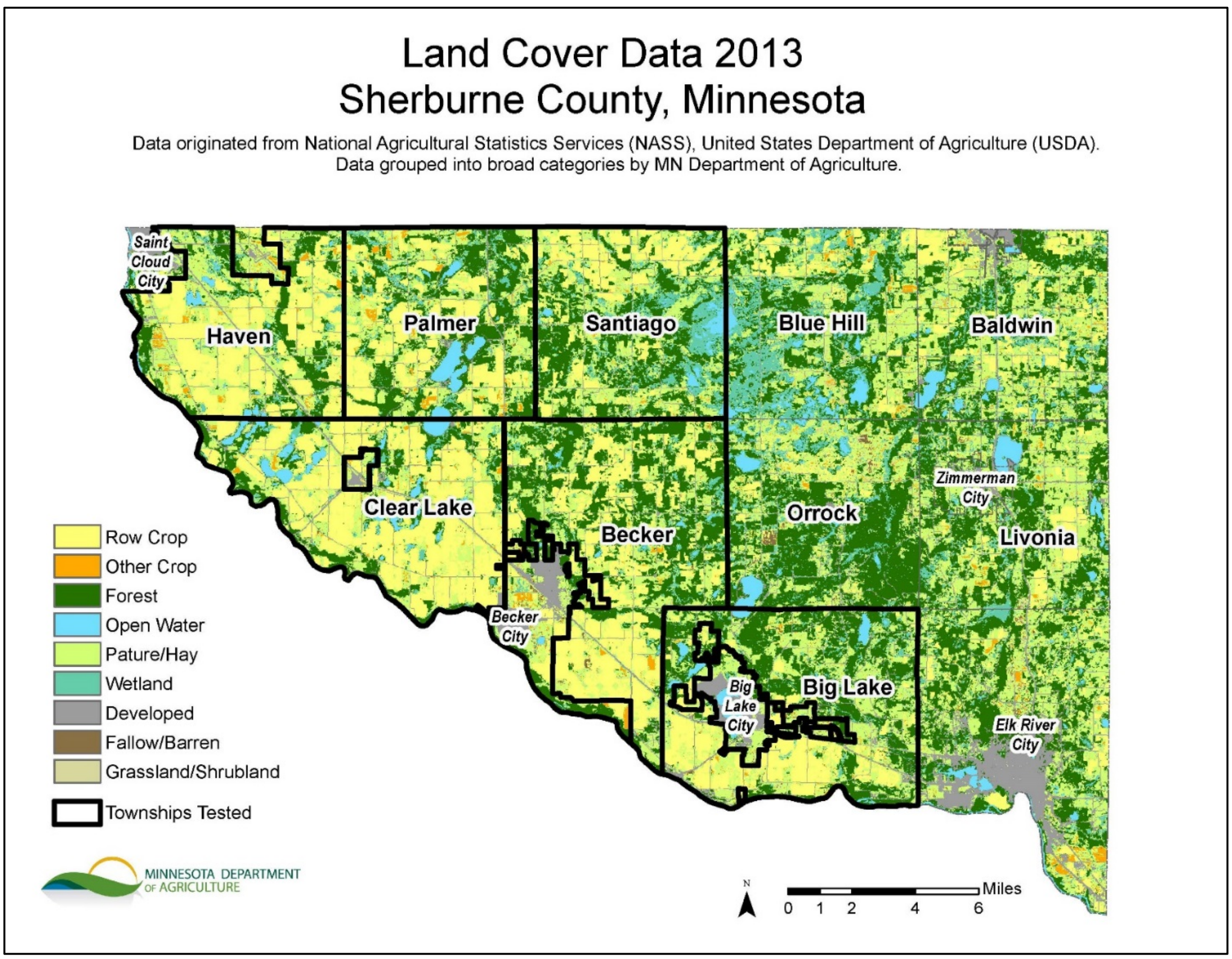

Figure 9. Land Cover in Sherburne County (USDA NASS Cropland Data Layer, 2013)

