The Wells and Increased Infant Sensitivity and Exposure (WIISE) Study:

A pilot project to evaluate private well users' exposure to manganese and other contaminants of concern for children's health

Summary Report

July 2017

Dakota County Environmental Resources Department

Minnesota Department of Health, Environmental Health Division

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The authors gratefully acknowledge James Lundy (MDH) for review of this report and Frieda Von Qualen and Nancy Rice (MDH) for formatting assistance. A special thank you to the members of the 274 households who volunteered their time to participate in the WIISE Study.

Funding

Funding for the project was provided by:
Clean Water, Land, & Legacy Amendment funding provided to the Minnesota Department of Health
Dakota County Environmental Resources Department

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Definitions and Acronyms

Ambient Study: Dakota County's on-going Ambient Groundwater Quality Study which began in 1999
Anthropogenic: caused by human activity
Aquifer: any water-bearing bed or stratum of earth or rock capable of yielding groundwater in sufficient quantities that can be extracted (as defined in Minnesota Rules 6115.0630)
Aquitard: a geologic formation that may contain ground water but is incapable of transferring that water to the surface
Birm®: a proprietary filter medium commonly used for the reduction of iron and/or manganese from water supplies
Bottled Water: water that is intended for human consumption and sealed in bottles or other containers with no added ingredients, except that it may contain a safe and suitable antibacterial agent (as defined in Minnesota Rules 1550.3200)
CWS: community water system; a public system that supplies water to the same population year-round
Greensand: iron potassium phyllosilicate mineral, which usually has a green color
HA: Health Advisory; U.S. EPA's non-enforceable guideline for a concentration of a contaminant in drinking water that is expected to be without adverse effects on health.
HRL: Health Risk Limit; established by Minnesota Department of Health; the concentration of a chemical that is likely to pose little or no risk to human health; promulgated
IGH: Inver Grove Heights where the WIISE study sampled private wells
Ion exchange: process whereby one or more ions in water, such as calcium and magnesium, are exchanged for other ions, usually sodium or potassium, using a media like a resin
MCL: Maximum Contaminant Level. Enforceable water quality standard set by the U.S. Environmental Protection Agency under the Safe Drinking Water Act in 40 CFR 143 for public drinking water supplies.
MDL: the method detection limit is the smallest amount of an analyte in a sample that can be reliably determined by a laboratory with a given analytical method
MDA: Minnesota Department of Agriculture
MDH: Minnesota Department of Health
mg/L: milligrams per liter; one mg/L is approximately one part per million (ppm) in dilute water
MGS: Minnesota Geological Survey
MVTL: Minnesota Valley Testing Laboratories, Inc., private certified laboratory contracted with to analyze water samples for manganese, arsenic and iron
Neurotoxicant: a toxic compound that can cause damage to the central nervous system
RAA: Risk Assessment Advice; technical guidance issued by MDH that represents the concentration of a chemical that is likely to pose little or no risk to human health. RAA values have not been promulgated using the public process described in Minnesota Statutes Chapter 14.
RO: reverse osmosis, a method of extracting purified water from polluted or salt water by forcing the water under pressure against a semipermeable membrane, through which the pure water molecules pass and salts and other dissolved impurities are filtered out.
SMCL: Secondary Maximum Contaminant Level. A non-enforceable water quality standard set by USEPA under the SDWA in 40 CFR 143.

SMWAL: Southeastern Minnesota Water Analysis Laboratory, private certified laboratory contracted with to analyze water samples for coliform bacteria (Colilert analysis), nitrate, nitrite, fluoride, sulfate, and chloride.

µg/L: micrograms per liter; one µg/L is approximately one part per billion (ppb) in dilute water

µmho: a unit of measurement for conductivity. Micromhos (µmho/cm) is the reciprocal of the unit of resistance, the ohm.

USEPA: United States Environmental Protection Agency

USGS: United States Geological Survey

WIISE Study: Wells and Increased Infant Sensitivity and Exposure Study

I. Executive Summary

The Wells and Increased Infant Sensitivity and Exposure (WIISE) study is a pilot project to evaluate the potential exposure of residents on private wells to manganese, a naturally-occurring contaminant of emerging concern. Manganese is highly prevalent in private wells throughout Minnesota and the U.S., and recent studies have shown that infants may be more sensitive than adults to the harmful effects of manganese. The Dakota County Environmental Resources Department and the Minnesota Department of Health (MDH) conducted the WIISE study from June 2015 through June 2016. In the first phase of the study, untreated outdoor faucets at 274 homes served by private wells in Inver Grove Heights, MN were tested for manganese and other contaminants of particular concern for children's health. Of these, 194 (71%) exceeded MDH's manganese health-based drinking water guidance value of 100 micrograms per liter (µg/L) established for infants younger than 12 months old. Fifty-six percent of samples exceeded the manganese guidance value of 300 µg/L that is applicable to all other populations. Based on survey results, there was a positive relationship between the concentration of manganese in well water and increased concern about aesthetic issues and mineral content of drinking water, as well as increased use of home treatment devices or water avoidance behaviors.

In the second phase of the study, homes with manganese concentrations found to exceed MDH's guidance value of 100 µg/L in phase I were offered manganese testing of water from an inside drinking water tap. The majority of households that participated in inside tap sampling reported using at least one well water treatment system or device. Of the 109 inside tap samples submitted, 36% still exceeded the manganese drinking water guidance value of 100 µg/L. Results showed that household water softeners were effective at reducing manganese concentrations below the drinking water guidance value for infants. More research on softeners is needed to determine how iron concentration, water hardness, pH, and other factors may impact water softener manganese removal efficiency. Reverse osmosis (RO) systems are likely effective at reducing manganese concentrations as well, but could not be evaluated in the WIISE study because all RO-treated water samples were softened. Carbon filters, iron filters, and sediment filters did not consistently reduce manganese levels.

Although a relationship was seen between higher manganese concentrations in well water and a modest increase in aesthetic concerns and mitigative actions, the inside tap results provide evidence that a portion of residents in Minnesota may be drinking water with manganese above levels of health concern. While manganese concentrations were correlated with several water quality parameters (e.g., iron, dissolved oxygen, arsenic), levels exceeded health-based guidance values across a wide range of geochemical parameters. Due to the lack of a consistent, reliable geochemical indicator for elevated manganese, widespread well sampling is required. The findings from this pilot project point to the need for state and local water and health programs to initiate outreach to Minnesota residents who drink water from private wells about testing for manganese and other contaminants of concern, and to provide information on effective and practical treatment options for manganese to homeowners and water conditioning contractors.

II. Background

A. Problem Statement and Study Purpose

Manganese is a naturally-occurring element found in water, food, air, and soil. It is widespread as a dissolved trace metal in Minnesota groundwater which serves as the drinking water source for 75% of residents. Epidemiology and toxicology studies published in the past ten years have found that manganese in drinking water poses a greater health risk than previously thought. Of greatest concern are formula-fed infants who have greater susceptibility to the harmful effects of manganese and consume the most water on a body-weight basis. Much is still unknown about manganese drinking water exposures, health risks and how to mitigate them. For example:

- Are well users drinking water with manganese concentrations that exceed levels of health concern?
- Do the "aesthetic" or "nuisance" effects of manganese in drinking water that exceeds health levels result in treatment or avoidance of the water?
- What mitigation options are both effective and practical for private well users to implement?

The Minnesota Department of Health (MDH) and Dakota County ("County") partnered on a study to address these questions[1]. The study was carried out in northern Dakota County (Inver Grove Heights) because recent groundwater monitoring conducted by the County suggested that higher levels of manganese may occur in this densely populated area compared to other areas of the county. The main goals of the Wells and Increased Infant Sensitivity and Exposure (WIISE) study were to:

1. Characterize manganese levels in Inver Grove Heights (IGH) groundwater;
2. Identify predictors of elevated manganese levels in well water that would indicate the need for a well owner to test;
3. Determine how groundwater concentrations translate into actual drinking water exposures; and
4. Identify practical mitigation measures that private well users can implement to reduce exposure.

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[1] The County received grant funds from MDH to carry out well sample collection, participant communication activities, and other activities. MDH's funding was provided by the Clean Water, Land and Legacy Amendment. The County also contributed financial support and in-kind staff time towards the project. MDH and the County collaborated on study planning and design, development of participant communication tools, data analysis, and community outreach/results reporting.

B. Manganese Health Effects and Health-based Guidance Values

Manganese is an essential nutrient, meaning our bodies require small amounts to maintain health. Due to its presence in soil, manganese levels in vegetable and animal foods reliably provide a sufficient amount to meet nutritional requirements. Studies in occupational workers (mining, factories) have established that exposure to high levels of inorganic manganese in air results in neurotoxicity (ATSDR 2012). In contrast to inhalation exposure, manganese intake from both food and drinking water has been regarded by many scientists and regulatory agencies as relatively safe. However, recent epidemiology and toxicology studies suggest that manganese in drinking water may cause subtle changes in neurodevelopmental endpoints in infants and children (Coetzee et al. 2016, Bjorklund et al. 2017). These include intellectual impairment (Bouchard et al. 2011) and reduced memory and motor function (Oulhote et al. 2014). In older children and adults, consuming higher levels of manganese in drinking water over time may also cause neurological symptoms, including lethargy, tremors, and slow speech (ATSDR 2012). Further, the Institute of Medicine (2001) reported that the dissolved forms of manganese in drinking water are more bioavailable compared to protein-bound manganese in food, increasing the likelihood of overexposure.

Beginning in 2011, MDH conducted a thorough review of recent and relevant scientific human and animal studies about manganese to determine whether the existing 1993 Health Risk Limit (HRL[2]) for drinking water (300 µg/L) was health protective for all populations. The HRL_{93} is the same as U.S. EPA's current lifetime health advisory (HA) of 300 µg/L for manganese (USEPA 2004). While EPA's manganese health effects support document recognizes increased infant sensitivity to manganese and states that "the potential impacts on children are likely to be irreversible" (USEPA 2003b), EPA did not base the HA's reference dose on a neurotoxicity endpoint and did not use infant body weight and a water intake rate for formula fed infants to derive the HA. In 2012, MDH determined that a guidance value of 300 µg/L continued to be an appropriate level of protection for children and adults, including nursing mothers and infants who are exclusively breastfed. However, based on recent animal toxicity studies and updated risk assessment methodology, a lower health-based guidance value of 100 µg/L for manganese was needed to adequately protect infants who drink tap water or are fed formula mixed with tap water (MDH 2012b). This guidance was issued as Risk Assessment Advice in 2012 (RAA_{12}). In sum, MDH developed "tiered" water guidance for manganese to provide an appropriate level of health protection for different groups based on age-related susceptibility to the harmful effects of manganese. The guidance is:

- 100 µg/L for infants 12 months of age or younger who are drinking the water
- 300 µg/L for exclusively breast-fed infants, and all other age groups.

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[2] Health-based guidance for water is a concentration of a chemical (or a mixture of chemicals) in drinking water that is likely to pose little or no health risk to humans over a lifetime of exposure. The values are expressed as micrograms of chemical per liter of water (µg/L), which is the same as parts per billion (ppb).

C. Regulation of Manganese in Minnesota's Drinking Water

Private well owners are responsible for ensuring the quality and safety of their well water. Minnesota's public water systems may strive to meet MDH's health-based guidance for contaminants, such as the manganese RAA, when it is possible and cost effective. However, public water suppliers are not required by federal or state regulations to provide water below the guidance values. U.S. EPA has set a Secondary Maximum Contaminant Level (SMCL[3]) for manganese in public water supplies of 50 µg/L based on laundry staining, scaling on fixtures, and taste considerations. Achieving the SMCL is not required or legally enforceable.

Under federal Food and Drug Administration regulations, bottled water suppliers are required to meet the SMCL of 50 µg/L, except water labeled as "mineral water". The Minnesota Department of Agriculture (MDA) is responsible for enforcing the federal government's allowable level of 50 µg/L for bottled water distributed in Minnesota.

D. Communicating with Well Users about Manganese

Communicating to private well users about manganese is complex because:

- There are separate health-based guidance values for different groups based on age-related susceptibility. This approach is in contrast to nitrate where the MDH guidance value and federal Maximum Contaminant Level (MCL) of 10 mg/L are set to the lowest value for the most sensitive age group, bottle-fed infants.

- Risk perception may be influenced by the fact that manganese is naturally-occurring in groundwater, is an essential nutrient, and has multiple sources of exposure including food and infant formula.

- The lack of a federal MCL for manganese in public water supplies results in conflicting risk messages and advice for private well and public water users.

- Underwriter's Laboratories, NSF International and the Water Quality Association currently have no water treatment devices certified for manganese reduction to aid well owners in selecting the right treatment device for their well water (MGA 2015).

- Groundwater manganese concentrations do not necessarily reflect drinking water exposures. Unlike arsenic or nitrate which have no taste or color to alert well users to their presence, elevated manganese in well water may result in taste and staining issues. A common assumption is that well users would find the taste of the water unpleasant at levels of health concern and take mitigative action (i.e., treatment or avoidance). It is common for well owners

[3] A SMCL is a non-mandatory water quality standard that is established by USEPA only as a guideline to assist public water systems in managing their drinking water for aesthetic considerations, such as taste, color, and odor.

to use treatment devices to address aesthetic issues, and these devices may already be reducing levels of manganese to an unknown extent.

E. Other Well Water Contaminants in the WIISE Study

In addition to manganese, other common well water contaminants to which infants and young children are more sensitive to the toxic effects were included in the WIISE Study. These are: arsenic and lead (brain development); fluoride (developing bones and teeth); coliform bacteria and sulfate (greater likelihood of gastrointestinal illness/dehydration); and nitrate/nitrite (methemoglobinemia). The County also included two analytes not directly related to children's health. Chloride was added to assess road salt use impacts to groundwater in this densely populated area. Iron was included because it has been shown to be positively correlated with manganese (Science Applications International Corporation, 1999). Brief descriptions of the additional study analytes are located in Appendix A.

F. Manganese in Dakota County and Minnesota Groundwater

Dakota County is located in southeast Minnesota and borders both Hennepin County (which includes Minneapolis) and Ramsey County (which includes St. Paul) (Figure 1). Several Twin Cities surburban communities are located in the northern portion of Dakota County, while the southeastern portion is primarily rural. The County has the highest birthrate in Minnesota after Hennepin and Ramsey Counties[4] making it an ideal location for a pilot study focused on manganese exposure, as the most vulnerable sub-population is formula-fed infants.

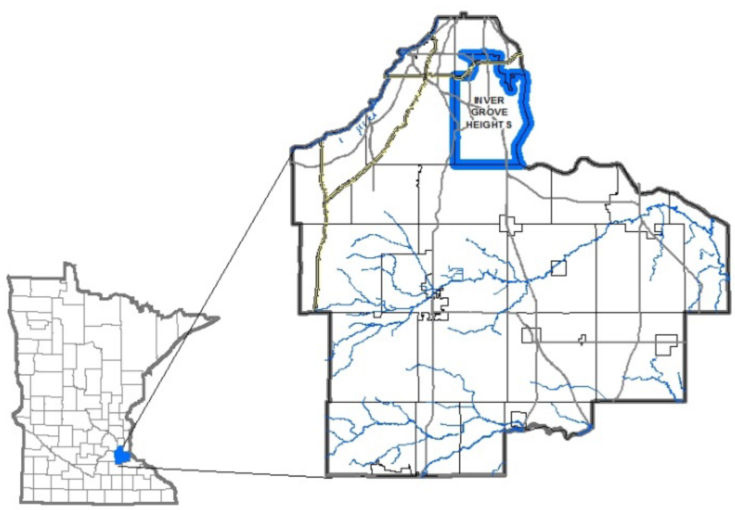

Figure 1: Location of Study Area in reference to Dakota County and Minnesota

An estimated 90% of Dakota County residents use groundwater for their drinking water supply, either from a municipal water source or a private well. The two most heavily used aquifers in the county are the Prairie du Chien Dolomite (Opdc) and the Jordan Sandstone (Cjdn). Based on the County's septic system

[4] MDH. 2013. Minnesota County Health Tables (http://www.health.state.mn.us/divs/chs/countytables/profiles2013/bbirth12.pdf).

inventory, the County estimates that approximately 8,000 private domestic wells are in use county-wide, since households with septic systems generally also use private wells.

To evaluate potential problems and water quality trends in private drinking water wells county-wide, the County has conducted an on-going study (the Ambient Groundwater Quality Study ("Ambient Study")) since 1999. In this study, the same 74 private drinking water wells have been sampled for manganese in five different years. All of the unfiltered and untreated samples were collected by County staff at outside faucets served by private wells. Manganese concentrations exceeded the MDH guidance value of 100 µg/L in 34% of the wells. The majority of elevated manganese concentrations were from wells located in IGH and Rosemount, which is located directly south of IGH (**Appendix B**, Figure 23).

In addition to the Ambient Study, the County measured manganese in private well samples in conjunction with MDA's "Township Testing" nitrate sampling program in 2014, funded by a Clean Water, Land, and Legacy Amendment grant to the County through MDA. Well owners collected an unfiltered, untreated water sample. Manganese exceeded the guidance value of 100 µg/L in 21% of the wells tested. Elevated manganese was most frequently found in northern Rosemount and in Greenvale Township in the southwest corner of the County (**Appendix B**, Figure 24).

IGH has more than 34,000 residents and is primarily served by municipal water, with six active community water system (CWS) wells. All of the active community wells pump water from the Jordan Aquifer[5]. The IGH CWS has a water treatment plant that reduces manganese. The manganese concentration in the raw water is reported by the IGH CWS as 250 µg/L. The multi-step water treatment process of oxidation and filtration results in manganese being reduced to 20 µg/L in the finished water that is delivered to residents[6]. Therefore, concern regarding consumption of elevated manganese in IGH drinking water is confined to residents on private wells. Approximately 1,463 households in IGH rely on private drinking water wells, more than any other municipality or township in the county.

The presence and magnitude of manganese is not limited to Northern Dakota County groundwater. Based on a statewide sample of 9,010 private wells in Minnesota, about half (49%) are estimated to exceed the 100 µg/L guidance value for manganese (MDH 2012c). Manganese distribution in groundwater is highly variable throughout the state. Many areas have concentrations consistently above 100 µg/L (Figure 2). On a larger geographic scale, manganese is common in wells throughout glacial aquifer system of the Northern U.S[7]. In this region that includes Minnesota, 10% of drinking water wells are found to exceed EPA's lifetime health advisory level of 300 µg/L (Groschen et al. 2008). At a national level, EPA estimates that approximately 2.3 million people are served by public water systems with manganese above 300 µg/L (USEPA 2003b).

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[5] Personal communication between V. Demuth, Dakota County and Scott Thureen, Public Works Director, City of Inver Grove Heights, 8/3/2016

[6] City of Inver Grove Heights website http://mn-invergroveheights2.civicplus.com/DocumentCenter/View/3875

[7] The glacial aquifer system includes parts of 26 states and underlies most of New England, extends through the Midwest, and underlies portions of the Pacific Northwest and Alaska.

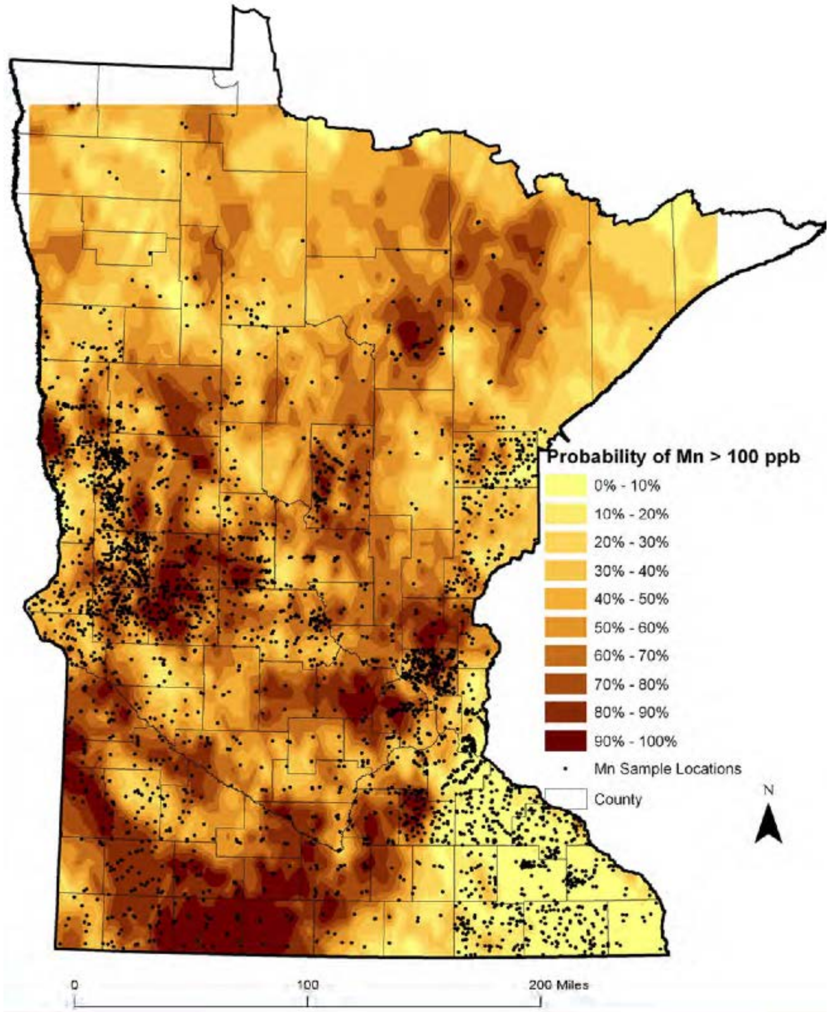

Figure 2: Probability of Manganese Greater than 100 µg/L in Minnesota Groundwater[8]

G. Water Treatment to Reduce Manganese

Since manganese is a common groundwater contaminant in Minnesota, identifying treatment options that are effective, practical, and economically feasible for private well users to implement is critical. While water treatment device manufacturers do not currently certify treatment devices for manganese removal though any formal certification groups, information is available on water treatment options (MGA 2015). Treatment types commonly used by private well owners and evaluated as part of the WIISE Study are described here:

- An oxidizing filter (commonly called an iron filter) can reduce dissolved manganese. It works by oxidizing the dissolved iron and manganese in the water, converting them from dissolved ions to a particle, and then filter media filters out the particles from the water.