Table 15. Land Cover Data (2013) by Township, Sherburne County (USDA NASS Cropland Data Layer, 2013)

Township	Total Acres	Row Crop	Other Crops	Forest	Open Water	Pasture/ Hay	Wetland	Developed	Fallow/ Barren	Grassland/ Shrubland
Becker	30,763	29%	1%	34%	1%	26%	5%	4%	0%	1%
Big Lake	25,953	19%	1%	34%	3%	29%	6%	6%	0%	1%
Clear Lake	27,456	47%	1%	15%	7%	21%	4%	5%	0%	1%
Haven	21,646	37%	3%	18%	2%	30%	5%	4%	0%	1%
Palmer	23,319	24%	3%	29%	4%	27%	7%	4%	0%	1%
Santiago	23,244	17%	1%	32%	2%	27%	16%	3%	0%	1%
Average	25,397	29%	2%	27%	3%	27%	7%	4%	0%	1%

WATER USE

Water use permits are required for wells withdrawing more than 10,000 gallons of water per day or 1,000,000 gallons of water per year (MDNR, 2016). There are a total of 471 active groundwater well permits in the study area and 450 are used for irrigating major crops (Figure 10). Over 50,000 acres of cropland is permitted for groundwater irrigation in this area (Table 16). Most permitted wells are withdrawing groundwater from water table aquifer (Table 17; MDNR, 2013).

Table 16. Active Groundwater Use Permits by Township, Sherburne County

Township	Major Crop Irrigation Well Permits	Average Depth (feet)	Acres Permitted
Becker	71	73	7,785
Big Lake	68	223	7,323
Clear Lake	137	81	16,344
Haven	91	79	12,196
Palmer	61	85	5,448
Santiago	22	68	1,381
Total	450	102*	50,477

* Represents an average value

Table 17. Active Groundwater Use Permits by Aquifer, Sherburne County

			Aquifer System				
Water Use Well Permits	Total Wells	Average Depth (feet)	Quaternary (Water Table)	Quaternary (Buried)	Paleozoic	Precambrian	Not Classified
Major Crop Irrigation	450	101	196	168	44	1	41
Non-Crop Irrigation	7	75	4	3	0	0	0
Waterworks	6	136	0	3	3	0	0
Industrial Processing	6	180	3	1	2	0	0
Air Conditioning	2	128	1	0	1	0	0
Total	471	102*	204	175	50	1	41

* Represents an average value

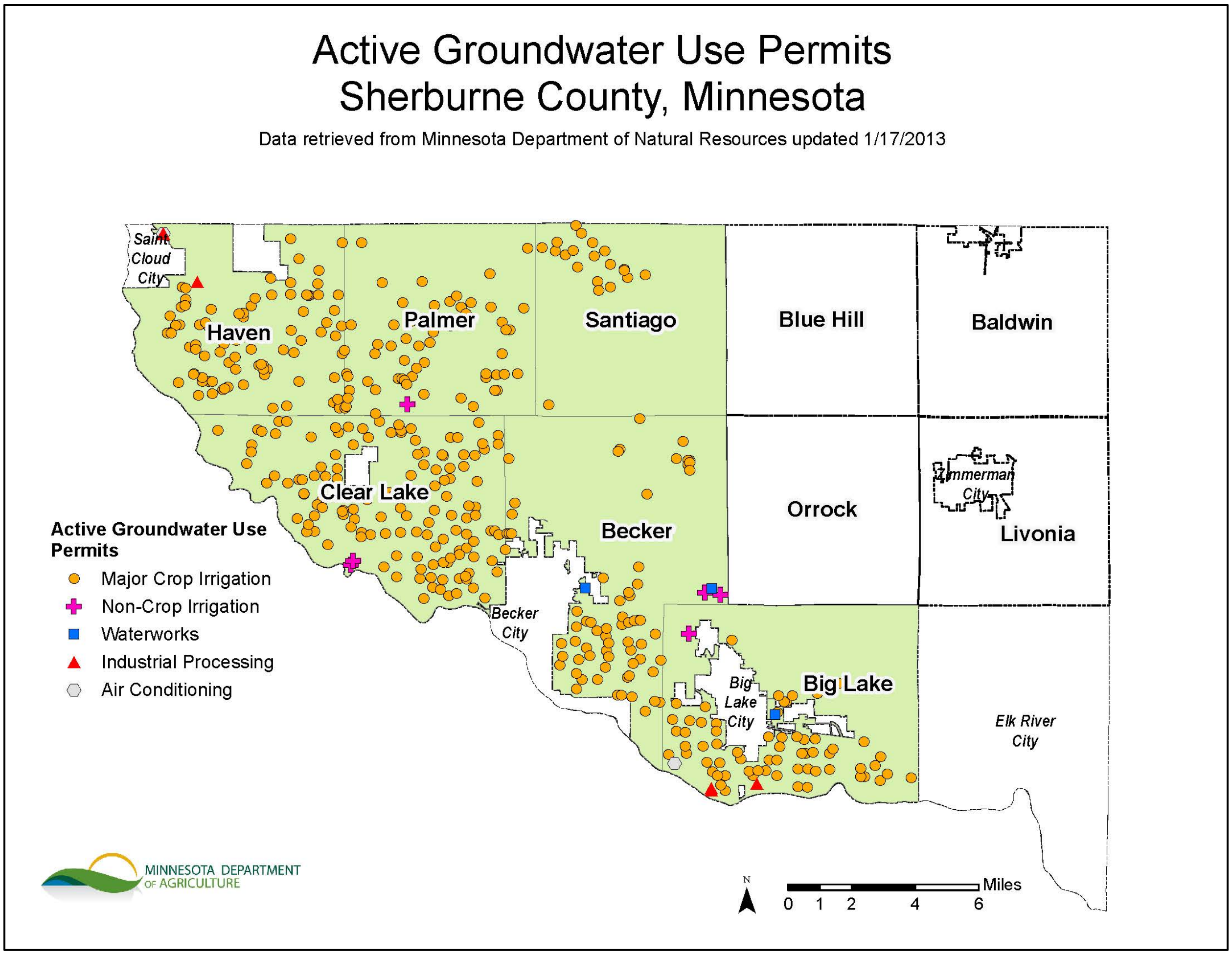

Figure 10. Active Groundwater Use Permits in Sherburne County (MDNR, 2013)

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

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

APPENDIX E

Table 18. Reasons Wells Were Removed from the Final Well Dataset by Township, Sherburne County

Township	Point Source	Well Construction Problem	Hand Dug Well	Irrigation 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	Duplicate Extra Kit	Total
Becker	3	2	0	0	1	0	1	0	0	7
Big Lake	3	0	0	0	1	0	2	0	0	6
Clear Lake	2	0	0	0	3	2	5	0	0	12
Haven	7	3	0	0	3	8	9	0	0	30
Palmer	3	0	1	0	1	2	6	0	0	13
Santiago	3	0	1	0	1	1	3	0	0	9
Total	21	5	2	0	10	13	26	0	0	77

Table 19. Completed Site Visits for Wells Removed from the Final Well Dataset by Township, Sherburne County

Township	Site Visit	No Site Visit	Total Wells Removed
Becker	5	2	7
Big Lake	2	4	6
Clear Lake	6	6	12
Haven	14	16	30
Palmer	3	10	13
Santiago	3	6	9
Total	33	44	77

APPENDIX F

MINNESOTA WELL INDEX

The MWI was used to gather information about the six townships in Sherburne County included in the study. This section includes all drinking water wells in the study area, not just wells MDA sampled. Table 20 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, 2016):