[8] Map source: Lundy J and Soule R. MDH memo. September 5, 2012 Initial Assessment of Manganese in Minnesota Groundwater (http://www.health.state.mn.us/divs/eh/water/swp/maps/mnreport.pdf).

- A sediment filter can only reduce particulate or precipitated manganese in the water, but not dissolved manganese.

- A water softener can be very effective at reducing dissolved manganese if the water conditions are right. However, iron in excess of 5 mg/L and manganese in excess of 500 µg/L can foul the softener resin bed and reduce the softening/filtering capacity (Skipton and Dvorak, 2014). An iron filter prolongs the life of the softener by preventing the plugging of the valve and other components, and increases its efficiency which leads to lower salt use.

- Carbon filters, in which contaminants accumulate on the surface of the filter media, may be effective at reducing manganese, particularly if the filter has a built-in ion exchange feature.

- A reverse osmosis (RO) system reduces dissolved solids, including manganese, from water as the water moves across a non-porous membrane. RO systems typically have three filters: a sediment filter, a RO membrane filter and a carbon filter.

III. Methods

A. Study Area and Well Selection

County staff completed an inventory of the 1,463 IGH households with private wells as their primary water supply, including the age, depth, and aquifer of the wells, where known. Of these, 800 households were randomly selected and mailed an *introductory letter* and *study chemical fact sheet* (**Appendix D**), explaining the project and inviting those interested to respond by August 24, 2015. The size of the initial mailing was based on the goal of enrolling 160 participants and knowing the response rates from previous County groundwater studies of 20-25% (20% of 800=160). No study incentives were offered to participants beyond the free water testing. Potential participants were told in the letter that the study results are legally classified as public data. A total of 274 well owners responded to the initial mailing by the deadline (response rate=34%). All 274 households were included in the study. The higher than expected response rate may be due to differences between the mainly rural households that have participated in previous groundwater studies and the largely suburban households in IGH.

B. Data Collection

Outdoor spigot water sampling: In fall 2015, County staff collected a well water sample of unfiltered, untreated water from an outside spigot at each of the participating homes. For stabilization parameters (pH, temperature, dissolved oxygen and specific conductance), county staff used an YSI field instrument, which was owned and calibrated by the Southeastern Minnesota Water Analysis Laboratory. A Hach test strip for water hardness was used to ensure that the spigot was not receiving softened water. The outside faucet was purged for approximately 15 minutes before field water quality parameters were measured. Water samples were collected once the field water quality parameters reached stabilization; when three consecutive measurements of pH varied by less than 0.1, temperature varied by 10% or less, specific conductance varied by 5% or less and dissolved oxygen varied by less than 0.5 mg/L. The water sample collected is considered representative of aquifer water and not water standing in contact with the plumbing.

Survey: An adult member of the household responsible for well water quality was asked to complete an *online survey* (Survey Monkey®) about any water treatment devices in the home, the primary source of drinking water, and risk perceptions and concerns about well water quality (**Appendix C**). An informational flyer was left at each house after the water sample was collected, notifying the well owner that a sample had been collected and providing the website address to access the online survey. Participants were informed on how to request a paper version of the survey. The County sent reminders to any households that did not complete the survey.

Inside tap sampling: In late spring 2016, households with a manganese result above 100 µg/L in their outdoor faucet sample were mailed an *invitation letter* (**Appendix D**) asking them to participate in free follow-up sampling of manganese from an inside drinking water tap. County staff mailed water sample bottles and instructions, along with information about the four dates and times available for sample drop-off. The residents were directed to collect a sample of their primary drinking water, after it had gone through any treatment devices typically used in the home prior to drinking. The purpose of the inside tap sampling was to assess the effectiveness of commonly-used water treatment devices to reduce manganese. Participants also submitted a water hardness test strip and a *Water Test Form* (**Appendix C**) during sample drop-off on which they recorded the sample location (e.g, kitchen tap; refrigerator water dispenser) and any treatment devices the water went through.

C. Data Analysis

The County contracted with two state-accredited laboratories for water sample analysis. Minnesota Valley Testing Lab (MVTL) measured manganese, iron, and arsenic. Southeastern Minnesota Water Analysis Laboratory (SMWAL) analyzed for coliform bacteria (Colilert analysis), nitrate, nitrite, fluoride, sulfate, and chloride. All coliform bacteria samples were delivered to the lab within a 30 hour holding time. The method detection limits (MDLs) are shown in Table 1.

Survey and results data were analyzed using Minitab 17 and SAS® software, version 9.4 (SAS Institute Inc. 2011). Maps were generated using ArcGIS version 10.4.1. In multivariate regression modeling and non-parametric tests used to evaluate differences between groups (e.g., Kruskal-Wallis test), statistical significance was defined at a confidence level of 95% or higher. Notched boxplots were used to show the distribution of outdoor tap manganese concentrations by analyte concentration groupings, typically a non-detectible category (0) and increasing concentration tertiles (1-3). Non-detects were set to zero in caluculating the summary statistics.

Table 1: Method detection limits (MDLs) for WIISE Study analytes

Analyte	Manganese (µg/L)	Arsenic µg/L	Lead µg/L	Iron (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Chloride (mg/L)
MDL	5	0.5	0.5	0.015	0.25	0.10	0.20	0.50	0.50

D. Participant Communications

The County received analytical results from outside spigot testing directly from SMWAL and MVTL. Customized results packets were then mailed to each participating household. MDH created the results packet that included a results table and personalized results interpretation. For any results above levels of concern, additional information and suggested actions were provided. These actions and materials are described below:

- Households with a manganese result above 100 µg/L were provided with the MDH *Manganese and Drinking Water Fact Sheet*[9] and the *Summary Table of Water Treatment Options to Reduce Manganese* (**Appendix D**). The Summary Table of Water Treatment Options describes both point of use and point of entry water treatment options.

- The results letter informed households with a manganese result above 100 µg/L that the County would mail a water sample bottle for them to collect a water sample at their primary drinking water tap to test for manganese at no charge.

- MDH does not consider any amount of lead safe to consume. As such, MDH advised all study participants whose outside spigot lead result exceeded the MDL of 0.5 µg/L to resample at their inside drinking water tap. A sample bottle order form was mailed to the participants. MDH provided contact information for staff that could assist residents with interpreting inside tap results and offer treatment advice.

- The MDH fact sheet titled *Arsenic in Minnesota's Well Water*[10] was sent to all study participants whose arsenic result exceeded the MDL.

    - For arsenic results above the MCL of 10 µg/L, the results letter recommended that the water not be consumed over the long term and that a treatment system should be installed to remove arsenic. It was also recommended that households using a treatment device designed to remove arsenic should test the treated water for arsenic to ensure the system is working properly.

    - For arsenic results above the MDL of 0.5 µg/L but less than 10 µg/L, the results letter stated that while the level is below the MCL, it is not low enough to completely eliminate all risk of cancer and other health effects and that they may want to consider treating the water.

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[9] http://www.health.state.mn.us/divs/eh/risk/guidance/gw/mninfosheet.pdf

[10] http://www.health.state.mn.us/divs/eh/wells/waterquality/arsenic.pdf

- All households that had a coliform bacteria positive test were mailed an MDH fact sheet titled *Bacterial Safety of Well Water*[11] and a sample bottle order form for retesting for coliform bacteria from inside the home from the faucet on the pressure tank.

As a public service, County staff mailed a letter to 255 well owners with household wells located within 1,500 feet of any WIISE study well with an arsenic result higher than 7 µg/L, notifying them of the elevated arsenic in the groundwater in their vicinity. They were invited to drop off a water sample for analysis at one of the four drop-off dates and times set up for WIISE study manganese resampling, at their expense. Twenty-three percent of the 255 well owners participated. Since these samples are not part of the WIISE study, the results are not described herein.

For follow-up manganese testing, MVTL sent the results to both the county and the participating households. The County then sent letters with personalized advice on mitigation to well owners whose inside tap manganese result exceeded 100 µg/L.

IV. Results

A. Survey Results

Ninety-four percent of participants completed the survey (n=269). The results are described below.

1. Household Demographics

- In 34% of the homes, at least one woman of childbearing age (defined as between ages 18-44) was a resident (4 missing responses).

- Nineteen percent of homes included a child 9 years old or younger[12] (2 missing responses). An infant 12 months old or younger lived in 5% of the homes (3 missing responses).

2. Drinking Water Source and Treatment

Well users frequently reported using more than one water source for drinking at home. For example, it was not uncommon for a respondent to report "mostly or always" drinking softened or filtered well water but "sometimes" drinking bottled water and "sometimes" drinking well water that was not filtered or softened.

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[11] http://www.health.state.mn.us/divs/eh/wells/waterquality/bacteria.pdf

[12] Twelve months old and nine years old were selected as upper-end cut-offs in the survey questions about children's age. Recommendations to use an alternative source of water due to excess nitrate and manganese are based on both the sensitive developmental window during infancy and the assumption that parents follow current guidelines to switch from reconstituted formula to cow's milk at 12 months of age. CDC's recommendation to provide an alternative source of water if fluoride levels exceed the recommended guideline are based on children younger than 9 years old. Read more at Community Water Fluoridation: Private Wells (http://www.cdc.gov/fluoridation/faqs/wellwater.htm).

The majority of respondents drank filtered or softened well water:

- Seventy-one percent "mostly or always" drink well water that is softened or filtered. An additional 11% "sometimes" drink filtered or softened water.

- Twelve percent of respondents "mostly or always" drink water that is <u>not</u> filtered or softened. An additional 14% "sometimes" drink water that is not filtered or softened. In total, 26% of respondents reported drinking unfiltered/unsoftened well water at least some of the time.

- Only 4% "mostly or always" drink well water processed with a distiller.

Thirteen percent of respondents mostly or always avoid well water for drinking:

- Ten percent of respondents "mostly or always" drink bottled water, while an additional 39% "sometimes" drink bottled water.

- Three percent of respondents "mostly or always" get their drinking water from another source (e.g., bring water home from work). An additional 7% "sometimes" use another water source.

In the thirteen homes with infants under twelve months old, four respondents (33%) reported that the infant drinks a different source of water than the other members of the household, while eight households (67%) use the same water source (1 missing response).

3. Cooking Water Source and Treatment

Softened or filtered well water was the main source of water for cooking; however, 30% use untreated water at least some of the time:

- Seventy-four percent "mostly or always" use softened or filtered water for cooking. An additional 10% of respondents "sometimes" use softened or filtered water for cooking.

- Eighteen percent "mostly or always" use well water that is <u>not</u> filtered or softened for cooking and an additional 12% "sometimes" uses well water that is <u>not</u> filtered or softened for cooking.

A small percent respondents "mostly or always" avoid well water for cooking.

- Only 1% of respondents "mostly or always" use bottled water for cooking, with an additional 3% "sometimes" using bottled water for cooking.

4. Treatment device maintenance

When asked about water treatment maintenance, 23% report strictly following instructions, 59% report usually following instructions, 10% report seldom following instructions, and 7% are professionally maintained (25 missing responses).

5. Water Quality Concerns and Opinions

The water quality issue that respondents were most likely to be "very concerned" about, when provided the choices in Table 2 below, was contamination with chemicals from industry, landfills, or dumps (30%)[13]. Sixty percent of respondents were "somewhat" or "very" concerned about iron or minerals[14].

Table 2: Survey results: Water quality levels of concern

Concerns about your well water*?	Very Concerned	Somewhat Concerned	Not Very Concerned	Not At All Concerned
Taste, odor, color	8%	26%	32%	34%
Iron or other minerals	20%	40%	23%	17%
Bacterial contamination	22%	24%	35%	19%
Nitrate contamination	22%	30%	30%	19%
Contamination with herbicides or other lawn or farming related chemicals	25%	26%	30%	19%
Contamination with chemicals from industry, landfills, or dumps	30%	29%	24%	16%

*Frequency missing ranged from 2 to 10.

Of the 258 respondents, 54% agreed or strongly agreed that they have ample opportunities to learn about the quality of their water.

Table 3: Survey result: Opportunities to learn about water quality

I have ample opportunities to learn about the quality of my water	Frequency	Percent
Strongly Agree	17	7%
Agree	121	47%
Don't Know	46	18%
Disagree	62	24%
Strongly Disagree	12	5%

Almost half of respondents did not know if governments were doing an adequate job protecting groundwater in their community. Twenty-one percent disagreed or strongly disagreed that governments were doing enough to protect groundwater. Thirty-three percent agreed that governments were doing an adequate job.

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[13] IGH has an active landfill, a closed landfill, and an oil refinery (all at the southeast border). The contaminant plumes from these sources flow east to the Mississippi River and there are no active drinking water wells that would be impacted.

[14] Note that the study invitation letter did not mention manganese as a mineral of particular interest.

Table 4: Survey result: Governments protect groundwater in my community

Federal, state and local governments are doing an adequate job protecting groundwater in my community	Frequency	Percent
Strongly Agree	3	1%
Agree	83	32%
Don't Know	117	46%
Disagree	42	16%
Strongly Disagree	12	5%

1 missing response

B. Well Characteristics and Field Parameters

For the majority of participating households, well characteristics were available in the well construction records on file with the County. These records are also available on the Minnesota Well Index on the MDH website[15]. Wells were either screened in glacial unconsolidated sediments or completed below the sediments in the bedrock aquifers. The majority of the sampled wells were completed in one of three aquifers:

- 133 wells were screened in the sand and/or gravel aquifer
- 62 wells in the Prairie du Chien dolomite
- 35 wells in the Jordan sandstone.

In addition, one well was completed in the Platteville Limestone, one well in the St. Peter Sandstone, one well in both the St. Peter and Prairie du Chien, and 4 wells in the Tunnel City Formation. The aquifer was unknown for 37 of the wells because there was no available well construction record. Inver Grove Heights has relatively more private wells completed in unconsolidated sediments than other Dakota County communities because it has a “buried bedrock valley” under much of the city. The bedrock layers were eroded down to the Tunnel City Formation to a depth of more than 500 feet at the deepest point from west to east by the Glacial River Warren. This ancient river valley has since been filled in with glacial sediments from subsequent glaciations (Appendix B, Figure 25).

Temperature, specific conductance, dissolved oxygen and pH were measured while purging the outdoor water spigot prior to water sample collection. Summary results are shown in Table 5. Temperature ranged from 9.2 to 13.4°C; the mean of 10.7 °C and median of 10.6°C were similar. The specific conductance ranged from 345 µmhos/cm to 1582 µmhos/cm, with a similar mean of 571 µmhos/cm and median of 552 µmhos/cm. Dissolved oxygen ranged from 0.1 mg/L to 16.4 mg/L, with a differing mean of 2.1 mg/L and a median of 0.9 mg/L, indicating a right-skewed, non-normal distribution. The pH ranged from 6.7 to 9.72, with a similar mean of 7.46 and a median of 7.47.

[15] http://www.health.state.mn.us/divs/eh/cwi/

Table 5: Summary statistics for field parameters*

Parameter	N*	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max
Temperature (degrees C)	268	10.7	0.65	9.2	10.3	10.6	11.0	13.4
Specific Conductance (µmhos/cm)	266	571	156	345	486	552	626	1582
Dissolved Oxygen (mg/L)	266	2.1	2.5	0.1	0.5	0.9	2.4	16.4
pH	266	7.5	0.3	6.7	7.3	7.5	7.6	9.7

*Field parameters were not recorded for 6-8 samples because a battery malfunction resulted in fluctuating and unreliable readings.

C. Contaminant Results

1. Manganese

Manganese was detected in 220 of 274 samples (80%). Manganese concentration results are summarized in Table 6. The median manganese concentration of 344 µg/L in WIISE study wells is over 13 times higher compared to the Ambient Study (25 µg/L), which represents the county as a whole. Both mean and the median concentrations were above the MDH guidance value for children and adults. Seventy-one percent of wells sampled from the outside spigot exceeded the 100 µg/L health-based guidance value for manganese (Table 7) which is higher than the state average, estimated to be 49% (MDH 2012c).

Table 6: Summary statistics for manganese

Parameter	N	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max
Manganese (µg/L)	274	357.3	321.5	<MDL	41.8	344	530.5	1790

Table 7: Manganese results in comparison to MDH manganese guidance values

Manganese	Frequency	Percent
Greater than 100 µg/L (Health-based guidance value for bottle-fed infants)	194	71%
Greater than 300 µg/L (Health-based guidance value for all other populations)	153	56%

Of the 13 households in which an infant twelve months or younger was present, eight (62%) had outside spigot manganese levels above 100 µg/L. Infant water source and treatment devices for the thirteen households are described in Table 8.

Table 8: Manganese outside spigot results and related factors for 13 households with an infant ≤12 months old

Manganese (µg/L)	Alternate Water Source for Infant	Water Treatment Devices in Home
<MDL	Yes (Bottled Water)	softener
<MDL	Yes (Breastfed)	softener/sediment filter/pitcher water filter
5	No	softener/distiller sometimes/sediment filter/RO/fridge carbon
6	Yes (Bottled water)	softener/fridge carbon
10	No	softener/mostly purchase bottled water/iron filter/pitcher water filter
144	No	softener/whole house carbon
204	No	softener/sediment filter/whole house carbon
257	No	softener/iron filter/sediment filter/whole house carbon
308	No	softener/distiller sometimes/iron filter/RO/fridge carbon
320	No	softener/sediment filter/fridge carbon/pitcher water filter
468	Yes (Distilled water)	softener/fridge carbon/potassium permanganate iron reduction system
558	No	softener/iron filter
692	No	softener/iron filter/sediment filter

As shown in Figure 3, manganese levels above MDH guidance values are distributed throughout the study area.

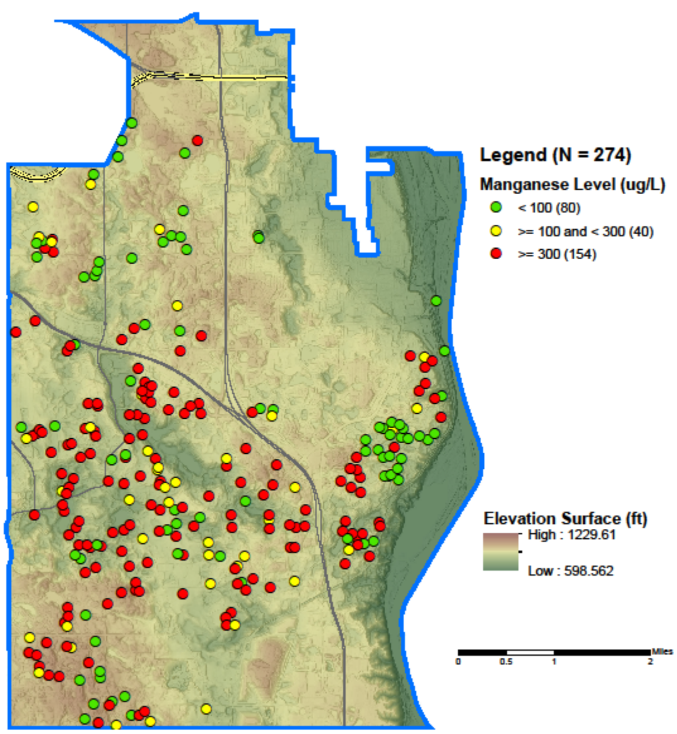

Figure 3: Spatial distribution of manganese concentration in outside spigot samples

When examining the manganese results by aquifer, well depth, dissolved oxygen, and well construction year (Appendix B, Figure 25-Figure 29), spatial clustering of these factors are visible. Typically, well drillers complete a well in the first available aquifer, increasing the likelihood that wells located near each other will have similar geology and well construction. More information on the influence of well characteristics on manganese concentration is found in Section IV.D2.

2. Lead

Lead was detected in 144 of 273 outside spigot water samples above the laboratory MDL of 0.5 µg/L (53%). Lead concentration results are summarized in Table 9.

Table 9: Summary statistics for lead (outside spigot)

Parameter	N	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max
Lead (µg/L)	273	1.7	7.4	<MDL	<MDL	0.6	1.2	111.1

Five lead results exceeded 15 µg/L, the EPA Safe Drinking Water Act (SDWA) action level (AL) for public water supplies (note that the MCL goal for lead is 0 µg/L).