In these townships, there are 5,568 documented (have a verified location in the MWI) wells:

- Fourteen percent are completed in the shallow Quaternary Water Table Aquifer (QWTA) and are 65 feet deep on average.
- At 65 percent, the vast majority, are completed in a Quaternary buried aquifer and are 82 feet deep on average.
- On average cretaceous aquifers are utilized in only one percent of the wells, with a majority of these wells found in Haven. The average depth is 152 feet deep.
- Fourteen percent of wells are completed in the Paleozoic (Pre-Cretaceous) aquifers, with a majority of these wells completed in Big Lake. The average depth is 146 feet deep
- Only two percent of wells were completed in the Precambrian aquifers, with a majority of these well completed in Big Lake Township.

Table 20. Aquifer Type Distribution of Wells in Minnesota Well Index

	Township	Becker	Big Lake	Clear Lake	Haven	Palmer	Santiago	Average
	Wells	1,274	2,093	486	532	746	437	5,568*
Aquifer Type	Quaternary Water Table	10%	6%	30%	26%	20%	24%	14%
	Quaternary Buried	80%	51%	67%	59%	77%	70%	65%
	Quaternary Undifferentiated	1%	0%	1%	0%	0%	0%	0%
	Cretaceous	0%	0%	0%	11%	0%	0%	1%
	Paleozoic	4%	36%	0%	0%	0%	3%	14%
	Precambrian	1%	6%	0%	1%	0%	0%	3%
	Undesignated	4%	1%	2%	2%	2%	1%	2%
	Other	1%	0%	1%	0%	0%	2%	1%

*Represents a total

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, Sandpoint, Hand dug, Other, 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: 0-50 feet, 51-99 feet, 100-299 feet, and 300 or more feet.

10. Distance to an active or inactive feedlot
    Answer choices: 0-50 feet, 51-99 feet, 100-299 feet, and 300 or more feet.

11. Distance to a septic system
    Answer choices: 0-50 feet, 51-99 feet, 100-299 feet, and 300 or more feet.

12. Distance to an agricultural field
    Answer choices: 0-50 feet, 51-99 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, with 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 21. Property Setting for Well Location

Township	Total	Country	Lake home	River home	Sub-division	Municipal /City	Not available
Becker	386	54.1%	0.8%	7.8%	28.8%	0.8%	7.8%
Big Lake	781	32.7%	3.3%	13.8%	26.1%	0.0%	24.1%
Clear Lake	207	38.2%	27.5%	16.4%	13.0%	0.5%	4.3%
Haven	254	57.5%	9.4%	8.7%	15.4%	0.0%	9.1%
Palmer	315	40.3%	38.4%	0.6%	10.5%	0.0%	10.2%
Santiago	127	79.5%	0.0%	0.0%	8.7%	0.0%	11.8%
Total	2,070	44.3%	11.2%	9.5%	20.5%	0.2%	14.3%

Table 22. Well Construction Type

Township	Total	Drilled	Sand point	Hand dug	Other	Not available
Becker	386	74.9%	5.7%	0.0%	0.3%	19.2%
Big Lake	781	65.8%	2.3%	0.0%	0.0%	31.9%
Clear Lake	207	77.8%	9.7%	0.0%	0.5%	12.1%
Haven	254	82.3%	6.3%	0.0%	0.0%	11.4%
Palmer	315	67.3%	16.5%	0.3%	0.0%	15.9%
Santiago	127	70.9%	12.6%	0.8%	0.0%	15.7%
Total	2,070	71.3%	7.0%	0.1%	0.1%	21.6%