Table 10: Frequency and percent of samples below and above the lead MDL and SDWA AL

Lead Concentration	Frequency (n=273)	Percent
Less than the MDL of 0.5 µg/L	129	47%
Between 0.5 µg/L and 15 µg/L	139	51%
Greater than 15 µg/L	5	2%

Missing=1 (result was not reportable by MVTL)

The five households with lead results above 15 µg/L were offered lead testing at the inside tap at no cost[16]. All five wells were resampled by the residents at the kitchen faucet and where applicable, after treatment. As shown in Table 11, *first draw* sample results (collection after water has sat in the pipes for a period of time) were much lower than the outside spigot sample results. After running the water until it turned cold (*purged sample*), no lead was detected above 0.5 µg/L. One likely scenario for the discrepancy between the outside and inside tap results is that the high lead in the outside samples originated in the spigot gate valves. While the outside spigot water was running to purge stagnant water from the household plumbing and well casing, the spigot was connected to a garden hose to direct the water away from the home's foundation. Then the water was turned off to disconnect the hose and turned back on to collect the sample. The turning on of the spigot may have provided an opportunity for lead in the gate valve to become dislodged, subsequently introducing lead into the sample. It is unlikely that the lead in the outside spigot sample originated from inside plumbing, well casing, or well pump because the water collected from the outside faucets was purged for approximately 15 minutes before sample collection. As such, there was no standing time for water to leach lead from metal plumbing. Also, the first draw sample results from the drinking water faucet were significantly lower in lead

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[16] In all other households with detectible lead in the outside spigot sample, the County advised residents to re-sample from the primary inside drinking water tap but did not provide free testing.

concentration. It is also unlikely that the lead level in the outside spigot sample is representative of aquifer water, since groundwater in the County is unlikely to contain lead above the AL[17] and the purged inside tap samples contained no detectible lead.

Table 11: Lead results for households with lead >15 µg/L in outside spigot samples

Household	Sample Description	Lead Result (µg/L)
A	Outside Faucet	111.1
A	1st draw kitchen faucet	3.04
A	Purge at kitchen faucet	0.5
A	Fridge filter (carbon)	< 0.5
B	Outside Faucet	21.4
B	1st draw kitchen faucet	< 0.5
B	Purge at kitchen faucet	< 0.5
B	Fridge filter (carbon)	< 0.5
C	Outside Faucet	31.4
C	1st draw kitchen faucet	1.13
C	Purge at kitchen faucet	< 0.5
D	Outside Faucet	15.9
D	1st draw kitchen faucet	< 0.5
D	Purge at kitchen faucet	< 0.5
D	RO	< 0.5
E	Outside Faucet	25.4
E	1st draw kitchen faucet	0.6
E	Purge at kitchen faucet	< 0.5
E	Carbon filter with ion exchange	< 0.5

3. Arsenic

Arsenic concentration results are summarized in Table 12.

Table 12: Summary statistics for arsenic

Parameter	N	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max
Arsenic (µg/L)	274	1.9	2.6	<MDL	<MDL	0.8	3.0	13.3

MDH's health-based guidance value for arsenic is 10 µg/L for private wells (equivalent to the federal MCL). Arsenic was detected in three wells (1%) above the guidance value. All three wells were screened wells located on the same residential street and only one of the three homes had water treatment that

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[17] Median lead levels in study area aquifers range from 0.19 µg/L to 0.43 µg/L, with a maximum concentration of 5.2 µg/L (MPCA 1999)

would reduce arsenic at the drinking water faucet. As mentioned in Section II.D, the County notified households on wells located within 1,500 feet of one of the twelve WIISE study wells with more than 7.0 µg/L arsenic about their proximity to a well with an arsenic level approaching the MCL. Arsenic levels above 7.0 µg/L are mainly located on the west side of IGH (Figure 4). Of the 15 wells with arsenic above 7.0 µg/L: thirteen are screened wells, two are bedrock wells in the Tunnel City Formation, and one is in the Prairie du Chien.

Table 13: Arsenic results in comparison to the MDL and guidance value

Arsenic concentration	Frequency (n=274)	Percent
Less than the MDL of 0.5 µg/L	119	43.4%
Between the MDL and 6.9 µg/L	140	51.1%
Between 7 µg/L and 10 µg/L	12	4.4%
10 µg/L or greater	3	1.1%

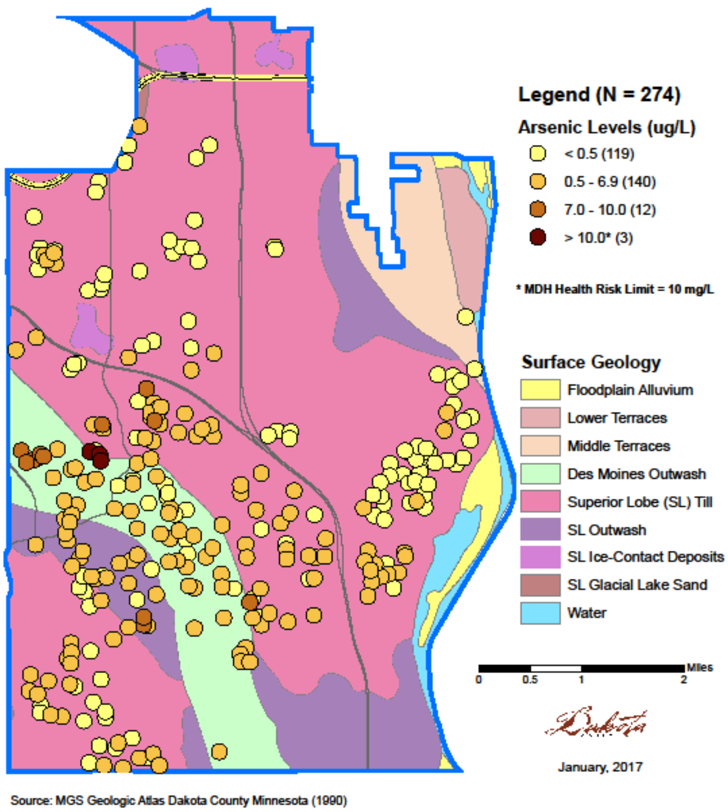

Figure 4: Arsenic levels overlying surface geology map

Study staff consulted with the USGS Minnesota Water Science Center (Melinda Erickson Ph.D.) about potential sources of elevated arsenic in the IGH cluster. After ruling out several possible causes (e.g., nearby petroleum spill or leak sites, dumps or landfills, large wetlands), Dr. Erickson suggested that the source of the elevated arsenic may be clay layers within the Des Moines Lobe outwash shown in light green in Figure 4. The Des Moines Lobe tends to be finer grain material with higher organics. It is more biochemically active and conducive to mobilizing arsenic into groundwater than other geologic conditions in Dakota County. Geochemical conditions at the boundary of an aquitard to the aquifer are especially geochemically reactive.

In hydrogeologic settings where arsenic source material is present, Dr. Erickson has shown a high likelihood of the occurrence of mobile arsenic in wells screened a short interval away from the lower geologic contact of the clay till confining layer (Erickson et al. 2005). This fact suggests that screen placement is a control on the occurrence of arsenic in well water. Screen placement at depths that maximize the distance from the clay till contact could avoid the creation of geochemical conditions that mobilize arsenic (Erickson et al. 2005).

4. Fluoride

Seventy-nine percent of samples were above the fluoride MDL of 0.02 mg/L. Fluoride concentration results are summarized in Table 14.

Table 14: Summary statistics for fluoride

Parameter	N	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max
Fluoride (mg/L)	274	0.12	0.075	<MDL	0.08	0.15	0.18	0.27

All fluoride results were less than the EPA's SMCL of 2.0 mg/L to protect against dental fluorosis in children. All results were also less than CDC's recommended fluoride level in drinking water for good oral health (0.7 mg/L). Therefore, parents of children in homes with fluoride levels below this value should discuss the need for fluoride supplements with their child's dentist or pediatrician.

5. Coliform bacteria and E. coli

Sixty-seven water samples (25%) tested positive for coliform bacteria. The laboratory that conducted the testing (SMWAL) reported that this percentage is similar to what they find annually. All positive tests were further tested for *E. coli*. Only one well tested positive for E. *coli*; this well's wellhead was below grade and the yard contained a large number of free-roaming poultry. Other issues that could result in bacterial contamination of the water were visually apparent for several wells such as cracked or broken well caps or the top of the wellhead less than 12 inches above the ground surface (example shown in Figure 5).

Table 15: Frequency and percent of samples positive for coliform bacteria

Coliform Bacteria	Frequency (n=270)	Percent
Not present	203	75%
Present	67	25%

The County advised all study participants whose sample contained coliform bacteria to have a sample collected from the pressure tank analyzed for coliform bacteria and provided them with an MDH fact sheet, a link to the MDH well disinfection guide[18] and a bottle order form for resampling. Of the thirteen households that reported having an infant 12 months old or younger, only one had a positive coliform bacteria test. There is a concern that bacteria will colonize in filters and this household had several filters in use.

Figure 5: Coliform bacteria-positive well lacking watertight and vermin-proof cap/cover

6. Nitrate and Nitrite

Nitrate concentration results are summarized in Table 16. Nitrite was not detected above the MDL of 0.10 mg/L in any of the well samples and is therefore not discussed further in this report.

Table 16: Summary statistics for nitrate

Parameter	N	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max
Nitrate (mg/L)	274	0.61	1.12	<MDL	<MDL	<MDL	0.8	6.1

When comparing the WIISE Study median nitrate level to the median for the county as a whole, nitrate levels in IGH are eight times lower (0.10 mg/L versus 0.83 mg/L). This was expected, as the Ambient Study found nitrate levels to be highly correlated with the percent of nearby land use in row crop agriculture, and IGH is primarily residential. Natural levels of nitrate in Minnesota groundwater are usually quite low (less than 1 mg/L) (MDH 2015). Nitrate concentrations in the range of 1-3 mg/L are considered "transitional", and nitrate concentrations above 3 mg/L and less than 10 mg/L are considered "elevated". Nitrate concentrations of 10 mg/L or above exceed the MCL. As shown in Table 17, only 10 WIISE Study wells had a nitrate concentration above the background level of 3 mg/L. MDH's health-based guidance value for nitrate is 10 mg/L (equivalent to the federal MCL). No well had a nitrate concentration above the guidance value.

[18] MDH. Well Disinfection (http://www.health.state.mn.us/divs/eh/wells/waterquality/disinfection.pdf).

Table 17: Frequency and percent of samples by nitrate concentration category

Nitrate concentration	Frequency (n=274)	Percent
Less than MDL (0.25 mg/L)	186	67.9%
Between 0.25 mg/L and 1 mg/L (background)	29	10.6%
Greater than 1 mg/L and less than 3 mg/L (transitional)	49	17.9%
3 mg/L or greater (max=6.1 mg/L) (elevated)	10	3.6%

Nitrate results above 3.0 mg/L are distributed fairly evenly across the study area (Appendix B, Figure 30). The wells with nitrate concentrations above the background level of 3.0 mg/L were drilled between 1952 to 1998 and completed in either the Prairie du Chien, Jordan, or screened in the unconsolidated sediments. The well depths ranged from 127 feet to 383 feet deep. The nitrate levels above 3 mg/L in WIISE Study wells may originate from septic systems or past use of nitrogen fertilizer. The density of septic systems is higher in IGH than in any other city or township in the county.

7. Sulfate

As shown in Table 18, all sulfate results were well below EPA's Health Advisory Level of 500 mg/L. Statewide sampling of groundwater wells finds that sulfate concentrations are substantially higher in southwestern and northwestern Minnesota compared to the rest of the state due to natural sources (MPCA 2013). However, urban land use, such as the case in IGH, can increase sulfate concentrations in groundwater (MPCA 2013).

Table 18: Summary statistics for sulfate

Parameter	N	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max
Sulfate (mg/L)	274	26.6	12.0	0.5	16.6	25.8	33.3	75.2

D. Other Chemical Results

1. Iron

Iron concentration results are summarized in Table 19.

Table 19: Summary statistics for iron

Parameter	N	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max
Iron (mg/L)	274	1.37	1.74	<MDL	0.08	0.88	2.09	12

Eleven percent of well sample results were less than the MDL of 0.015 mg/L (Table 20). Twenty-seven percent ranged from above the MDL to below the SMCL of 0.3 mg/L. Sixty-three percent of well samples exceeded the iron SMCL of 0.3 mg/L. The median iron result of 0.88 mg/L is higher than the county-wide Ambient Study median of 0.11 mg/L.

Table 20: Frequency and percent of samples above the iron MDL and SMCL

Iron	Number of wells (n=274)	Percent
Less than MDL of 0.015 mg/L	29	10.6%
Between 0.015 mg/L (MDL) and 0.3 mg/L (SMCL)	73	26.6%
Greater than the SMCL of 0.3 mg/L	172	62.8%

2. Chloride

Chloride concentration results are summarized in Table 21. Chloride was detected in all samples above the MDL of 0.50 mg/L.

Table 21: Summary statistics for chloride

Parameter	N	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max
Chloride (mg/L)	274	26.6	37.4	1.1	3.3	15.6	33.9	288.0

Only one WIISE Study well (<1%) exceeded the SMCL of 250 mg/L for chloride (Table 22). The natural background level of chloride is considered to be 3 mg/L or less. Chloride is above background in 76% of the WIISE Study wells which indicates that the water has been impacted by human activities.

Table 22: Frequency and percent of samples above the chloride MDL and SMCL

Chloride	**Number of wells (n=274)**	**Percent**
Between 1 mg/L (min) and 3 mg/L	65	23.7%
Greater than 3 mg/L and less than 249 mg/L	208	75.9%
Greater than the SMCL of 250 mg/L	1	0.4%

Compared to the Ambient Study, median chloride levels are higher in the WIISE Study wells (15.6 mg/L compared to 11.5 mg/L in the Ambient Study). Potential sources of the relatively elevated chloride levels could be water softeners discharging chloride-rich brine to septic systems or the density of roads and road salt use. All study participants had a septic system and 92% reported having a water softener. The most common product used in a water softener is sodium chloride. Water softeners exchange the sodium ion for calcium and magnesium ions, the two minerals that make the water hard. The calcium, magnesium, and chloride-rich brine is then discharged to septic systems. Road salt, in use since the 1950's, may be another contributor. Storm water ponds could retain surface water enriched with chloride from road salt and contribute to elevated chloride in the groundwater.

There is some clustering of wells with elevated chloride levels (Appendix B, Figure 31). When a 500 foot buffer was placed around all the designated storm ponds, the WIISE study wells within the buffers had 30% higher chloride levels compared to wells outside the buffers. In future efforts to determine if chloride in groundwater is from septic systems or road salt, water samples could be tested for cyanide, an anti-caking agent in road salt.

E. Influential factors in the concentration of manganese

A main study objective was to identify influential factors in manganese well water concentrations[19]. Since manganese is mobilized from the aquifer when the dissolved oxygen is low (MPCA 2013), we expect concentrations to be highest in wells with the least dissolved oxygen.

1. Redox Processes

The reduction-oxidation potential (redox) of the groundwater affects the fate and transport of many geochemical parameters (Hem 1985). The dissolved oxygen, nitrate, manganese, iron, and sulfate results were entered into the USGS Excel Workbook for Identifying Redox Processes in Groundwater (Jurgens et al. 2009) to look at the possible relationships between manganese and the reduction/oxidation (redox) condition of the water samples collected. Based on results from the USGS redox spreadsheet, the data from 268 wells (8 wells lacked dissolved oxygen data) can be summarized into three general categories: 55 wells are oxic, 51 wells are anoxic and 160 wells are mixed (oxic and anoxic). As shown in Table 23, elevated manganese in groundwater in IGH is most likely to occur in anoxic and mixed water.

Table 23: Manganese results (µg/L) summarized by redox category

Redox Category	N	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max
Anoxic	51	449.1	300.5	<5.0	242	384	563	1660
Mixed	160	441.1	306.6	<5.0	222	402	615	1790
Oxic	55	4.65	11.09	<5.0	<5.0	<5.0	<5.0	43

Since there was no significant difference in the median manganese concentration between the anoxic and mixed groups based on the Mann-Whitney Test, the two groups were combined in Table 24. As shown in this table, manganese concentration is higher in the anoxic/mixed category, which is consistent with the redox hypothesis.

Table 24: Summary statistics of manganese concentration by redox category

Parameter	Redox Category	N	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max
Manganese (µg/L)	Anoxic/Mixed	211	443.1	304.4	<5	240	397	612	1790
	Oxic	55	4.65	11.09	<5	<5	<5	<5	43

2. Well Characteristics

Due to potentially differing source materials, differences in manganese by aquifer were examined. Aquifer information was available for 239 wells. The three major aquifers were unconsolidated sediments (n=133), Prairie du Chien Dolomite (n=63) and Jordan Sandstone (n=36). Manganese concentration was highest for wells in unconsolidated Sediments (Figure 6).

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[19] Influential factors in the concentration of other study analytes is discussed in Appendix E

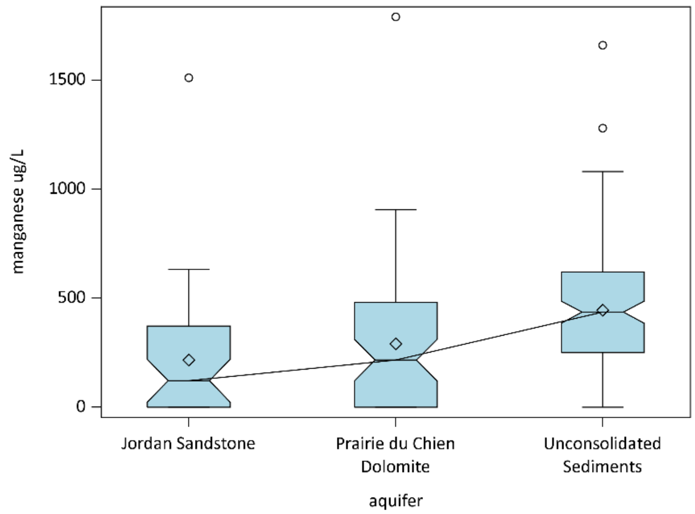

Figure 6: Manganese concentration by aquifer[20]

The vertical distance below a source material may influence manganese concentration. Well depth was available for 224 WIISE Study wells. Total depth was divided into three categories: <250 feet (n=73), 250 to <350 feet (n=56) and 300+ feet (n=95). Manganese concentration was not notably different across depth categories (Figure 7).

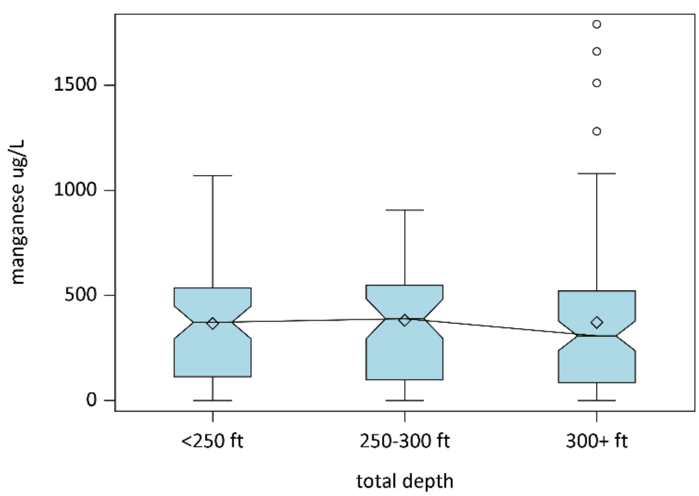

Figure 7: Manganese concentration by total well depth

[20] In the notched boxplots, medians are presented by horizontal lines while means are shown as diamonds. The boxes represent the intra-quartile range (IQR). The whiskers that extend from each box indicate the range of values outside the IQR, but are not considered outliers. Outliers are shown as circles and represent values greater than ±1.5*IQR. The notches represent the 95% confidence interval of the median. If the notches of two groups do not overlap, this is strong statistical evidence that their medians differ.

3. Relationships between manganese and other analytes

Relationships between the concentration of manganese and geochemical properties and other contaminants (iron, chloride, arsenic, sulfate) were explored.[21]

a. Dissolved Oxygen

Manganese concentrations were lowest in the highest tertile of dissolved oxygen (Figure 8). As described in Section IIID.1, the environment becomes more reducing as oxygen content drops,, which increases the solubility of manganese.

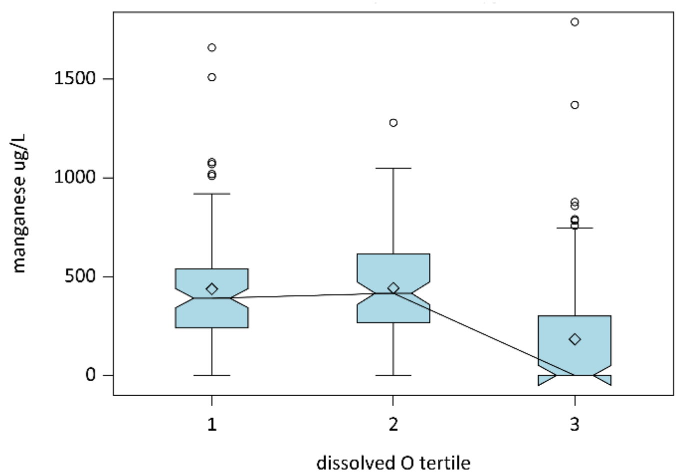

Figure 8: Manganese concentration by dissolved oxygen tertile

b. pH

Manganese levels are lowest in the lowest pH tertile (Figure 9). The importance of this finding is unclear, as the range of pH results is not very wide.

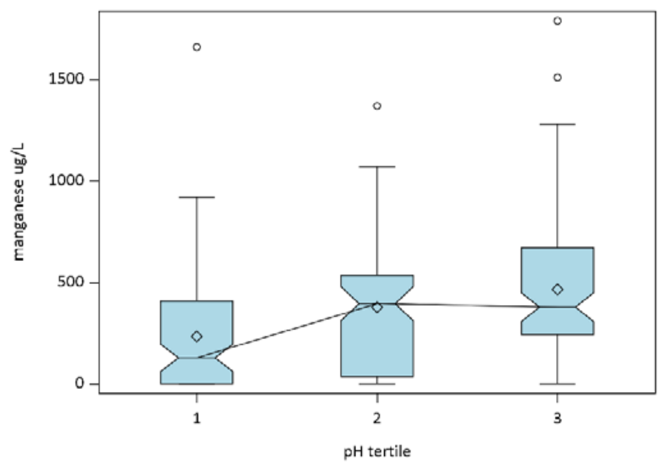

Figure 9: Manganese concentration by pH tertile

[21] Relationships between manganese and lead were not evaluated because the lead results are considered to be associated with the plumbing rather than conditions in the aquifer.

c. Iron

Manganese concentrations in the non-detectible iron category and first iron tertile are much lower compared to the higher iron tertiles (Figure 10). Positive relationships between iron and manganese in groundwater have been previously described (Groschen et al. 2008).

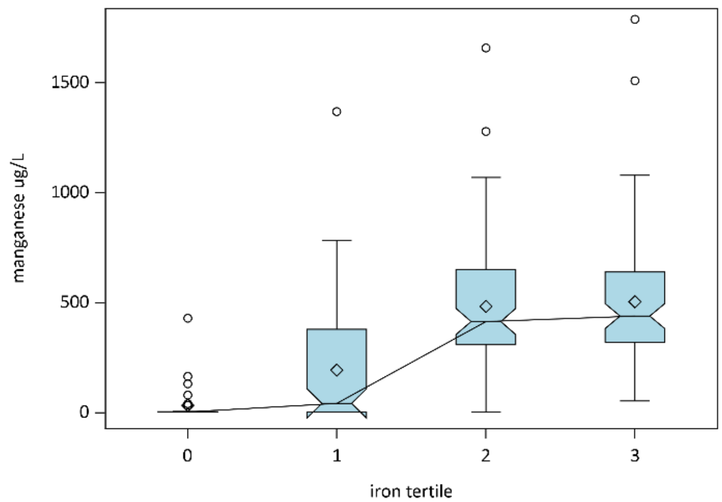

Figure 10: Manganese concentration by iron tertile

d. Chloride

Manganese concentration is lower at the highest chloride tertile (Figure 11; there was no non-detect category for chloride). These results are expected since chloride originates from anthropogenic sources and will be elevated in wells that are more susceptible to surface contamination where there would be more dissolved oxygen. In contrast, manganese is more prevalent in reducing conditions with less dissolved oxygen and less influence from surface contamination.

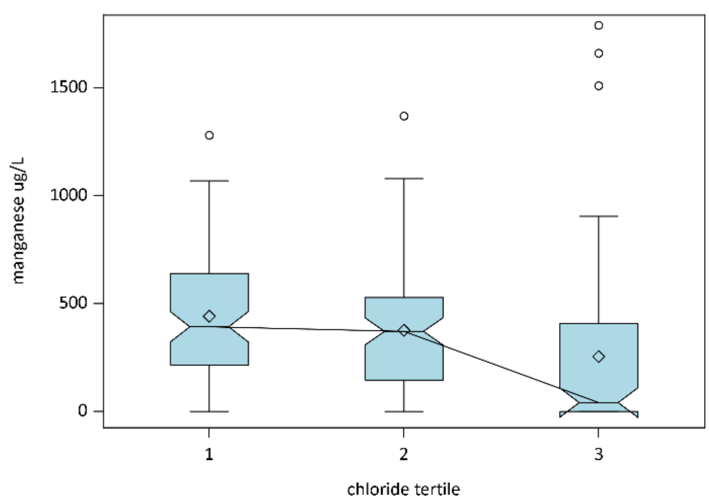

Figure 11: Manganese concentration by chloride tertile

e. Arsenic

A consistent, positive relationship is seen between manganese concentration and arsenic concentration tertiles (Figure 12). Arsenic is also strongly correlated to redox conditions in groundwater.

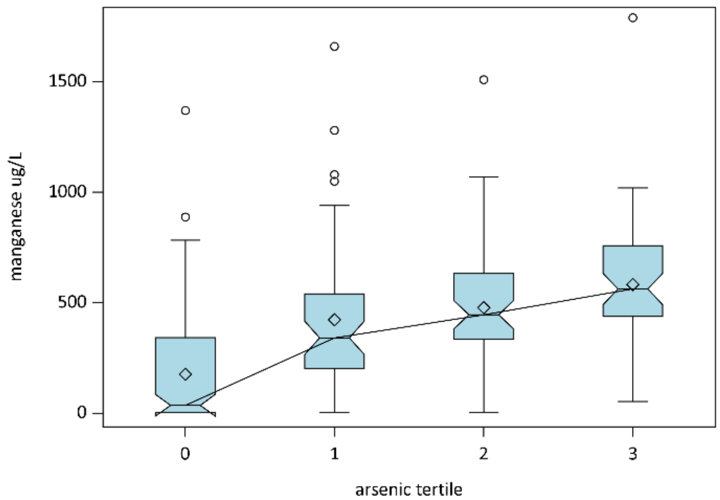

Figure 12: Manganese concentration by arsenic tertile

f. Sulfate

Manganese levels do not differ across tertiles of sulfate concentration (Figure 13). This is most likely because there are both natural and anthropogenic sources of sulfate in groundwater.

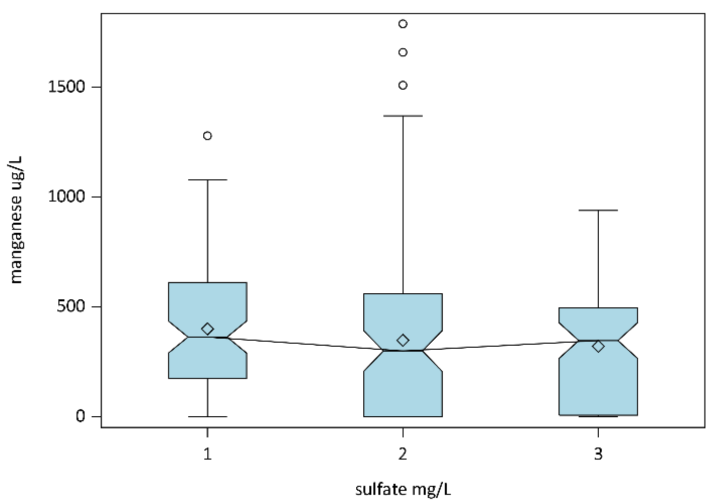

Figure 13: Manganese concentration by sulfate tertile

Kruskal-Wallis tests[22] support the visual findings in the boxplots (Table 25). There were significant differences in manganese concentration between groups (tertiles of detectible concentration and the non-detection category if applicable) for all study analytes except for sulfate. The largest Kruskal-Wallis statistics (corresponding to the largest discrepancy among rank sums) were seen for iron, arsenic, and dissolved oxygen. For dissolved oxygen, manganese concentrations were higher in the first two tertiles, with the start of the third tertile corresponding to 0.6 mg/L. For iron, a significant increase in manganese began in the second iron tertile, which corresponded to an iron concentration of 0.4 mg/L. Results corresponding to >0.4 mg/L iron, >MDL for arsenic, (or <0.6 dissolved oxygen) may indicate a greater likelihood for elevated manganese levels.

Table 25: Kruskal-Wallis test results for manganese concentration by analyte tertiles

Parameter	H test statistic	Degrees of Freedom	Pr>Chi-Square
Dissolved oxygen	63. 02	2	<0.001
pH	28.13	2	<0.001
Iron	104.87	3	<0.001
Chloride	29.34	2	<0.001
Arsenic	94.00	3	<0.001
Sulfate	4.76	2	0.093

F. Treatment system effects on manganese concentration in drinking water

The collection of both outside spigot and inside tap samples in the WIISE study allowed for evaluation of manganese treatment device effectiveness. Out of the 194 households with an outside spigot manganese result above 100 µg/L, 100 households participated in sampling for manganese from an inside tap. A total of 110 water samples were submitted (10 households brought in two water samples from different treatment devices or taps). One result from an inside tap not used for drinking was excluded, bringing the total number of households to 99 and the number of samples to 109. Participants collected 98 samples (90%) from the kitchen tap and 11 samples (10%) from the refrigerator.

[22] The Kruskal-Wallis test is a non-parametric test used to determine if two or more samples are from the same distribution. The null hypothesis is that the medians of all groups are equal, and the alternative hypothesis is that at least one median of one group is different from the median of at least one other group.

1. General comparison of inside tap and outside spigot manganese concentration results[23]

Manganese concentrations were lower in the inside tap samples compared to outside spigot samples (Figure 14). The red histogram/density curve representing the inside tap samples is greatly shifted to the left of the blue histogram/density curve representing the outside spigots. However, 39 of 109 inside tap samples (36%) were still above the 100 µg/L health-based guidance value for bottle-fed infants and 27 of 109 samples (25%) were still above the 300 µg/L guidance value of all other populations. Only one of the 13 households that reported having an infant 12 months or younger participated in collecting a sample for manganese at the inside drinking water tap. In this home, manganese was effectively reduced by treatment systems below 100 µg/L.

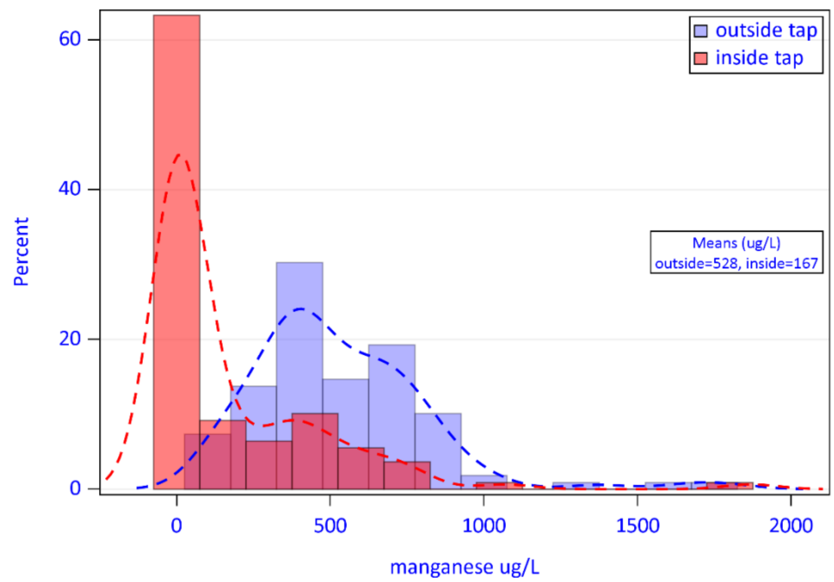

Figure 14: Outside and inside tap manganese histograms with smoothed density curves

2. Effect of inside tap treatment devices

a. Water softener

Well owners with water softeners may soften all water in the home or leave the cold water kitchen tap unsoftened due to taste preference. For data analysis, softened water status was mainly based on the result of the Hach test strip's categories for water hardness (Figure 15). These are: 0 to 120 mg/L (soft); 120 to 250 mg/L (hard); 250 to 425 mg/L (very hard). The setting on water softeners is adjustable to the residents' preference for the hardness of the water. Results in the 0–120 mg/L range are considered softened water in this data analysis. Otherwise, the water was considered not softened.

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[23] While the County requested an *untreated* outside spigot for sampling, it is possible that both outside spigots and indoor taps may have gone through the same type of treatment, reducing manganese levels overall at both locations. According to Matt Jasper of Culligan Service and Sales in IGH, (email correspondence, 12/22/16) most residents install iron and sediment filters only for use indoors to prolong its effectiveness.

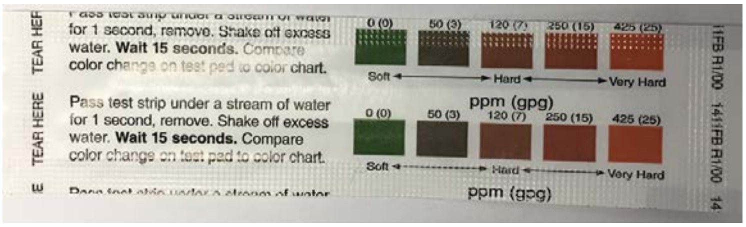

Figure 15: Hach Water Hardness Test Strip

In cases with unclear or unmarked test strip results, samples were assigned a softening status if there was adequate information on the form to indicate whether the sample went through a water softener[24]. Sixty-one percent of samples were softened, 38% were not softened, and 2% were unknown[25].

As shown in Figure 16, water softeners had a dramatic effect on manganese reduction. The majority of unsoftened samples fall along the diagonal line of unity, meaning that the outside spigot and inside tap concentrations are not very different. In contrast, all of the softened samples are along the bottom of the plot, showing that manganese has been greatly reduced in the inside tap sample. All softened samples were below both health-based guidance values, shown at 100 µg/L and 300 µg/L as horizontal lines. Water softening showed the same level of manganese reduction effectiveness across the entire range of outside spigot sample levels. **Based on these results, all treatment system results that follow will be stratified by softening.**

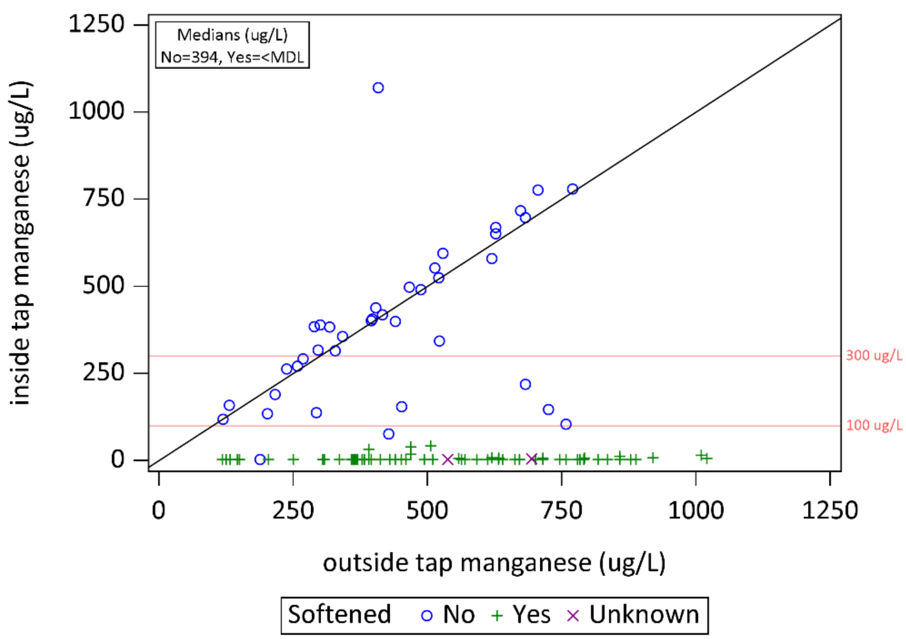

Figure 16: Outside spigot versus inside tap manganese concentration by softened status

[24] For example, if a participant marked both 250 and 425 ppm on the form, the sample was assigned to the not softened category.

[25] May not add up to 100% due to rounding.

Table 26 shows inside tap manganese concentrations by the softener test strip result[26].

Table 26: Manganese concentration by softener test strip result (inside tap)

Softener test strip result (mg/L)	Percent	Manganese mean (µg/L)	Manganese median (µg/L)
0	28%	4.1	<MDL
50	30%	5.2	<MDL
120	7%	14.7	<MDL
250	24%	391.1	399.0
425	10%	491.8	241.0

MDL=method detection limit

b. Carbon filter

Twenty-two samples went through carbon filters. All participants reported a carbon filter with no or unknown cation exchange[27]. There were only thirteen samples that went through a carbon filter but were not softened, which is not a large sample size to evaluate the effectiveness of carbon filters to reduce manganese. Manganese reduction effectiveness was seen for five of the thirteen unsoftened samples[28] (Figure 17). The other samples were generally along the line of unity.

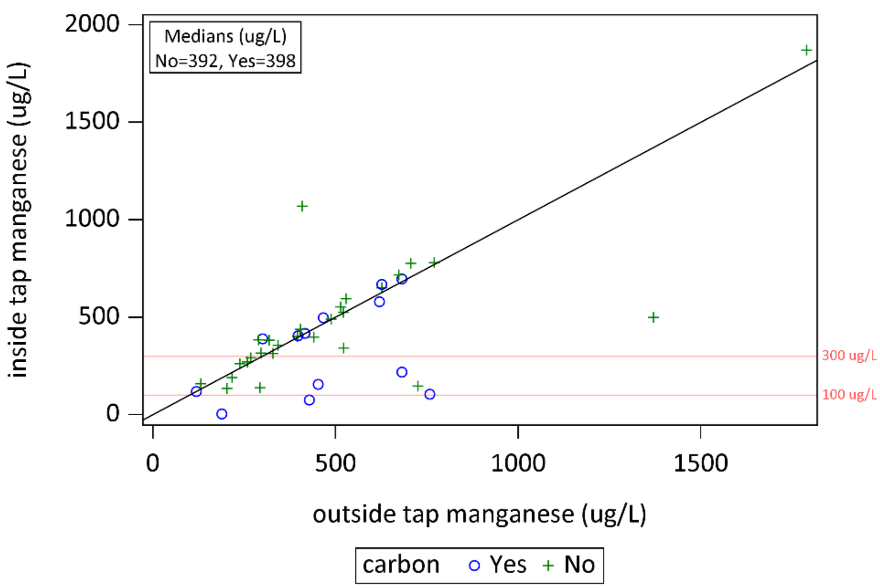

Figure 17: Outside spigot versus inside tap manganese by carbon filter (unsoftened)

[26] Thirteen samples with unclear or unmarked test strip results are excluded. However, softened status (yes/no) for many of these excluded results could still be ascertained from the form.

[27] Point-of-use pour-through carbon filter pitchers with cation exchange resins have been found to be more effective at reducing manganese over the life of the filter when compared to activated carbon block filters, under-the-sink, and tap-mounted filters with a water hardness in the range of 122 to 126 mg/L (Carriere et al. 2011).

[28] None of the 13 samples went through RO.

Percent change in manganese concentration for these five samples ranged from 66–94% (Table 27). However, manganese was reduced to below the guidance value for bottle-fed infants in only two of five cases. Since manganese reduction was seen in three kitchen tap samples and two refrigerator samples, there is no indication that carbon filter effectiveness differs by location (e.g., residents less likely to change out a refrigerator carbon filter compared to a filter on a faucet).

Table 27: Manganese results for five unsoftened samples showing carbon filter effectiveness

Carbon Filter Treatment	Outside Spigot (µg/L)	Inside Tap (µg/L)	Percent decrease
"Whole House HDX"	452	155	66%
Refrigerator	188	11	94%
Refrigerator	428	76	82%
Pitcher water filter	758	105	86%
Filter at kitchen faucet then filtered through pitcher water filter	682	219	68%

c. Reverse Osmosis (RO) and Distillation

Fourteen inside tap samples went through an RO system. However, all of the RO samples were softened (n=13) or softening was unknown (n=1). In general, most RO systems receive softened water to prolong the life of the filters. Therefore, it is impossible to parse out the effectiveness of softening versus RO. No participants reported that the inside tap sample went through distillation.

d. Sediment filter

According to the re-sampling form, forty-eight inside tap samples went through a sediment filter and of these, eighteen were not softened. Five of the eighteen sediment filtered samples also went through a carbon filter. Figure 18 shows inside tap versus outside spigot sample results stratified by sediment filter for non-softened samples. The samples that went through both a sediment filter and a carbon filter are marked "C". There is no indication that sediment filters are effective at reducing the inside tap manganese concentration, as most sediment filter data points are along the line of unity. Sediment filters may remove precipitated manganese, but will not remove dissolved manganese.