Table 23. Age of Well

Township	Total	0-10 years	11-20 years	21-40 years	Over 40 years	Not available
Becker	386	16.3%	39.6%	33.2%	3.1%	7.8%
Big Lake	781	11.4%	27.5%	37.5%	4.4%	19.2%
Clear Lake	207	11.1%	28.0%	47.3%	10.1%	3.4%
Haven	254	5.5%	22.0%	50.0%	17.3%	5.1%
Palmer	315	9.5%	31.7%	40.6%	8.9%	9.2%
Santiago	127	12.6%	54.3%	18.9%	7.9%	6.3%
Total	2,070	11.4%	31.4%	38.6%	7.2%	11.4%

Table 24. Depth of Well

Township	Total	0-50 feet	51-99 feet	100-299 feet	Over 300 feet	Not available
Becker	386	12.2%	48.2%	16.8%	0.8%	22.0%
Big Lake*	781	3.8%	22.5%	35.0%	1.5%	37.1%
Clear Lake	207	13.0%	60.4%	11.1%	0.5%	15.0%
Haven	254	15.0%	48.4%	19.3%	1.2%	16.1%
Palmer	315	20.6%	48.9%	11.7%	0.6%	18.1%
Santiago	127	26.0%	39.4%	11.0%	0.0%	23.6%
Total	2,070	11.6%	39.3%	22.3%	1.0%	25.8%

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

Table 25. Unique Well ID Known

Township	Total	No Unique Well ID	Yes Unique Well ID	Not available
Becker	386	12.7%	26.2%	61.1%
Big Lake	781	15.4%	23.6%	61.1%
Clear Lake	207	26.6%	20.3%	53.1%
Haven	254	24.8%	17.7%	57.5%
Palmer	315	22.2%	20.6%	57.1%
Santiago	127	18.9%	30.7%	50.4%
Total	2,070	18.4%	23.0%	58.6%

Table 26. Livestock Located on Property

Township	Total	No Livestock	Yes Livestock	Not available
Becker	386	93.3%	0.5%	6.2%
Big Lake	781	81.7%	0.5%	17.8%
Clear Lake	207	95.7%	1.9%	2.4%
Haven	254	94.5%	0.4%	5.1%
Palmer	315	91.4%	2.2%	6.3%
Santiago	127	92.1%	3.1%	4.7%
Total	2,070	88.9%	1.1%	10.0%

Table 27. Fertilizer Stored on Property

Township	Total	No Fertilizer Stored	Yes Fertilizer Stored	Not available
Becker	386	93.0%	0.8%	6.2%
Big Lake	781	81.6%	0.0%	18.4%
Clear Lake	207	97.1%	0.5%	2.4%
Haven	254	94.5%	0.4%	5.1%
Palmer	315	93.3%	0.0%	6.7%
Santiago	127	95.3%	0.0%	4.7%
Total	2,070	89.5%	0.2%	10.3%

Table 28. Farming on Property

Township	Total	No Farming	Yes Farming	Not available
Becker	386	89.6%	3.9%	6.5%
Big Lake	781	79.9%	1.8%	18.3%
Clear Lake	207	92.3%	4.3%	3.4%
Haven	254	86.2%	8.3%	5.5%
Palmer	315	87.0%	6.0%	7.0%
Santiago	127	81.9%	13.4%	4.7%
Total	2,070	84.9%	4.6%	10.5%

Table 29. Distance to an Active or Inactive Feedlot

Township	Total	0-50 feet	51-99 feet	100-299 feet	Over 300 feet	Not available
Becker	386	4.7%	0.5%	2.3%	75.1%	17.4%
Big Lake*	781	4.6%	0.3%	0.5%	62.2%	32.4%
Clear Lake	207	5.3%	0.5%	2.4%	82.1%	9.7%
Haven	254	4.7%	0.8%	1.6%	78.7%	14.2%
Palmer	315	5.1%	1.3%	1.0%	76.2%	16.5%
Santiago	127	7.1%	1.6%	2.4%	71.7%	17.3%
Total	2,070	4.9%	0.6%	1.4%	71.4%	21.7%