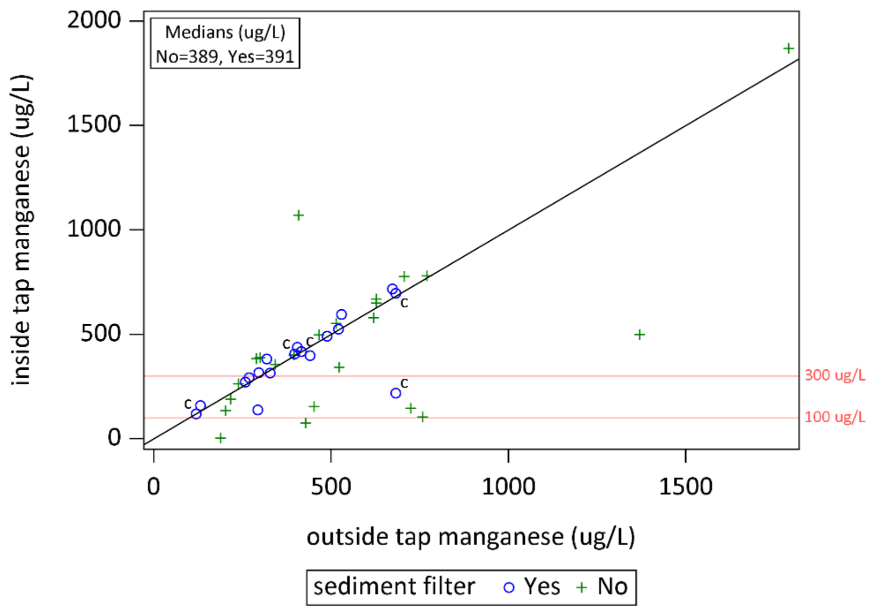

Figure 18: Outside spigot versus inside tap manganese by sediment filter (unsoftened)

e. Iron filter

Twenty-seven inside tap samples went through an iron filter and of these, nine were not softened. None of the nine samples went through RO but two went through a carbon filter (marked with a "C" in Figure 19). There is no consistent evidence that iron filters are effective at reducing the inside tap manganese concentration.

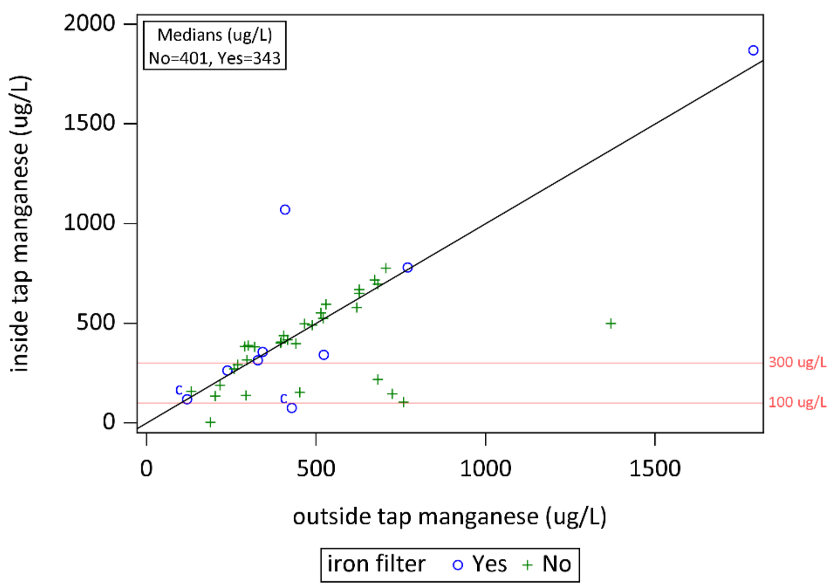

Figure 19: Outside versus inside tap manganese concentration by iron filter (unsoftened)

3. Multivariate regression modeling of treatment types on manganese concentration

A multivariate regression model was created to simultaneously assess multiple factors that may influence treatment effectiveness. The regression model included the inside tap manganese concentration as the dependent variable and the outside spigot manganese concentration and treatment devices as independent variables. Manganese concentrations were log-transformed. The backward selection model started with all candidate treatment variables (softener, carbon filter, iron filter, and sediment filter), along with interaction terms between treatment types as appropriate. RO was not included since all RO samples were softened. Paired samples with unknown softening status were excluded. A total of 105 observations were included in the model.

Significant variables retained in the final model are shown in Table 28. As expected, the inside tap manganese concentration showed a statistically significant, positive association with the outside spigot manganese concentration. Also as expected, use of a water softener was strongly associated with reduced inside tap manganese concentration. Households not using a softener had average manganese concentrations 85% higher than households that did use water softeners (e^4.44=85). Not using a carbon filter, holding other variables constant, was associated with a 48% higher manganese concentration, which was a significant difference (p=0.0350). No interaction terms were significant. The model explained 90% of the variance. The diagnostic plots looked adequate (e.g., residuals normally distributed) except for the obvious graphical display of censored manganese data in residual plots.

Table 28: Final regression model for inside tap manganese concentration

Parameter	Estimate	Standard Error	t Value	p-value
Intercept	-5.37	0.21	-26.18	<0.0001
Outside spigot manganese conc.	0.52	0.13	4.13	<0.0001
Carbon filter (ref=Yes)	0.39	0.18	2.14	0.0350
Water softener (ref=Yes)	4.44	0.15	30.25	<0.0001

As a sensitivity analysis, a separate model was evaluated that used percent change between the outside and inside tap sample as the dependent variable and treatment-related covariates as independent variables. Findings from the percent change sensitivity model did not differ remarkably from the main model (results not shown).

G. Exposure Assessment

One purpose of the WIISE study was to determine if well users are drinking water with manganese above levels of health concern, or whether the “aesthetic” or “nuisance” effects of manganese in water at these levels result in treatment or avoidance of the water. We first looked to see if the manganese concentration in the well, represented by the outside spigot sample result, influenced well users’ concerns about aesthetic issues or their treatment behaviors. Participants completed a survey about their water-related concerns and behaviors prior to receiving their water quality results. For data analysis, manganese concentrations were binned into below the guidance value for infants, between the guidance value for infants and all other populations, and above the guidance value for all other populations.

Figure 20 shows that the lower the manganese level, the lower the level of concern regarding taste, odor, or color. For example, 84% of those with manganese below 100 µg/L said they were not at all or not very concerned about the taste, odor, or color of their water compared to 73% in the next higher bin and 54% in the highest concentration bin. These differences were statistically significant (Chi-square test of concern categories by manganese concentration categories: X^2=25.72, df=6, p<0.0001; Kruskal-Wallis test of continuous manganese concentration by concern categories: H=23.17, df=3, p<0.0001).

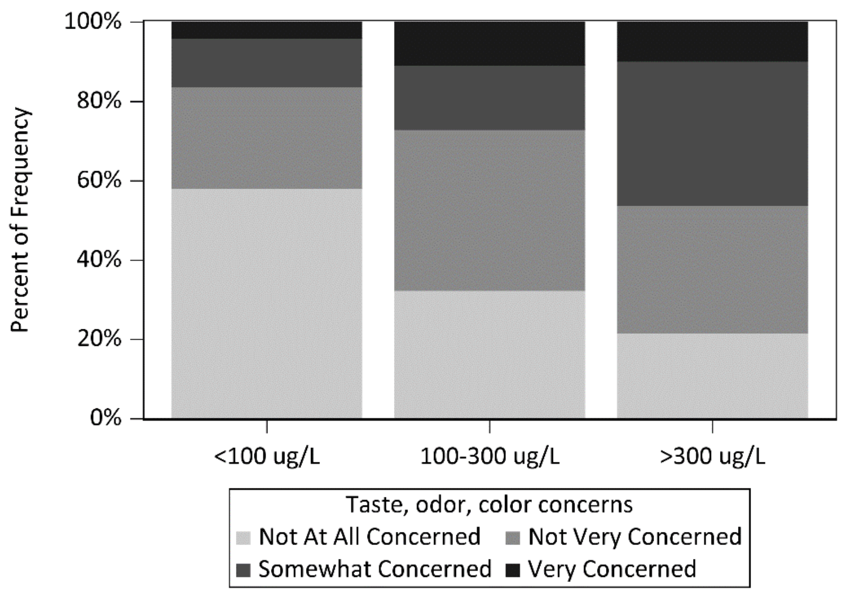

Figure 20: Well water taste, odor or color concerns by manganese concentration category.

Similarly, we compared people's concerns about "iron and other minerals" by manganese concentration bin. Concern significantly increased with increasing manganese concentration (Figure 21). For example, 32% of those with manganese below 100 µg/L said they were not at all or not very concerned about the taste, odor, or color of their water compared to 16% in the next higher bin and 9% in the highest concentration bin (Chi-square test of mineral concern categories by manganese concentration categories: X^2=345.65, df=6, p<0.0001; Kruskal-Wallis Test of continuous manganese concentration by concern categories: H=25.06, df=3, p=<0.0001).

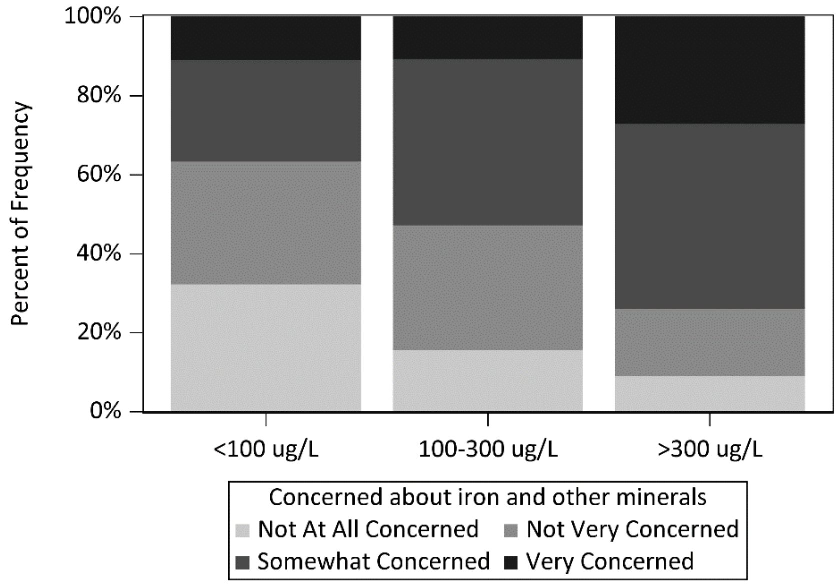

Figure 21: Well water taste, odor or color concerns by manganese concentration category.

Finally, we compared manganese concentration at households that reported “mostly or always” using softened or filtered water or purchasing bottled water to those that do not “mostly or always” take these mitigative actions (Figure 22). Households with outside spigot manganese concentrations above 300 µg/L were significantly more likely to report treating or softening their water or using bottled water (X^2=6.72, df=2, p=0.0347). The Kruskal-Wallis Test of manganese concentration by mitigative action (treated or bottled water) was also significant (H=5.59, df=1, p=0.0180). However, there was no significant difference in mitigative action when limiting the comparison to the two lowest manganese concentration bins.

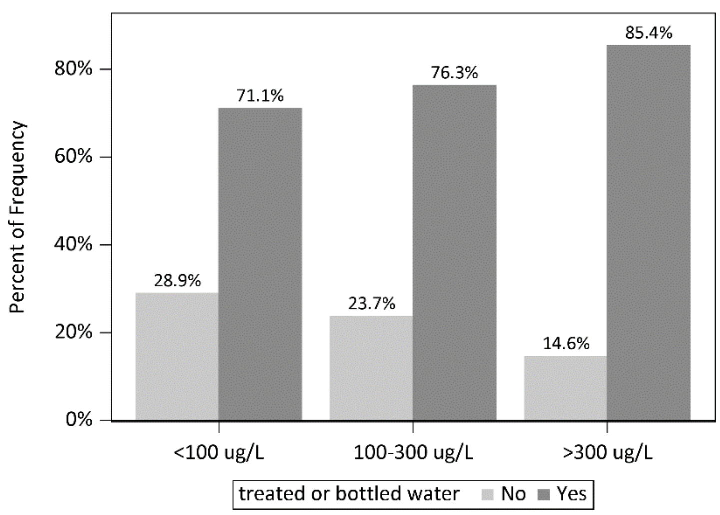

Figure 22: Treated or bottled water use by manganese concentration category

While we see an increase in awareness of aesthetic issues and mitigative action at higher manganese well water concentrations, it is important to note that indoor tap sample results from 37 of 99 households (37%) were above the 100 µg/L and results from 26 of 99 households (26%) were above 300 µg/L. Of the

37 households with an inside tap result over 100 µg/L, only eight households (22%) practiced water avoidance (i.e., reported "mostly or always" drinking bottled water or getting drinking water from another source). Of the 26 households with an inside tap result over 300 µg/L, four households (15%) practiced water avoidance. In conclusion, 37% of households that took part in the inside tap sampling had a finished water result above the guidance value of 100 µg/L and of these households, 29/37 (78%) regularly drink the water. In households with an inside tap manganese concentration over 300 µg/L, 85% regularly drink the water.

VI. Conclusions and Recommendations

A. Conclusions

The study conclusions are organized by the main objectives of the WIISE study:

1. Characterize manganese levels in Inver Grove Heights, MN groundwater

Manganese is present in the drinking water aquifers in IGH at levels that exceed MDH's health-based guidance values. The 100 µg/L guidance value for infants was exceeded in 71% of the water samples collected from outside spigots, which is greater than what has been found in Minnesota statewide sampling (49%), Dakota County Township Testing (29%) and the Dakota County Ambient Study (34%). Fifty-six percent of outside spigot samples exceeded the 300 µg/L guidance value for all other populations.

2. Identify predictors of manganese concentration in well water

Water chemistry parameters, in particular redox conditions, dissolved oxygen, and pH influenced manganese concentrations. Manganese was inversely correlated with dissolved oxygen. In contrast, manganese was positively correlated with pH as well as with iron concentration, a finding observed elsewhere which indicates that these two metals are closely related in groundwater. A positive correlation between manganese and arsenic was also seen. More study is needed as this finding has not been as well supported in the literature as the iron-manganese correlation. The distribution of arsenic at the higher end of concentrations was more geographically localized in IGH compared to the distribution of manganese levels. Manganese concentrations were significantly higher in unconsolidated sediments than in the dolomite (OPDC) or sandstone (CJDN) aquifers. This may reflect the glacial material which constitutes the UCS Shales such as the Decorah which are still present just north of IGH may be a source of manganese through glacial transport and subsequent weathering.

Manganese concentrations were correlated with several water quality parameters (iron, arsenic, chloride, dissolved oxygen, pH) but exceeded the health-based guidance values across a range of the above parameters and across the Inver Grove landscape, highlighting the complex nature of its occurrence and mobilization.

3. Determine how groundwater concentrations translate into actual drinking water exposures

We found that well users' concerns about aesthetic issues and minerals in their water significantly increased as manganese concentration increased. Further, those whose outside spigot manganese concentration was above 300 µg/L were more likely to report treating or softening their water or using bottled water. Therefore, we see some evidence of increased awareness of aesthetic issues possibly linked to manganese and a modest increase in mitigative action. Even so, 37% of the inside post-treatment results were still above MDH's guidance value of 100 µg/L and 26% were above the guidance value of 300 µg/L. Seventy-eight percent of households with an inside tap result above 100 µg/L reported drinking the water. This study demonstrates that an elevated level of manganese in tap water may increase aesthetic concerns but is not a consumption deterrent in and of itself. While the study was limited to one geographic area, the results suggest that consumption of finished water with elevated levels of manganese could be a common occurrence in Minnesota.

In this study, we are particularly focused on infant exposures because formula-fed infants drink more water than any other subpopulation on a body-weight basis and their brains are rapidly developing. While the sample size of homes with infants was small (n=13), we can characterize drinking water exposures in these homes:

- In four of thirteen homes (31%), the infant drinks a different source of water than the other members of the household or is exclusively breastfed.
- Seven of the nine households where infants are likely drinking well water had an outside spigot manganese concentration above the level of concern for infants (max=692 µg/L).
    - Only one of these households participated in providing a sample from the primary drinking water faucet after treatment. In this home, manganese in the post-treatment sample (iron filter and water softener) was reduced to below 100 µg/L.
    - The other eight households also reported use of a water softener, but it is often the case that the cold water kitchen tap, which is most often used to reconstitute formula, is left unsoftened. It is our expectation that the manganese result and accompanying health risk information resulted in actions to limit infant exposure to manganese above the guidance value in these homes.
- Seven of the nine households where infants are likely drinking the well water had arsenic present in the well water, but below the MCL (max=7.3 µg/L).
- Three of the nine households where infants are likely drinking the well water had detectable lead in the outside spigot sample (max=8.4 ug/L).
- One of the nine households where infants are likely drinking the well water had coliform bacteria present, but the sample was negative for *E. coli*.

In sum, one should not assume that households on private wells are using an alternative source of water that has been tested and proven to be safe to feed infants. While all participants with infants reported treatment devices in the home, we could not confirm that the levels of all contaminants, such as lead, were below levels of concern in the drinking water.

4. Identify practical mitigation measures that well users can take to reduce manganese exposure

Water softeners dramatically reduced manganese concentrations in the well water, which suggests that the predominant form in WIISE Study drinking water is dissolved manganese. Past publications on manganese treatment (described in MGWA 2015) have cautioned that many softeners are not designed to handle higher levels of manganese, e.g., concentrations over 500 µg/L. In this study, there was no indication of reduced softener effectiveness across the entire range of manganese, up to 1000 µg/L. An RO system installed at the main drinking water tap is another practical option that has been shown to reduce manganese, but could not be evaluated as part of the WIISE Study. While carbon filters reduced manganese levels in some cases, they did not show a consistent and reliable ability to reduce inside tap manganese concentrations below health-based guidance values. A previous unpublished study by MDH found that a carbon filter that also contains an ion exchange resin was effective at removing up to 50% of the manganese in water, but that efficiency decreased with use. The WIISE survey and sample intake form asked whether the carbon filter contained an ion exchange resin but WIISE Study participants generally did not know. Iron filters and sediment filters did not show treatment effectiveness. Other potential treatment types (e.g., distillation) may be effective but could not be evaluated.

B. Manganese Recommendations

1. All well owners in Minnesota should test their water for manganese. This recommendation is not expected to pose a great hardship for well owners since a manganese test at an MDH-accredited lab typically costs less than $20.00 and sampling only needs to occur once since the level is not expected to change over time. If an infant will be drinking the well water, the goal is to have water with manganese below 100 µg/L at all drinking water faucets that provide water to the infant. If there is no infant in the household, the goal is to achieve a manganese level lower than 300 µg/L at all drinking water faucets. In homes with treatment systems, well owners should test their water for manganese at the main drinking faucet after treatment to ensure that the device(s) are achieving the manganese level goal of the household. Treatment devices should be maintained per the manufacturer's directions.

2. MDH should work with accredited laboratories to add information to lab reports about these health-based guidance values, which will allow homeowners to make informed decisions about their result.

3. Since water quality contractors will be consulted for treatment options, MDH should conduct outreach to contractors about treatment options for manganese.

4. Due to the limited types of treatment devices that could be evaluated in the WIISE Study and the lack of device certification for manganese, more research is needed to evaluate water treatment options to reduce manganese.

More specific treatment recommendations are based on life stage:

Adults and children ≥1 year old:

- A water softener is a relatively inexpensive device that can reduce manganese concentrations in well water below 100 µg/L. Since not all softeners may achieve this reduction under all conditions, homeowners should check the manufacturers' specifications.

- Drinking softened water is considered safe (Mayo Clinic, EPA 2003). However, adults under treatment for sodium-sensitive hypertension should first consult their health care provider regarding sodium levels in their drinking water supply.

- Elevated iron and manganese can foul the resin bed of a water softener and reduce the softening and filtering capacity, as well as plug components of the softener. Therefore an iron filter may need to be installed to treat water that will go to the softener. Using an iron filter before softening will reduce the iron and manganese which will allow the softener to run less frequently and conserve on salt usage.

- If the taste of softened water is objectionable, passing the drinking water through an RO system is another option, as it can remove the sodium from the water (and most likely the manganese as well). Sodium is not removed by carbon filters.

- Finished water should be tested for manganese to ensure that the treatment device (softener, RO, or softener+RO, etc.) is functioning properly. Users must follow the manufacturer's maintenance instructions.

Infants <1 year old:

- No information could be found on whether it is safe to use softened water to prepare infant formula due to the additional sodium added by the softener. Therefore, we do not recommend using softened water for formula feeding. Bottled water (not labeled "mineral" water) is recommended for reconstituted formula feeding and drinking if well water exceeds the manganese health-based guidance value of 100 µg/L.

- An RO system is another option: Finished water should be tested for manganese to ensure that the RO unit is functioning properly and users must follow the manufacturer's maintenance instructions to ensure continued effectiveness.

C. Recommendations for other WIISE study analytes

All wells older than 2008 should be tested for arsenic at least one time. Wells constructed since 2008 have been tested for arsenic by the well driller and the result can be requested from MDH. Treating the water to remove arsenic is advised. Since an arsenic concentration of 10 µg/L is not considered low enough to completely eliminate all risk of cancer and other health effects from arsenic, well users with levels below the MCL of 10 µg/L may wish to consider treating the water to further lower exposure. Many wells in the WIISE study tested positive for coliform bacteria. MDH recommends that private well users inspect their wellhead and test annually for coliform bacteria, preferably in the spring. It is also prudent to test for coliform bacteria before adding a water treatment system to avoid introducing bacteria into a new device. If the bacteria test is positive, the well should be disinfected and retested for coliform bacteria.

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VIV. Appendices

A. Description of WIISE study analytes
B. Maps
C. Study Instruments
D. Participant Communications Materials

Appendix A: Description of WIISE study analytes (excludes manganese)

Arsenic is a naturally occurring element found in rocks and soil across Minnesota. From these sources, small amounts of arsenic can dissolve into groundwater. Drinking water with low levels of arsenic over a long time is associated with diabetes and increased risk of cancers of the bladder, lungs, liver, and other organs. Drinking water with arsenic can also contribute to cardiovascular and respiratory disease, reduced intelligence in children, and skin problems such as lesions, discoloration, and the development of corns. Children's exposure to arsenic is associated with neurological deficits (ATSDR 2007, 2016). Human exposure to arsenic in drinking water is also associated with excess incidence of miscarriages, stillbirths, preterm births, and infants with low birth weights (ATSDR 2007). In addition, prenatal exposure of humans and animals to arsenic is associated with the development of cancer later in life (ATSDR 2007, 2016). MDH recommends that every well be tested for arsenic at least once. Since 2008, MDH requires all new wells to be tested for arsenic.

Lead is not usually found at detectible levels in ambient groundwater. The main source of lead in drinking water comes from pipes, pumps, fixtures, and lead-soldered water lines. Lead in pipes and other components in the household plumbing can dissolve into the water. In children, low levels of lead can alter physical development and interfere with growth, brain development, hearing and blood formation. Lead in drinking water is of particular concern for infants who drink formula made with tap water. In adults, adverse effects include increased blood pressure and shorter pregnancies for women. There is no known safe level of lead in drinking water. Due to heightened public awareness and concern about lead in drinking water during the study period (which overlapped with the Flint, MI lead crisis), lead was included as a study analyte. Since lead was measured in the purged outside spigot samples, the results were not considered reflective of actual drinking water concentrations at the inside tap, which can be strongly influenced by lead leaching from the inside plumbing. If lead was detected in the outside spigot sample, the County recommended that well users submit both purged and first draw follow-up samples from the inside tap used for drinking for lead analysis.

Fluoride is a naturally occurring element found in water, air and soil across Minnesota. Fluoride can help prevent tooth decay, but too much fluoride can damage teeth, bones, and joints. The recommended fluoride level in drinking water for good oral health is 0.7 milligrams per liter (mg/L). If fluoride levels in drinking water are lower than 0.7 mg/L, a child's dentist or pediatrician should evaluate whether daily fluoride supplements are necessary. At fluoride concentrations above 2 mg/L, children 8 years and younger have a greater chance for developing dental fluorosis, a cosmetic change in the appearance of the tooth's enamel. Only children aged 8 years and younger can develop dental fluorosis because this is when permanent teeth are developing under the gums. Fluoride levels above 4 mg/L may cause severe fluorosis in children and bone problems in adults. The highest fluoride concentrations in Minnesota are associated with Cretaceous aquifers in west-central Minnesota.

Coliform bacteria are common on the surface of the ground or near the surface (in the case of contamination from septic systems). When coliform bacteria are detected in a well, it can indicate that surface contamination is entering the well. This surface contamination may include infectious disease bacteria that cause stomach and intestinal illness, such as some strains of *E. coli*. Infants and young children have a higher risk of illness. MDH recommends that all private wells be tested for total coliform bacteria once per year. Spring is the best time of year to test. It is also wise to test well water for coliform bacteria any time the water changes in taste, odor, or appearance, and after flooding events.

Sulfate occurs naturally in rocks and soil across Minnesota. Human activities may also contribute sulfate to groundwater, including combustion of fossil fuels, commercial fertilizers, and some mining activities. From these sources, sulfate can enter groundwater and drinking water wells as it moves readily with water. If sulfate in water exceeds 250 mg/L (the SMCL), a bitter taste may make the water unpleasant to drink. High sulfate levels may also corrode plumbing, particularly copper piping. People drinking water with high levels of sulfate can experience short-term diarrhea and dehydration until their bodies become used to the sulfate levels in the water. Infants are more sensitive to the adverse effects of sulfate than adults due to a higher risk of dehydration from diarrhea. EPA's health-based advisory value for sulfate is 500 mg/L. EPA recommends that water above this level should not be used in the preparation of powdered infant formula.

Nitrate is the one of most commonly-detected groundwater contaminants in Minnesota, including Dakota County. Nitrate at low levels in water may be naturally-occurring, but high levels of nitrate in groundwater comes from human activities, including chemical fertilizers, septic systems and manure. In the Upper Midwest, the primary source of nitrate is nitrogen fertilizer used on agricultural crops. A nitrate level above the HRL of 10 mg/L or a nitrite level above the HRL of 1 mg/L in drinking water can be harmful to infants under six months of age. When infants consume water (or formula mixed with water) that is high in nitrate, they can develop "blue baby syndrome" (methemoglobinemia), a life-threatening condition. MDH recommends that all private wells be tested for nitrate before giving the water to an infant, and otherwise every one or two years.

Study Chemicals Unrelated to Children's Health:

Chloride occurs naturally in many common minerals in the rocks and soil across Minnesota. However, high levels of chloride in groundwater indicate contamination from human activities, including road salt, septic systems, or animal wastes. There is no health-based standard for chloride but EPA has established an SMCL of 250 mg/L to avoid undesirable tastes and odors.

Iron is a naturally-occurring element found in rocks and soil across Minnesota. From these sources, iron can enter groundwater and drinking water wells. Human bodies need a small amount of iron to help move oxygen through the blood. People get this iron from food. While iron in well water is not a health concern, iron in wells above 0.3 mg/L, (which is the SMCL for public water supplies), can cause aesthetic concerns such as a metallic taste and yellow, red, or brown stains on laundry, dishes, and plumbing. High levels of iron can also clog well screens, pumps, sprinklers, water softeners and other devices such as dishwashers, which can lead to costly repairs. Treatment used to remove iron in water through oxidation also removes manganese. The oxidation of iron tends to occur faster than the oxidation of manganese, so treatment systems can be overwhelmed by iron and become less effective for decreasing manganese (MGA 2015).

Appendix B: Maps

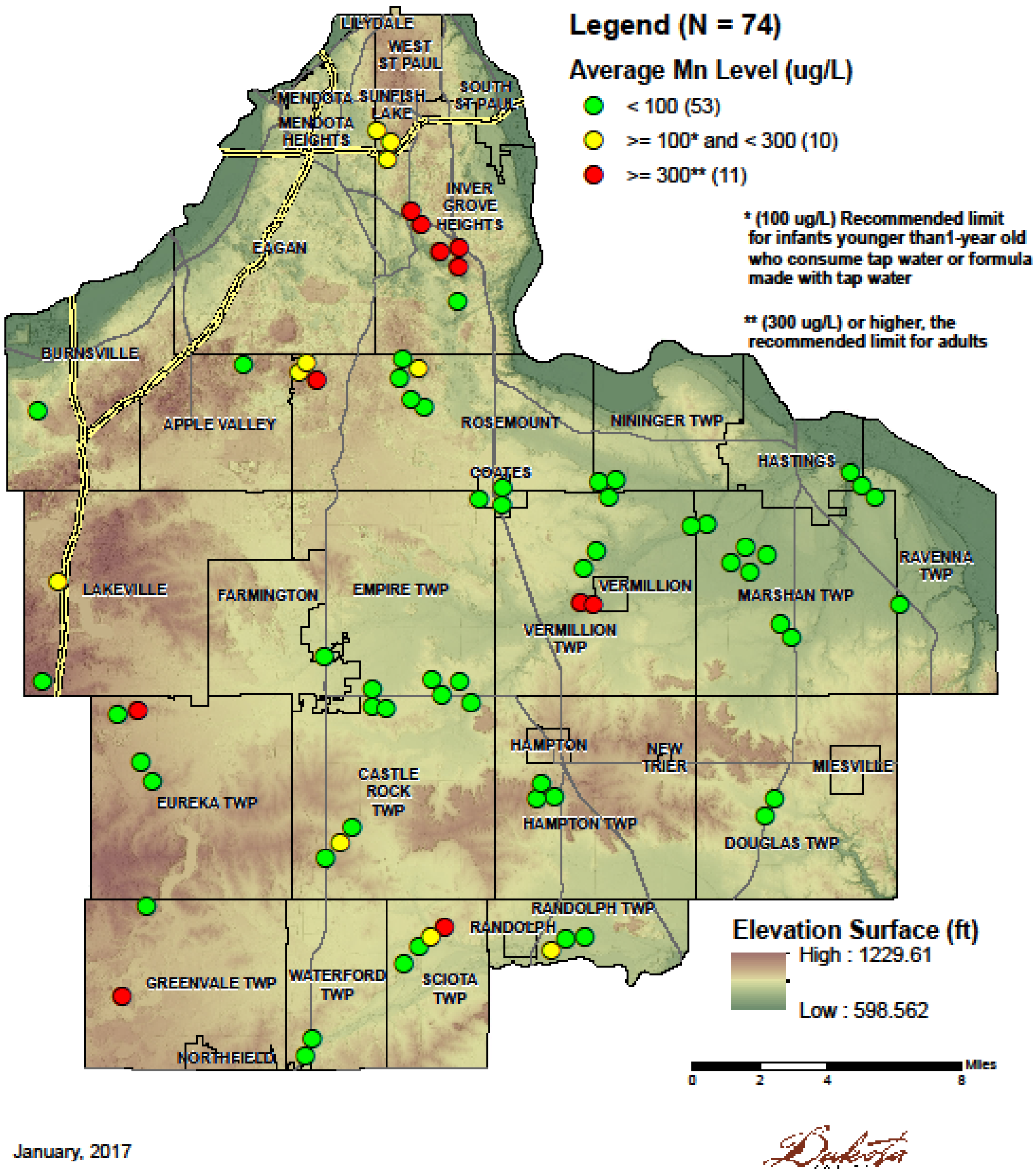


Figure 23: Ambient Groundwater Quality Study, manganese concentrations, 2005-2011.