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

Table 30. Distance to Septic System

Township	Total	0-50 feet	51-99 feet	100-299 feet	Over 300 feet	Not available
Becker	386	2.1%	31.3%	47.2%	8.8%	10.6%
Big Lake*	781	3.8%	27.3%	38.9%	7.0%	22.9%
Clear Lake	207	4.8%	34.3%	44.0%	10.6%	6.3%
Haven	254	8.7%	32.3%	46.1%	6.3%	6.7%
Palmer	315	7.6%	39.7%	37.8%	6.3%	8.6%
Santiago	127	2.4%	22.8%	49.6%	14.2%	11.0%
Total	2,070	4.7%	31.0%	42.3%	8.0%	14.1%

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

Table 31. Distance to an Agricultural Field

Township	Total	0-50 feet	51-99 feet	100-299 feet	Over 300 feet	Not available
Becker	386	1.3%	2.1%	9.8%	74.9%	11.9%
Big Lake*	781	2.0%	1.4%	5.1%	65.8%	25.6%
Clear Lake	207	3.4%	1.4%	19.8%	71.0%	4.3%
Haven	254	3.5%	6.7%	15.7%	67.7%	6.3%
Palmer	315	3.5%	1.6%	9.5%	75.2%	10.2%
Santiago	127	4.7%	4.7%	10.2%	72.4%	7.9%
Total	2,070	2.6%	2.4%	9.8%	70.1%	15.1%

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

Table 32. Drinking Water Well

Township	Total	Not used for drinking	Yes used for drinking	Not available
Becker	386	0.5%	92.7%	6.7%
Big Lake	781	0.6%	81.6%	17.8%
Clear Lake	207	1.0%	96.6%	2.4%
Haven	254	2.8%	92.9%	4.3%
Palmer	315	3.8%	89.8%	6.3%
Santiago	127	0.8%	94.5%	4.7%
Total	2,070	1.4%	88.6%	10.0%

Table 33. Treatment System Present (Treatment System Used for Drinking Water)

Township	Total	None	Filtering System	Reverse Osmosis	Distillation	Other	Not available
Becker	386	57.3%	16.1%	11.4%	0.0%	1.0%	14.2%
Big Lake	781	53.9%	15.7%	7.4%	0.1%	1.4%	21.4%
Clear Lake	207	53.6%	22.7%	11.1%	0.5%	3.4%	8.7%
Haven	254	55.9%	14.2%	16.9%	0.0%	3.9%	9.1%
Palmer	315	70.2%	11.4%	6.3%	0.0%	1.6%	10.5%
Santiago	127	57.5%	21.3%	7.9%	0.0%	2.4%	11.0%
Total	2,070	57.4%	16.0%	9.6%	0.1%	1.9%	15.0%

Table 34. 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 available
Becker	386	3.4%	7.5%	11.4%	18.1%	31.1%	28.5%
Big Lake	781	4.2%	5.8%	11.1%	15.5%	26.9%	36.5%
Clear Lake	207	3.9%	9.7%	18.8%	21.3%	21.3%	25.1%
Haven	254	4.3%	5.1%	16.5%	33.5%	18.1%	22.4%
Palmer	315	2.2%	6.0%	15.9%	16.8%	27.6%	31.4%
Santiago	127	0.0%	10.2%	15.7%	17.3%	31.5%	25.2%
Total	2,070	3.5%	6.7%	13.6%	19.1%	26.4%	30.7%

Table 35. Last Nitrate Test Result

Township	Total	<3 mg/L	3<10 mg/L	≥ 10 mg/L	Not available
Becker	386	7.0%	2.3%	2.1%	88.6%
Big Lake	781	9.9%	1.9%	1.5%	86.7%
Clear Lake	207	10.1%	5.8%	2.4%	81.6%
Haven	254	15.7%	7.1%	5.1%	72.0%
Palmer	315	7.6%	1.9%	1.3%	89.2%
Santiago	127	6.3%	3.9%	0.0%	89.8%
Total	2,070	9.5%	3.1%	2.0%	85.3%

APPENDIX I

Table 36. Well Construction Type for Final Well Dataset

Township	Samples	Drilled	Sand Point	Other	Not Available
Becker	379	294	21	0	64
Big Lake	775	543	20	0	212
Clear Lake	195	162	13	1	19
Haven	224	197	10	0	17
Palmer	302	217	43	0	42
Santiago	118	92	11	0	15
Total	1,993	1,505	118	1	369

Data compiled from well logs and homeowner responses.