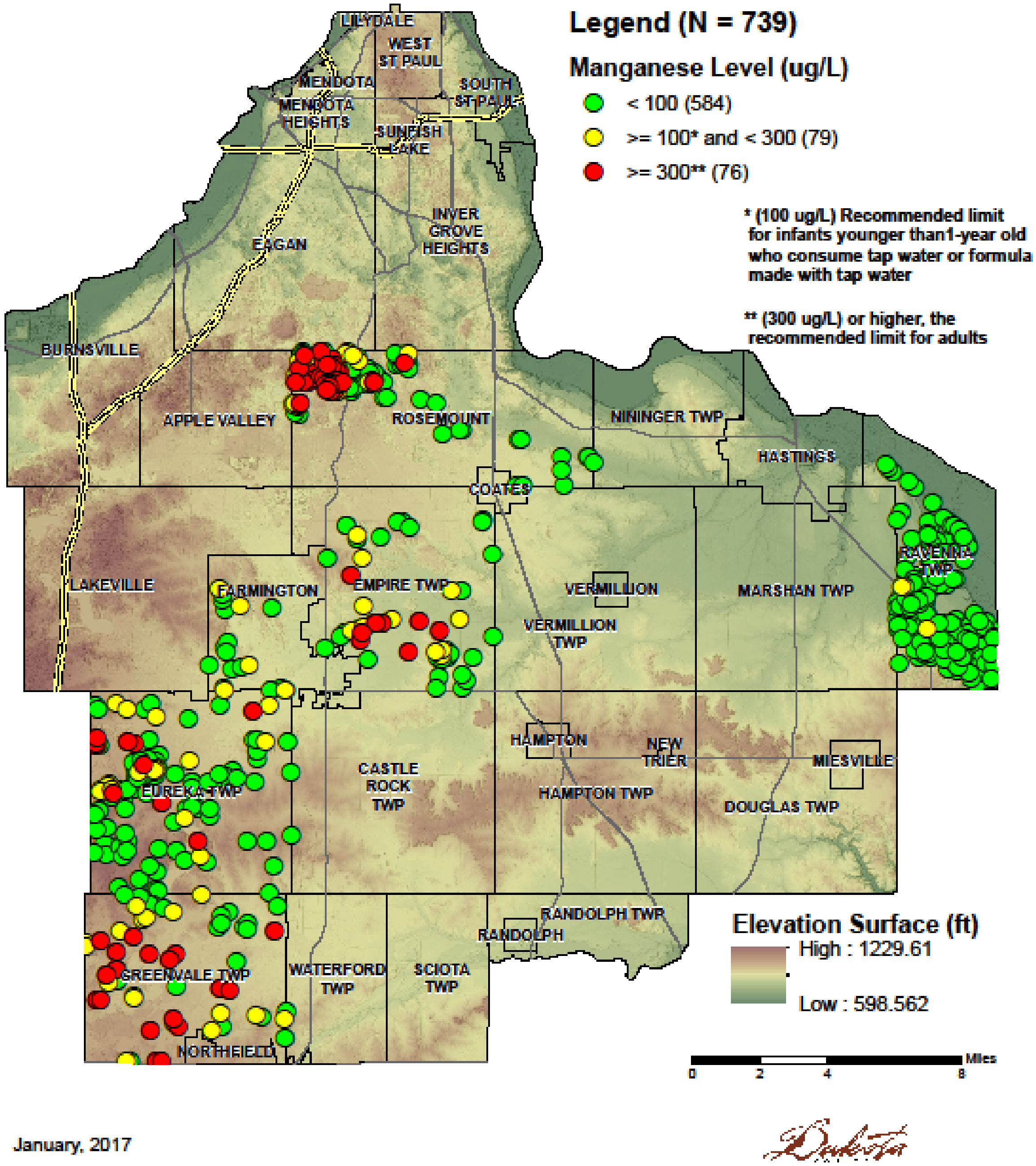


Figure 24: MDA Township Testing manganese results, Dakota County 2014

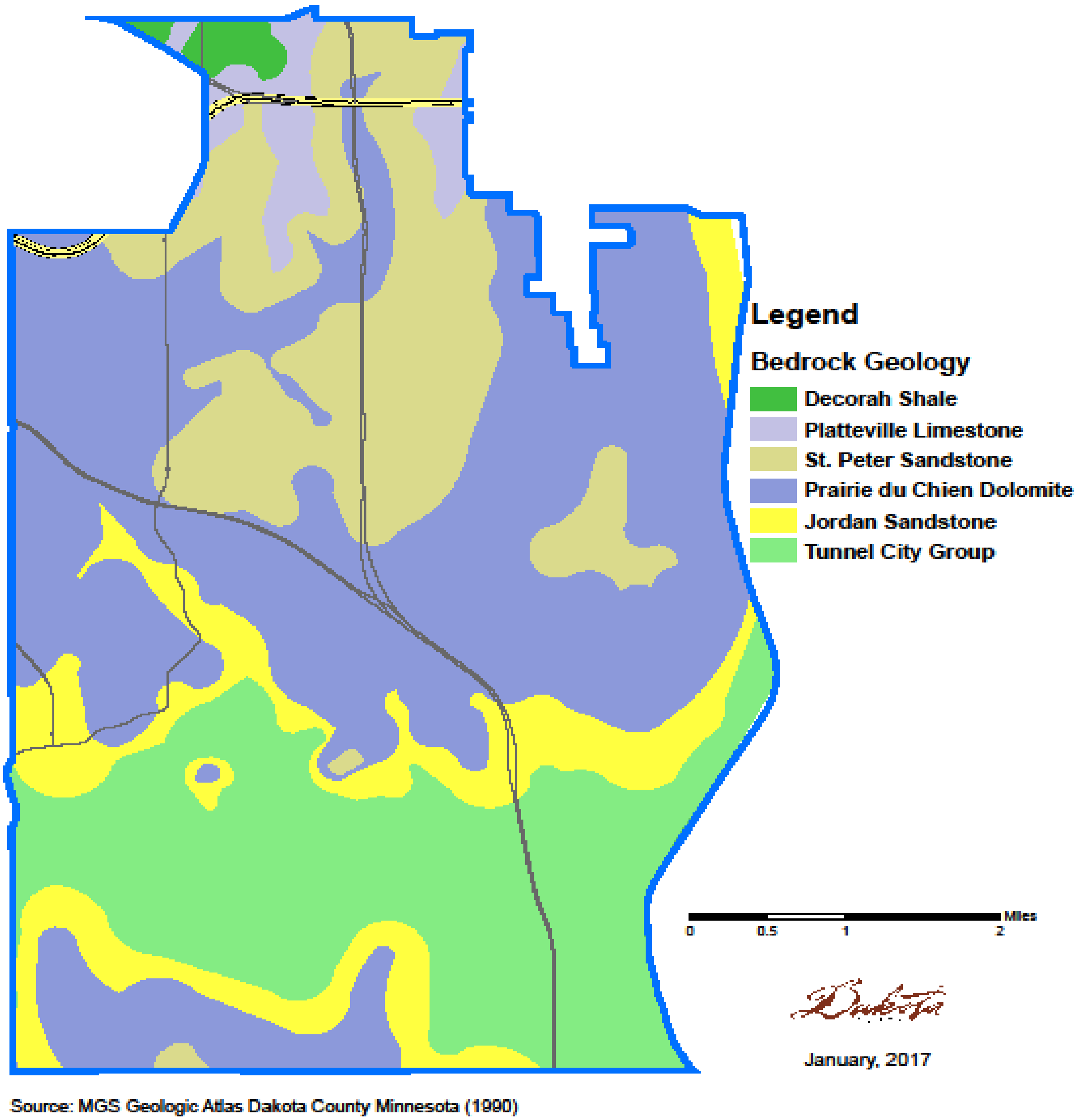


Figure 25: Inver Grove Heights Bedrock Geology

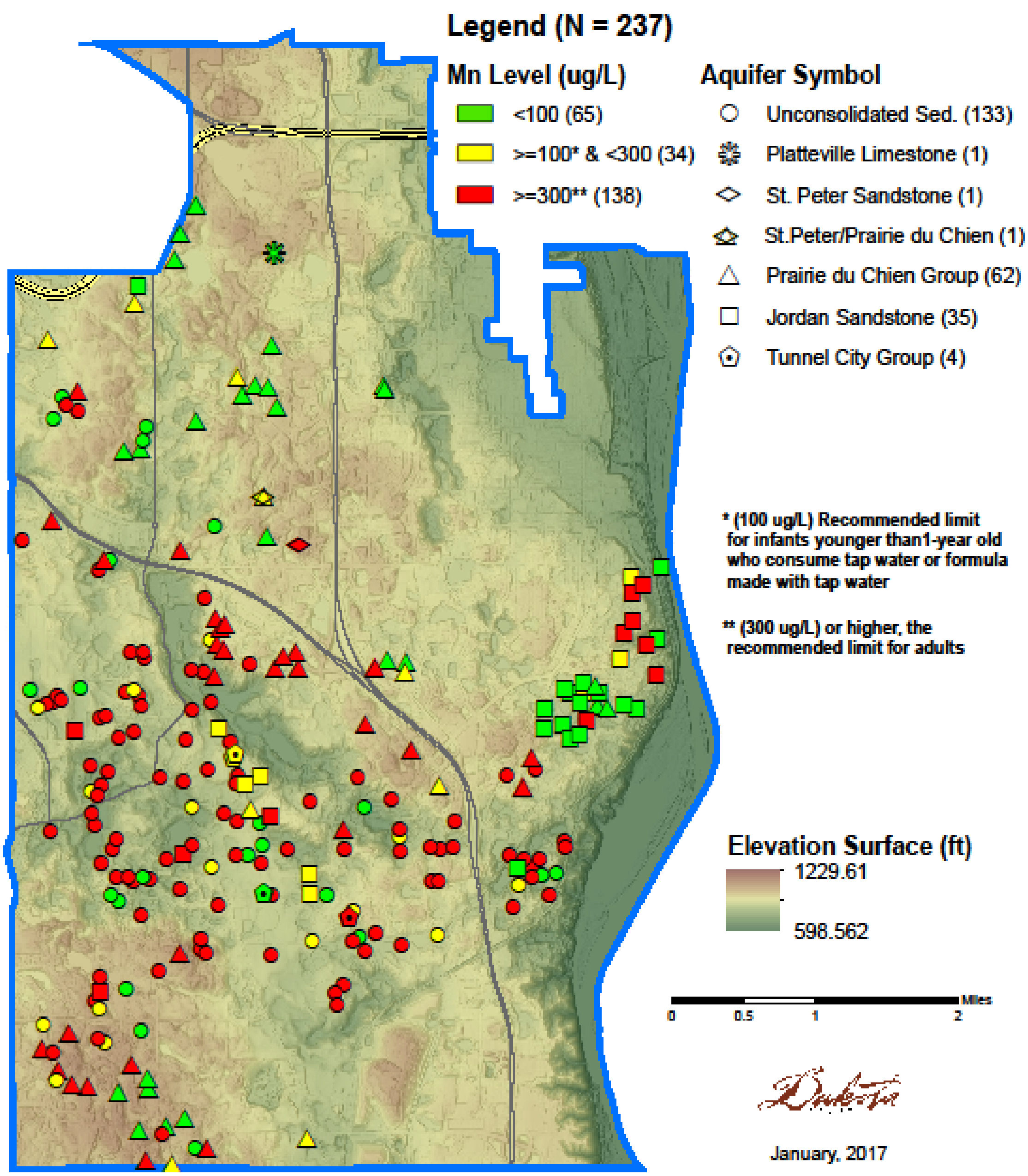


Figure 26: Manganese concentration by aquifer

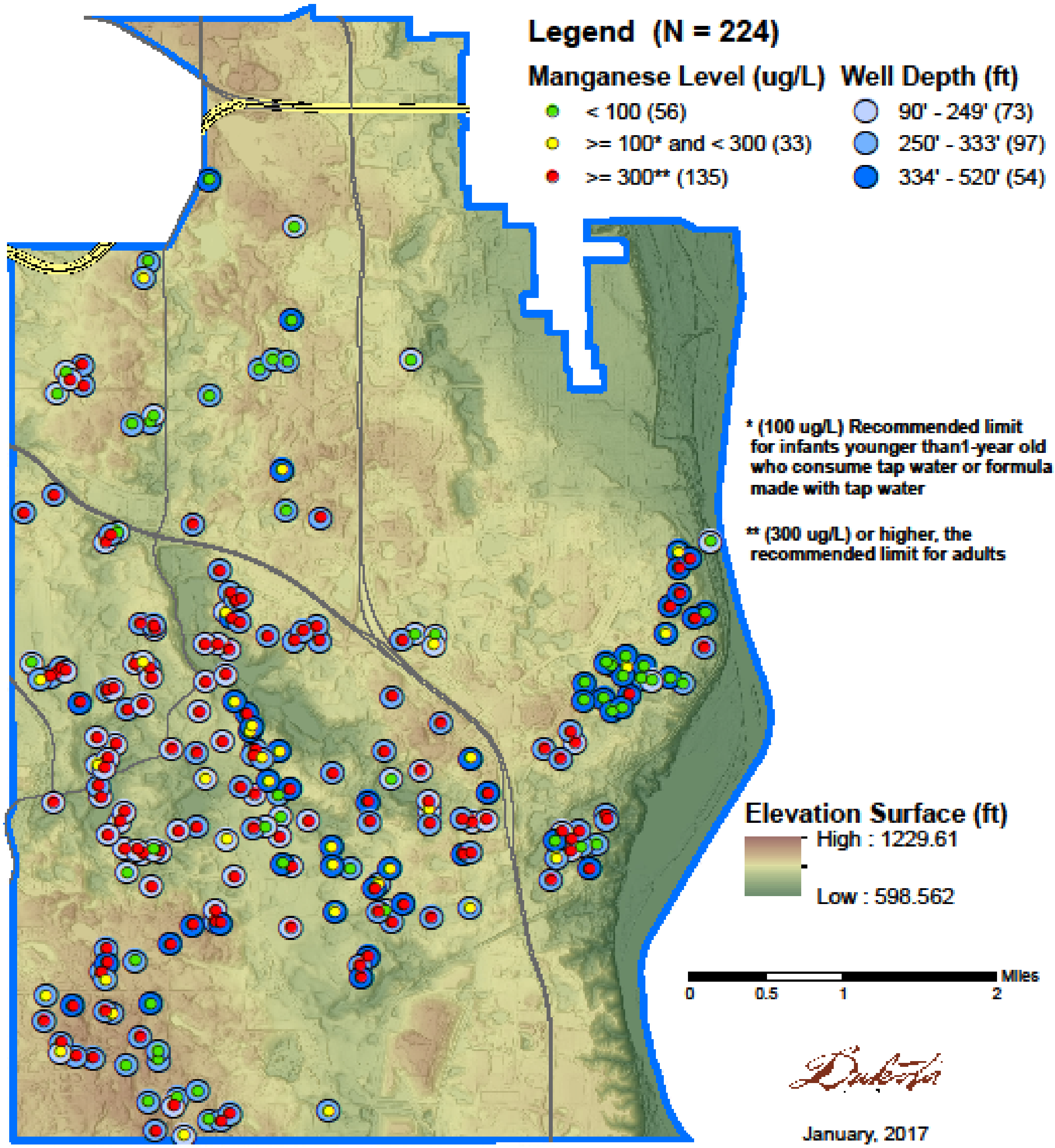


Figure 27: Manganese concentration by well depth

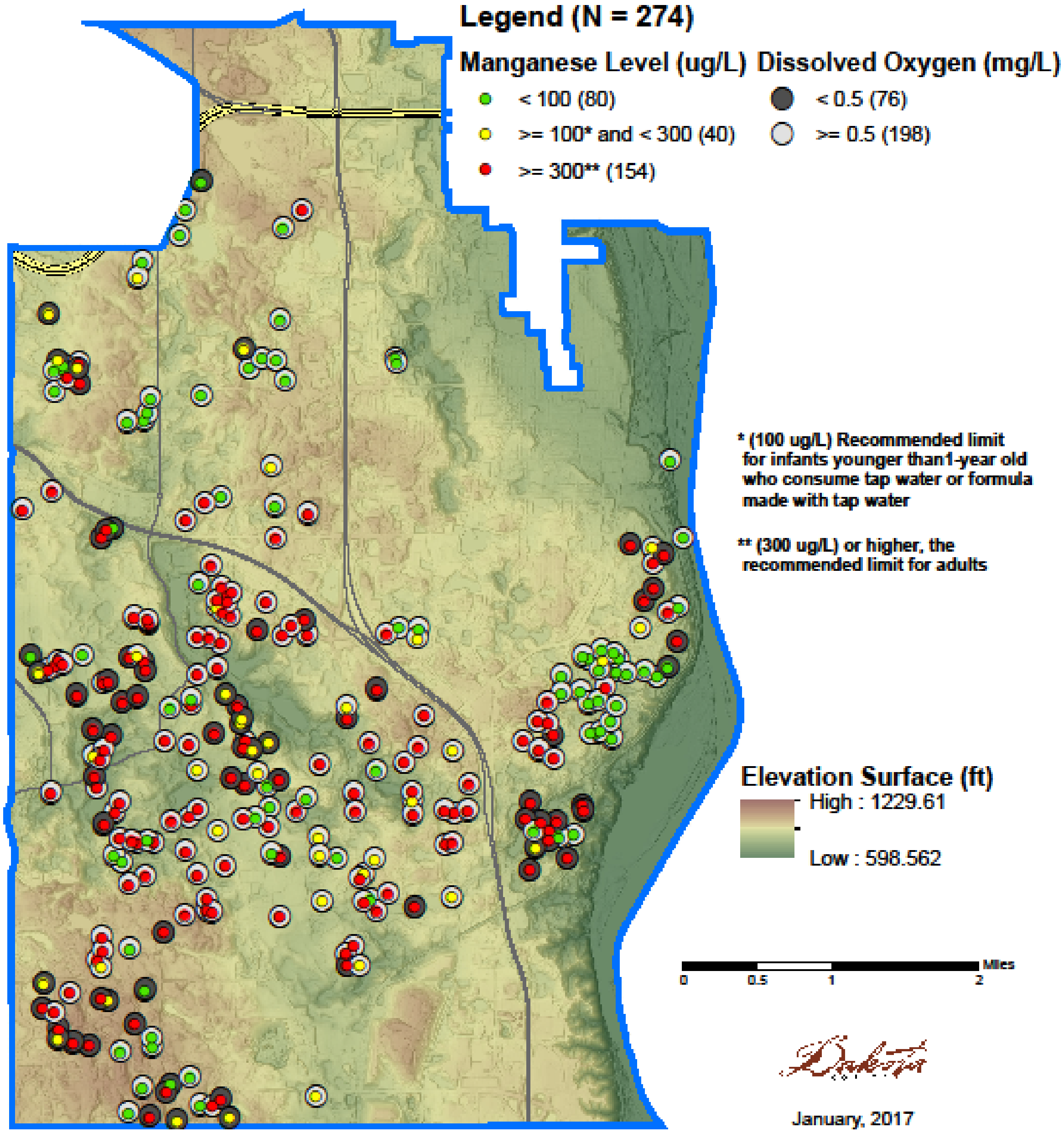


Figure 28: Manganese concentration by dissolved oxygen

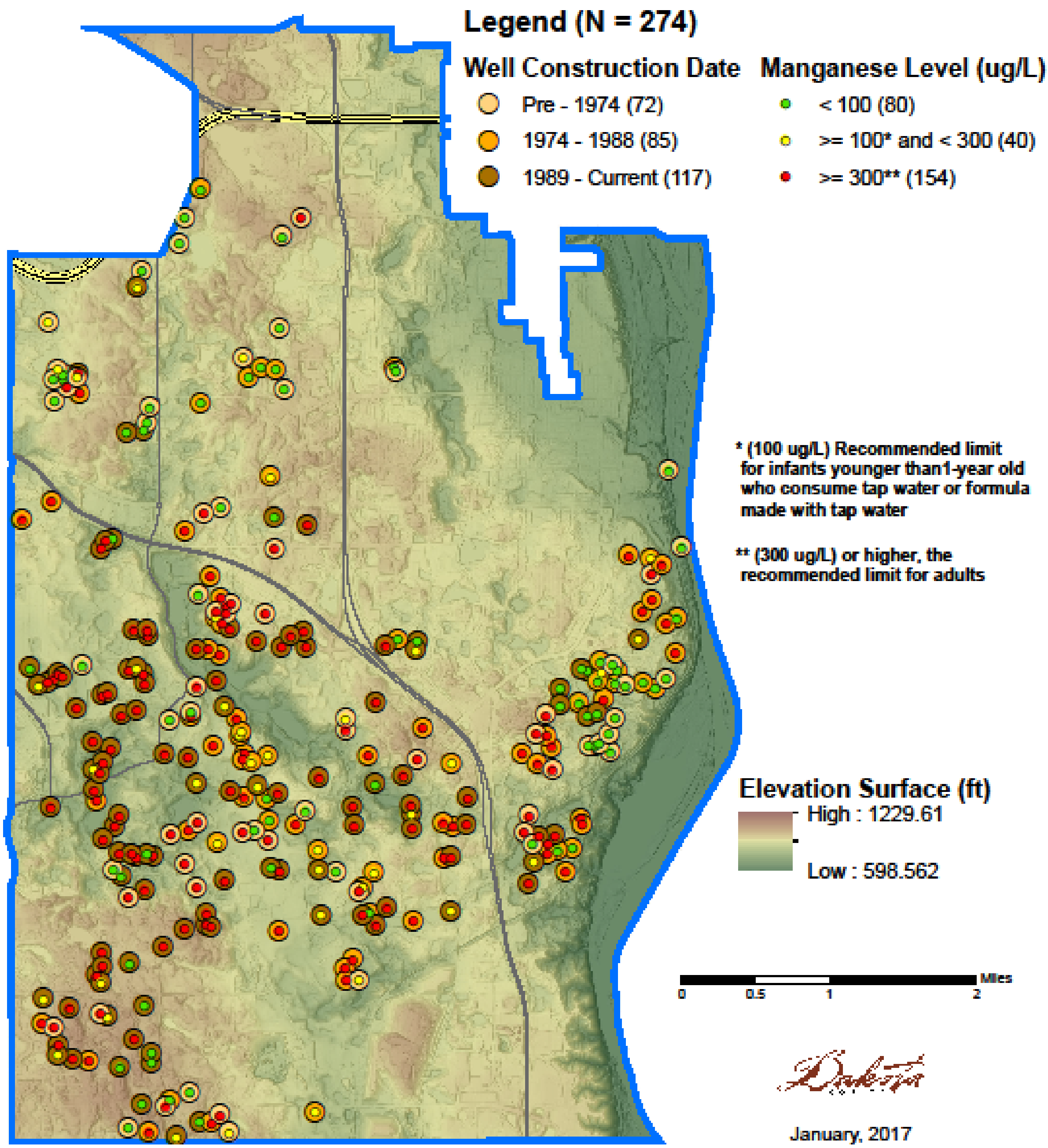


Figure 29: Manganese concentration by well construction date

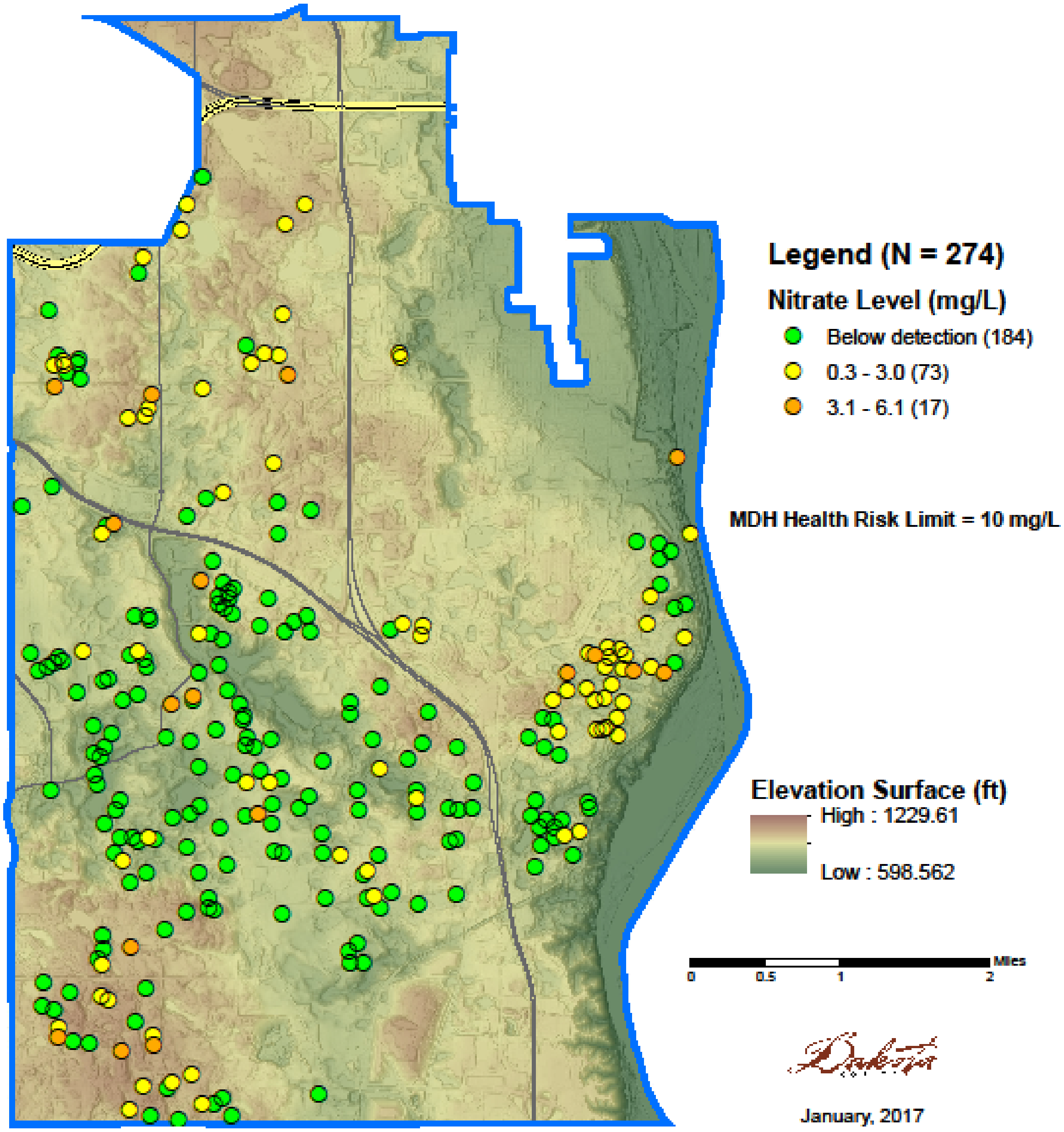


Figure 30: Nitrate levels in WIISE Study wells

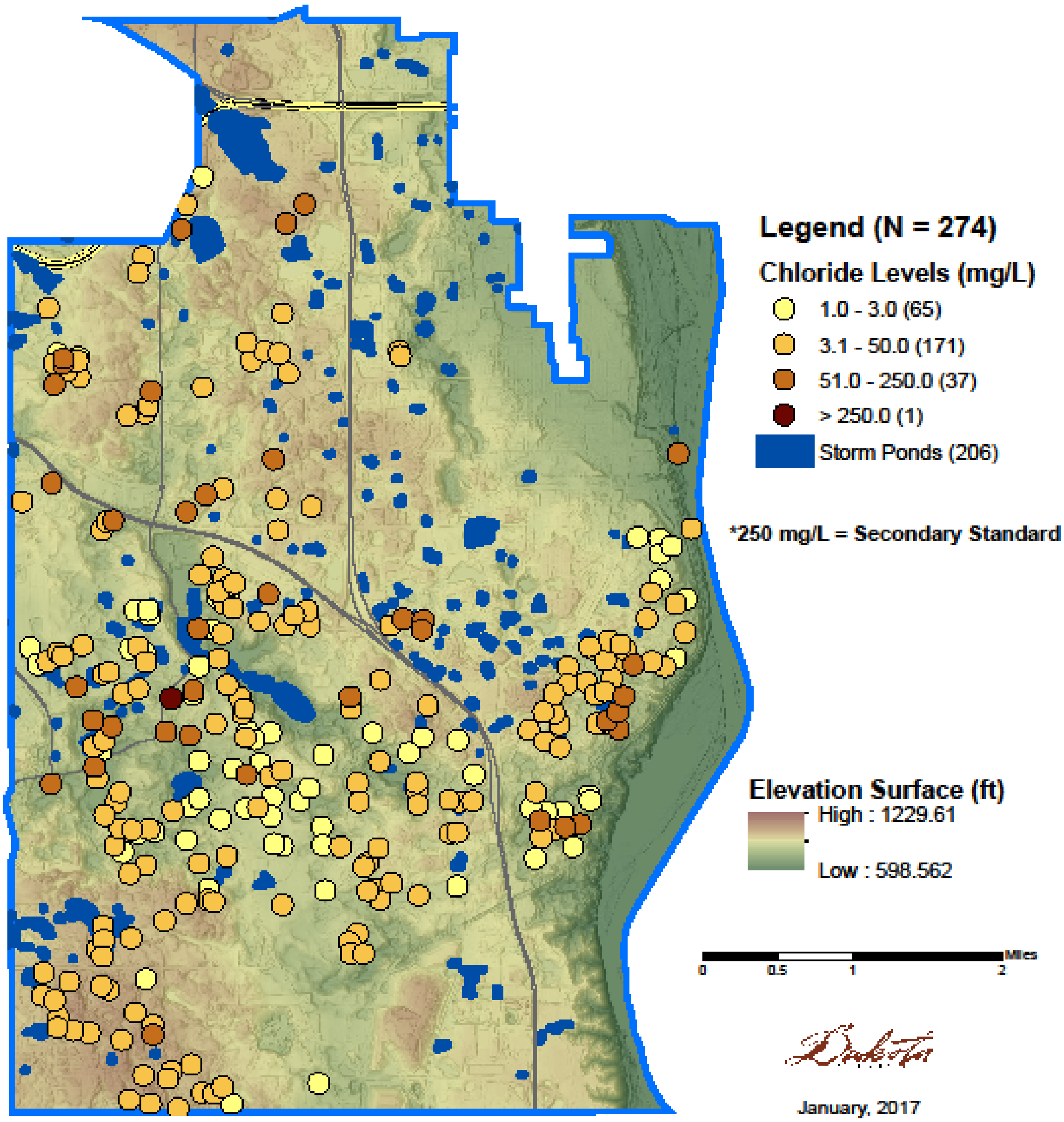


Figure 31: Chloride results in relation to storm water ponds

Appendix C: Study Instruments

Dakota County/Minnesota Department of Health
Private Well Water Survey

Thank you for taking the time to complete this survey, which should only take you a few minutes.

- Please do the best you can, because your answers are very important. This study will help us understand the groundwater quality in drinking water wells in Inver Grove Heights.
- Summary information from the survey may be included in reports, but we will not share your individual answers. However, your responses are not considered legally private and could be subject to disclosure.
- You may have more than one well on the property. Please answer the questions for the well you use most inside your home.

Contact Information

Name of person completing the survey __________

Well Street Address __________

Well Zip __________

1. Property Owner / Tenant / Other?

[ ]

If answer is other, please specify

____

2. Where do you get your drinking water?

	Never	Seldom	Sometimes	Mostly or Always
We drink water from our well that is either softened or filtered.	○	○	○	○
We drink water from our well that is <u>not</u> filtered or softened.	○	○	○	○
○ We drink water from our well that has been processed with a distiller.	○	○	○	○
We drink water from another source (i.e. bringing drinking water home from the work place, cabin, or relative's residence).	○	○	○	○
We drink purchased bottled water.	○	○	○	○

3. Where do you get water for cooking?

	Never	Seldom	Sometimes	Mostly or Always
We cook with water from our well that is either softened or filtered.	◯	◯	◯	◯
We cook with water from our well that is <u>not</u> filtered or softened.	◯	◯	◯	◯
We cook with water from our well that has been processed with a distiller.	◯	◯	◯	◯
We cook with water from another source (i.e. bringing drinking water home from the work place, cabin, or relative's residence).	◯	◯	◯	◯
We cook with bottled water.	◯	◯	◯	◯

4. Do you use any water treatment?

	Entire House (Yes, No, Don't Know)	Kitchen Faucet Only (Yes, No, Don't Know)	Refrigerator Water Dispenser (only if applicable) (Yes, No, Don't Know)
Water Softener			
Iron Filter - typically located on water line near pressure tank			
Sediment Filter - typically located on water line near pressure tank			
Reverse Osmosis - typically located under the kitchen sink with a dedicated spigot at the kitchen sink			
Carbon Filter (granular activated carbon (GAC) or charcoal) - this is the type of filter used in a refrigerator water dispenser, can be mounted on the kitchen faucet or located on a water line.			
No Treatment			
Don't Know			

Other Water Treatment - please describe

5. If using a pitcher-type water filter (for example, Brita or PUR, which use a carbon filter) check all that apply to the treatment the water poured into the pitcher has received, if any.