Table 37. Well Depth for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Becker	211	15	249	71	76
Big Lake	540	52	305	111	120
Clear Lake	103	25	190	71	79
Haven	97	17	413	88	104
Palmer	140	17	165	70	72
Santiago	71	22	126	66	68
Total	1,162	15	413	85	98

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

Table 38. Year of Well Construction for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Becker	209	1977	2013	1999	1998
Big Lake	539	1969	2015	1996	1995
Clear Lake	103	1979	2013	1995	1995
Haven	97	1975	2010	1994	1993
Palmer	140	1977	2012	1998	1997
Santiago	71	1979	2014	1999	1998
Total	1,159	1969	2015	1997	1996

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

Minnesota Department of Agriculture -Private Well Field Log

Well Unique#	**Site ID**	**Sample #'s**	**Date**	**Time**	**Well Depth (units)**
		Nitrate:			
Sampler:		**Pesticide:**			**Well Type:**
Well Owner Name:					
Well Owner Address:					
GPS: Latitude:		Longitude:			

Duplicates collected? Yes or No

Duplicate #'s: nitrate: ______________________ pesticide:____________________________

Sample point location (for example: outside tap on south side of home)________________________

Pump start time: _____________ Discharge rate: __________ Time sample collected:_____________

Stabilization Measurements

Time	Temp (units) (1.0°)	pH (0.1)	Specific Cond. (units) (10%)	DO (units) (10%)	Appearance/Notes

Wind (units)	Air temp (units)	Weather	Nearest possible pesticide source (type and distance)

COMMENTS/Notes:

Updated 5/18/2015

APPENDIX K

Table 39. Temperature (°C) of Well Water for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Becker	67	9.40	11.86	10.28	10.33
Big Lake	115	9.67	14.89	10.95	10.95
Clear Lake	57	9.02	19.02	10.52	11.13
Haven	73	9.00	12.35	10.21	10.21
Palmer	52	8.88	12.91	10.11	10.26
Santiago	15	9.26	11.03	9.98	9.94
Total	379	8.88	19.02	10.39	10.59

Table 40. pH of Well Water for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Becker	67	7.16	10.54	8.03	8.08
Big Lake	115	6.57	8.12	7.54	7.52
Clear Lake	57	7.13	8.64	7.58	7.74
Haven	73	7.17	8.35	7.58	7.62
Palmer	52	7.14	9.18	7.90	7.98
Santiago	15	7.85	9.18	8.53	8.44
Total	379	6.57	10.54	7.67	7.77

Table 41. Specific Conductivity (μS/cm) of Well Water for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Becker	67	281	1355	616	609
Big Lake	115	225	928	480	517
Clear Lake	57	130	1336	642	640
Haven	73	413	1312	619	634
Palmer	52	59	881	427	451
Santiago	15	308	1057	440	503
Total	379	59	1355	544	565

Table 42. Dissolved Oxygen (mg/L) of Well Water for Final Well Dataset

Township	Samples	Min	Max	Median	Mean
Becker	67	0.06	17.26	1.80	3.11
Big Lake	115	0.04	6.58	1.42	1.58
Clear Lake	57	0.04	8.85	1.64	2.29
Haven	73	0.02	7.41	2.46	2.61
Palmer	52	0.04	9.28	1.43	2.42
Santiago	15	0.12	6.60	1.16	1.81
Total	379	0.02	17.26	1.64	2.28