- ☐ Water Softener
- ☐ Iron Filter
- ☐ Sediment Filter
- ☐ Reverse Osmosis
- ☐ Carbon

6. How would you rate your history of maintenance or changing filters in all treatment systems accordance with manufacturer's instructions?

- ◯ Strictly follow instructions
- ◯ Usually follow instructions
- ◯ Seldom follow instructions
- ◯ Professionally maintained

7. Concerns about your well water?

	Very Concerned	Somewhat Concerned	Not Very Concerned	Not At All Concerned
Taste, odor, color	◯	◯	◯	◯
Iron or other minerals	◯	◯	◯	◯
Bacterial contamination	◯	◯	◯	◯
Nitrate contamination	◯	◯	◯	◯
Contamination with herbicides or other lawn or farming related chemicals	◯	◯	◯	◯
Contamination with chemicals from industry, landfills or dumps	◯	◯	◯	◯

8. To what extent do you agree or disagree with the following statements?

	Strongly Agree	Agree	Disagree	Strongly Disagree	Don't Know
I have ample opportunities to learn about the quality of my water.	◯	◯	◯	◯	◯
Federal, state and local governments are doing an adequate job protecting groundwater in my ◯ community.	◯	◯	◯	◯	◯
Poor drinking water quality has reduced property values in my COUNTY.	◯	◯	◯	◯	◯

9. In order for us to provide information about your well testing results that are more specific to you or other residents in your home, please answer the following:

In your Household:

	Yes	No
Are there any women between the ages of 18-44?	○	○
Are there any children 9 years old or younger?	○	○
Are there any infants 12 months old or younger?	○	○
Does the infant(s) drink a different source of water than consumed by the other members of the household?	○	○

If there is a different source used for an infant, please explain

Please provide a phone number that is best to reach you during the day:
(we may want to contact you about your well water results or to ask about collecting a follow-up water sample.)

I am interested in being contacted by the Minnesota Department of Health about future opportunities to participate in drinking water studies.

○ Yes

○ No

Questions about the survey? Please contact Vanessa Demuth, Dakota County Environmental Resources at 952-891-7010 or vanessa.demuth@co.dakota.mn.us

DAKOTA COUNTY ENVIRONMENTAL RESOURCES DEPARTMENT
14955 Galaxie Avenue, Apple Valley, MN 55124, (952) 891-7000

Water Test Form

Sample collection: Please collect the water sample from your primary drinking water faucet. If you mainly drink bottled water but use well water for cooking, please fill the sample bottle with the water used for cooking.

☐ I confirm that this sample was collected from the cold water kitchen tap. If other location, *write-in*: ______________

Address of water sample:
XXXX
INVER GROVE HEIGHTS MN

Mailing address:
Well Owner
XXXX
INVER GROVE HEIGHTS MN 55076

Well Unique Number: ###### Order No. #

In addition to the free manganese test, if you would like to request additional tests for a fee, mark the following boxes:
☐ Arsenic $15.00
☐ Lead $15.00

Make checks payable to Dakota County Treasurer

1. Water Softener *(select only one of the following two options)*

☐ There is NOT a softener in use in the home (*disregard enclosed test strip*)
☐ There IS a softener in use in the home. IMPORTANT: please run the water you are collecting for your sample over the enclosed test strip. The strip will change color to indicate the amount the water is softened. If the test strip is turns a green color, this indicates the water is not softened.

If softener in use, mark test strip result: ☐0 ppm (not softened) ☐50 ppm ☐120 ppm ☐250 ppm ☐ 425 ppm

2. The water in the sample bottle went through: (*select only one of the following options*)

☐ A reverse osmosis spigot, also called a RO system. An RO system is comprised of multiple filters, typically; one sediment, one or more carbon filters and a reverse osmosis membrane.

A pour-through pitcher or faucet-mounted filter, which are carbon filters, also known as charcoal or granular activated carbon (GAC) filters (example brands are Brita and PUR).
Some carbon filters have an ion exchange feature. Please locate information on your filter to determine if your filter has this added feature.
☐ Carbon filter that has added ion exchange feature
☐ Carbon filter that does not have added ion exchange feature
☐ Carbon filter, I do not know if the filter has ion exchange feature

☐ A refrigerator water dispenser that has no filter
☐ A refrigerator water dispenser that has a carbon filter (if different type of filter, *write-in*:____________________)

☐ A distillation device, which uses heat to evaporate water and reduces impurities.

☐ Not applicable (Sample collected from cold water kitchen faucet with no filter)

3. Additional Treatment Devices: *Select all that apply*

☐ **Whole house iron filter**. These can be an inline filter which can resemble a sediment filter or larger multiple tank systems that can resemble a water softener.
☐ There is a whole house iron filter in the home, but I'm not certain whether the water in this sample went through it.

☐ **Whole house sediment filter** which removes suspended particles from the water. May resemble an inline iron filter.
☐ There is a whole house sediment filter in the home but I'm not certain whether the water in this sample went through it

☐ Any other treatment device, *write-in*____

Appendix D: Participant Communications Materials

Dear Resident:

The Dakota County Environmental Resources Department, in partnership with the Minnesota Department of Health, will be collecting water samples from private drinking water wells in Inver Grove Heights as part of a groundwater study. The purpose of the study is to measure natural and man-made chemicals in the groundwater in Inver Grove Heights. We are asking your permission to include your water well in the study. If you agree to participate, we will ask you to complete a short survey and Dakota County staff will collect a water sample, most likely from an outside water spigot on your home.

Your well will be tested at no cost to you, and you will receive an explanation of your individual test results.

We would prefer to collect a sample of untreated and unfiltered water from an outside faucet that is close to the well. You will not need to be present if we can collect the water from an outside faucet. We will run the water for about 15 minutes to ensure that we collect water from the well and not water that has been stored in a tank or in your pipes. We can direct the runoff to your lawn, garden, or trees. Depending on your test results, we may ask you to collect an additional water sample and mail it to a laboratory (at no cost to you) and complete an additional survey.

A certified laboratory will analyze the collected sample for nitrate, nitrite, coliform bacteria, manganese, arsenic, iron, sulfate, chloride, fluoride and other characteristics of the water. The enclosed fact sheet provides more information.

The data from the tests of your well will be summarized in reports; your name and address will not be identified. However your well location and sampling results are not legally considered private and could be subject to disclosure. You will not be required to take any action with your water well based on participating in this study. For example, if the water sample is high in manganese, we will inform you of the results and explain water treatment options to improve your well water. You will not be required to drill a new well or use a filter.

Enrollment in this study is limited. We hope you agree to participate. If you are willing to participate or have questions, please contact me by Monday, August 24, 2015 at (952) 891-7010 or vanessa.demuth@co.dakota.mn.us.

Sincerely,

Vanessa Demuth

Vanessa Demuth, P.G.
Environmental Geologist

CHEMICAL DESCRIPTIONS

Coliform bacteria and E. coli

Coliform bacteria are common on the surface of the ground, but not very deep into the soil. When coliform bacteria are detected in a well, it can indicate that surface contamination is entering the well. This surface contamination may include infectious disease bacteria that cause stomach and intestinal illness. For example, some strains of E. coli pose a health risk. MDH recommends that all private wells get tested for total coliform bacteria once per year. Spring is the best time of year to test. It is also wise to test well water for bacteria any time the water changes in taste, odor, or appearance.

Nitrate and Nitrite

Nitrate is the most commonly detected groundwater contaminant in both the United States and in Dakota County. Nitrate is a naturally-occurring chemical in water, but high levels of nitrate in groundwater usually come from human activities, including septic systems and feedlots. In the Upper Midwest, the major source is nitrogen fertilizer used on agricultural crops. A nitrate level above 10 mg/L or a nitrite level above 1 mg/L in drinking water can be harmful to infants under six months of age. When infants consume water or formula mixed with water that is high in nitrate, they can develop “blue baby syndrome” (methemoglobinemia), a life-threatening condition. MDH recommends that all private wells get tested for nitrate annually or every two years. Always test for nitrate before giving the water to an infant. Spring is the best time of year to test.

Arsenic

Arsenic is a naturally occurring element found in rocks and soil across Minnesota. From these sources, arsenic can enter our groundwater and drinking water wells. Too much arsenic in drinking water has been linked to effects on the respiratory, nervous, immune, and endocrine systems. High levels of arsenic in drinking water are also associated with cancer. MDH recommends that every well be tested for arsenic at least once. The U.S. Environmental Agency has set a drinking water standard of 10 µg/L for arsenic, to reduce potential health risks. However, this level is not low enough to completely eliminate all risk of cancer and other health effects from arsenic.

Lead

When water stands idle in the plumbing pipes for more than a few hours, it can absorb lead if the plumbing has old lead pipes, lead-soldered copper pipes, or older brass plumbing components. Homes built before 1986 are more likely to have lead pipes, fixtures, and solder. Wells drilled over 20 years ago may also contain lead "packers" above the well screen. Some brands of submersible pumps manufactured before 1995 may contain leaded-brass components. Exposure to lead in drinking water can cause delays in physical and mental development in babies and children. Adults who drink water with elevated levels of lead over many years could develop kidney problems or high blood pressure.

Manganese

Manganese is a naturally occurring element found in rocks and soil across Minnesota. From these natural sources, manganese can enter our groundwater and our drinking water wells. Our bodies need a small amount of manganese to maintain health. We get this manganese from the foods we eat. Too much manganese in drinking water may cause neurological problems. Infants are more sensitive than children or adults to the effects. MDH recommends that every well be tested for manganese at least once. The current guidance value for manganese in drinking water is 100 µg/L for formula-fed infants and infants that drink tap water. The manganese guidance value for children and adults (including nursing mothers) is 300 µg/L.

Iron

Iron is a naturally-occurring element found in rocks and soil across Minnesota. From these sources, iron can enter our groundwater and our drinking water wells. Our bodies need a small amount of iron to help move oxygen through our blood. We get this iron from the foods we eat. While iron in well water is not a health concern, iron in wells above 0.3 mg/L can cause a metallic taste and yellow, red, or brown stains on laundry, dishes, and plumbing. High levels of iron can also clog wells, pumps, sprinklers, and other devices such as dishwashers, which can lead to costly repairs.

Sulfate

Sulfate is naturally-occurring and found in rocks and soil across Minnesota. From these natural sources, sulfate can enter our groundwater and our drinking water wells. If sulfate in water exceeds 250 mg/L, a bitter taste may make the water unpleasant to drink. High sulfate levels may also corrode plumbing, particularly copper piping. People drinking water with high levels of sulfate can experience short-term diarrhea and dehydration until their bodies become used to the sulfate levels in the water. This can be especially harmful to infants. As a precaution, water with a sulfate level exceeding 400 mg/L should not be used to prepare infant formula.

Chloride

Chloride is naturally-occurring and found in many common minerals in the rocks and soil across Minnesota. High levels of chloride in groundwater indicate contamination from human activities, including the application of road salt, or nearby septic systems or animal wastes. There is no health-based standard for chloride but EPA recommends levels no higher than 250 mg/L to avoid undesirable tastes and odors.

Fluoride

Fluoride is a naturally occurring element found in water, air and soil across Minnesota. Fluoride can help prevent tooth decay, but too much fluoride can damage teeth, bones, and joints. The recommended fluoride level in drinking water for good oral health is 0.7 mg/L. If fluoride levels in your drinking water are lower than 0.7 mg/L, your child's dentist or pediatrician should evaluate whether your child could benefit from daily fluoride supplements. At fluoride concentrations above 2 mg/L, children 8 years and younger have a greater chance for developing dental fluorosis, a cosmetic change in the appearance of the tooth's enamel. Only children aged 8 years and younger can develop dental fluorosis because this is when permanent teeth are developing under the gums. Fluoride levels above 4 mg/L may cause severe fluorosis in children and bone problems in adults.

Minnesota Department of Health
ENVIRONMENTAL HEALTH DIVISION

Summary of Water Treatment Options to Reduce Manganese

Point of Use Treatment	**Point of use (POU) treatment systems are designed to treat small amounts of water, usually for drinking and cooking. The treatment system is likely to be located on the counter, attached to the sink faucet, or installed under the sink. Some refrigerators with water/ice dispensers also have a treatment system installed.**			
Treatment Option	Description	Best For	Advantages	Disadvantages
Reverse Osmosis (RO)	In a reverse osmosis system, dissolved solids are removed from water as the water diffuses across a non-porous membrane.	Water with multiple contaminants.	Effectively reduces the widest array of contaminants, including manganese, nitrate, nitrite, chlorine, arsenic, sodium, other dissolved minerals, volatile organic compounds (VOCs), and pesticides.	Reverse osmosis systems create wastewater when the membrane is operating (to keep it clean and functioning). The amount of wastewater created can be 1 to 8 times the amount of clean drinking water produced.
Distillation	Distillers use heat to boil the water. Steam is produced and rises, leaving contaminants behind. The steam hits a cooling section where it condenses back to liquid.	Water with multiple contaminants, including bacteria.	Distillation can remove up to 99.5 percent of dissolved solids including manganese.	It can be expensive to heat the water to create the steam that is required for distillation.VOCs and other contaminants may not be removed. Water may taste 'flat' because oxygen and minerals are reduced.

Point of Use Treatment	**Point of use (POU) treatment systems are designed to treat small amounts of water, usually for drinking and cooking. The treatment system is likely to be located on the counter, attached to the sink faucet, or installed under the sink. Some refrigerators with water/ice dispensers also have a treatment system installed.**			
Treatment Option	Description	Best For	Advantages	Disadvantages
Carbon filter in a pour-through pitcher, faucet attachment, or refrigerator water/ice dispenser	Most carbon filters only reduce manganese that is oxidized. Organic contaminants adsorb on the surface of the activated carbon filter. The contaminants are discarded when the filter is removed and replaced with a new filter.	Water with manganese levels less than 200 ug/L for homes that have infants under 1 year. Water with less than 600 ug/L manganese for children over 1 year and adults.	Carbon filters are inexpensive, widely available, and easy to use. Carbon filters may reduce other contaminants, such as chlorine, VOCs, and pesticides.	Installed units are best used on a single tap or faucet because water with iron and/or manganese will fill the filter quickly and will need to be replace often. There is no clear indication that a carbon filter is no longer removing manganese.
Oxidation and Settling	Manganese is oxidized by aeration when you simply leave a pitcher of water standing overnight. Dissolved iron and manganese will form solids when oxidized, which will drop to the bottom of the pitcher.	Water without biological contaminants such as bacteria.	Does not require additional equipment or chemicals.	Uncertain exactly how effective this method is.

Manufacture's recommendations for installation and maintenance must be followed in order for a treatment unit to work properly. Treatment units that are not properly maintained may not effectively remove contaminants. In some cases, treatment units that are not maintained may actually make problems worse. For further questions about manganese treatment options, contact Krishna Mohan at MDH: 651-201-4699

Minnesota Department of Health | Environmental Health Division | P.O. Box 64975 | St. Paul, MN 55164-0975| (651) 201-4899| UPDATED 03/30/2016

Point of Entry (Whole House) Treatment	**Point of entry (POE) treatment systems are designed to treat all of the household water. POE systems are installed at the location where water enters the home. When a POE system is used, treated water will be available for all household uses including drinking, cooking, cleaning, bathing, and laundry.**			
Treatment Option	Description	Best For	Advantages	Disadvantages
Water Softening (Ion Exchange)	Manganese and dissolved minerals that are in water as cations are removed by water softener ion exchange resins. These resins typically switch sodium for the predominant hardness ions calcium and magnesium. They also reduce iron, manganese, and copper.	Water with iron below 1000 ug/L and manganese below 200 ug/L.	Water softeners are common and easy to use. Sodium chloride and potassium chloride are safe to handle.	Owner has to buy salt and resupply the storage tank as needed. An installed water softener may be piped to treat only the hot water. Or, the kitchen cold tap is left as the only hard water inside the house. To determine which taps are soft in your home, follow the plumbing or use a hardness test strip.
Oxidizing Filter Media	Oxidizing filters have a media bed that changes dissolved contaminants into solid particles. Those solid particles are then large enough to be filtered out of the water. The most common oxidizing filters are greensand filter and birm.	Water with iron up to 2000 ug/L and manganese up to 500 ug/Lug/L.	Properly maintained oxidizing filters are very efficient.	Greensand filters require periodic regeneration of the media, which is messy and must be handled and stored carefully according to specific safety measures. Birm filters require air to be added to the water.

Point of Entry (Whole House) Treatment	Point of entry (POE) treatment systems are designed to treat all of the household water. POE systems are installed at the location where water enters the home. When a POE system is used, treated water will be available for all household uses including drinking, cooking, cleaning, bathing, and laundry.			
Treatment Option	Description	Best For	Advantages	Disadvantages
Oxidizing by Ozonation and Filtration	Ozone is generated using electricity and then injected in the water. The ozone changes dissolved contaminants into solid particles. Those solid particles are large enough to be filtered out of the water.	Water with multiple contaminants, especially metals (such as manganese) and bacteria.	Useful when there are multiple water quality issues.	Ozonation systems require significant maintenance and may be more expensive than other treatment options.
Oxidizing by Aeration and Filtration	An aerator brings oxygen into the water. The oxygen helps change dissolved contaminants into solid particles. Those solid particles are large enough to be filtered out of the water.	Water with combined iron and manganese from 2000 ug/L to 10,000 ug/L.	Aeration does not add additional chemicals to the water and may reduce iron, hydrogen sulfide, volatile organic compounds (VOCs), and dissolved gasses in addition to manganese.	Water with too much oxygen can become corrosive and damage plumbing. Aeration filters may require a large tank or multiple tanks.
Oxidizing by Continuous Chlorination and Filter	A pump feeds chlorine into the water, which helps change dissolved contaminants into solid particles. Those solid particles are large enough to be filtered out of the water.	Water with relatively low manganese levels that also has biological contaminants, such as bacteria.	Useful when there are multiple water quality issues.	Chlorination may require a large tank or multiple tanks and regular maintenance is required. An additional carbon filter may be needed for drinking water to remove the chlorine taste.

May 17, 2016

Dear Study Participant:

Thank you for participating in the Dakota County and Minnesota Department of Health (MDH) Inver Grove Heights private well study. The purpose of the study is to test water from private wells in an area suspected to have naturally-elevated manganese levels in groundwater. We previously tested for manganese in water from your outside spigot, which may or may not reflect the level of manganese in water that you are actually drinking. Based on your initial manganese test result, we are asking that you now collect an additional water sample from the inside tap used most often for drinking and cooking. We will test this sample for manganese **at no cost to you**. A certified laboratory will analyze your sample and you will receive your results in the mail.

In addition to collecting a water sample, we are also asking you to fill out a 1-page form (enclosed) about any treatment systems or devices the water went through. This information will help us interpret your result. We appreciate your continued participation in this second and final sampling phase of the study. As a reminder, you will not be required to take any well-related actions based on participating in this study or your manganese result.

Once you collect the sample, please bring it, along with the enclosed form, to one of the following drop-off events:

Tuesday, May 24th	4pm to 7:30pm
Wednesday, May 25th	7am to 9:30am
Tuesday May 31st	4pm to 7:30pm
Wednesday, June 1st	7am to 9:30am

Where: Veterans' Memorial Community Center, 8055 Barbara Avenue, Inver Grove Heights Door A

What: Bring the enclosed sample bottle with water from your primary drinking water tap and the completed form

Who: Dakota County staff will be at the event and will be available to answer questions

Cost: Manganese is free to you.
If you would like additional analyses the costs are: Arsenic $15, Lead $15,
Make check **(cash and credit cards not accepted)** payable to Dakota County Treasurer

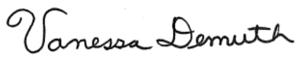
Additional Sample option: if you would like to have a water sample analyzed from a different source bring at least a 16-ounce (2 cups) water sample in a clean container. This water will be transferred into a sample bottle and your container returned to you at the sample drop off event. Plan to complete a separate water test form for this sample at the sample drop event.

Dakota County Environmental Resources | 14955 Galaxie Ave., Apple Valley, MN 55124 | 952-891-7000

Additional Sample cost per analyte is: Arsenic $15, Manganese $15, Fluoride $15, Lead $15, Nitrate $18
Make check **(cash and credit cards not accepted)** payable to Dakota County Treasurer.

If you have any questions, or if you are unable to attend any of the drop-off events, please contact me at (952) 891-7010 or by email at vanessa.demuth@co.dakota.mn.us.

Sincerely,



Vanessa Demuth, P.G.
Environmental Geologist