PRIVATE WELL MITIGATION COST-BENEFIT ANALYSIS

Minnesota
MDH Work Order #271319

Prepared for:

Minnesota Department of Health

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Acronyms and Abbreviations

µg/L .... micrograms per liter
ANSI .... American National Standards Institute
Bay West .... Bay West LLC
CDC .... Centers for Disease Control and Prevention
CGMP .... current good manufacturing practices
COC .... contaminants of concern
E. coli .... *Escherichia coli*
EPA .... U.S. Environmental Protection Agency
FDA .... Food and Drug Administration
gpm .... gallons per minute
HBV .... Health-Based Value
HRL .... health risk limit
MCL .... maximum contaminant level
MDA .... Minnesota Department of Agriculture
MDH .... Minnesota Department of Health
mg/L .... milligrams per liter
NSF .... NSF International
O&M .... operation and maintenance
PFAS .... per- and polyfluoroalkyl substances
POE .... point-of-entry
POU .... point-of-use
RAA .... Risk Assessment Advice
RO .... reverse osmosis
SDWA .... Safe Drinking Water Act

1.0 INTRODUCATION AND BACKGROUND

Minnesota Laws of 2023, chapter 40, Article 2, section 7, directs Minnesota Department of Health (MDH) to develop public health policies and an action plan to address threats to safe drinking water, including development of a statewide plan for protecting drinking water. One of the actions MDH named in that plan is conducting a cost-benefit analysis of mitigation approaches for private wells with water quality issues that could affect human health. Based on this action, MDH requested Bay West LLC (Bay West) to assist MDH in researching and documenting the cost and benefits of private well mitigation options and technology to address contaminants of concern (COCs) in private well water.

Bay West has prepared this Private Well Mitigation Cost-Benefit Analysis to identify and assess mitigation options for private well owners to address drinking water contaminated with five COCs identified by MDH: coliform bacteria, nitrate, arsenic, lead, or manganese. A feasibility study approach was used to assess the practicality and viability of proposed treatment methods. Strengths, weaknesses and costs related to other treatment options are discussed in the report.

Bay West used the following process to develop this document:

- **Mitigation Option Identification and Research** – Bay West conducted research to identify potential treatment technologies, repairs, and other mitigation options, using information provided by MDH for the five COCs in drinking water. Research also included a review of federal, state, and local laws and regulations that could potentially affect mitigation options.
- **Mitigation Option Screening** – Mitigation options identified in the research phase were screened against a set of criteria that are applicable regardless of which COC requires mitigation, including:
  - Technology availability,
  - Ease of installation,
  - Convenience
  - Operations and maintenance (O&M),
  - Cost, and
  - Additional considerations such as well conditions, hydrogeology, and other environmental conditions.

  This initial screening helped determine which options were appropriate for consideration as a mitigation option for each COC.
- **COC-Specific Mitigation Option Comparison and Ranking** – The mitigation options were then examined further with a focus on how mitigation options apply to individual COCs and given both a narrative relative comparison and numeric ranking based on established scoring criteria. The COC-specific mitigation option ranking included the following factors:
  - Effectiveness on the COC, and
  - Overall protectiveness and performance.

A summary discussing the results of the comparison and ranking of mitigation options for each COC is then provided. The narrative text in this document is paired with a series of tables:

- **Table 1** - outlines the mitigation options evaluated in this document and the COCs that are mitigated,

- **Tables 2A** through **2E** - a comparative analysis of applicable mitigation options specific to each COC; and,
- **Tables 3A** through **3E** - a numeric analysis of applicable mitigation options specific to each COC.

These tables serve to assist in quickly understanding which technology options are best suited to mitigate a particular COC.

MDH and their partners will use this document for the following purposes:

- Serve as a framework for local partners in implementing mitigation programs.
- Help guide household-specific recommendations about the best approach for addressing a private well water quality issue.
- Improve understanding of mitigation options available for a variety of private well and water quality scenarios to potentially inform policy and budgeting approaches/priorities.
- Provide the foundation for a larger scale social and public health analysis to understand and communicate the costs and benefit trade-offs of establishing a statewide system for free/low-cost private well testing and income-based financial assistance for mitigation.

2.0 PROBLEM STATEMENT

2.1 Scope and Magnitude

Over 1.1 million people in Minnesota rely on a private well for their drinking water. Private wells in Minnesota have the potential to contain contaminants such as coliform bacteria, nitrate, arsenic, lead and/or manganese. Consuming water with these contaminants can lead to short- and long-term health effects. The purpose of this Cost Benefit Analysis is to provide a better understanding of the actual costs of mitigating these contaminants on a single well basis, and to portray the most effective mitigation option for a variety of scenarios.

MDH estimates that about 50% of private wells have coliform bacteria present or elevated concentrations of nitrate, arsenic, lead, or manganese in the well water.

2.2 Challenges

2.2.1 Lack of Federal Protections

While federal agencies (such as the U.S. Environmental Protection Agency [EPA] and Centers for Disease Control and Prevention [CDC]) provide resources and guidance on well maintenance, contamination risks, and potential health impacts, it is up to individual states and local governments to implement any water quality testing or safety regulations for private wells. The EPA has established legally enforceable maximum contaminant levels (MCLs) for public water systems for some of the COCs discussed in this report for drinking water. MCLs incorporate risk and benefit factors, which include cost of treatment/mitigation at a large scale. The costs of mitigation/treatment can be very different for an individual household/private well than compared to a public water system. As such, solely health-based values can be a better guidance value for private wells than an MCL.

2.2.2 Limitations of State Protections

MDH has established health-based values and guidance to evaluate potential human health risks from exposures to some COCs discussed in this report, including Health Risk Limits (HRLs) and Health-Based Values (HBVs). HRLs and HBVs are guidance used by the public, risk managers, and other stakeholders to make decisions about managing the health risks of contaminants in groundwater and drinking water. It should be noted that HBVs and HRLs do not consider cost and technology of prevention and/or treatment. Additionally, MDH enforces Minnesota Statutes, chapter 103I and Minnesota Rules, chapters 4725 and 4727. These regulations are legally enforceable requirements and standards for well and boring construction and sealing, and water quality testing. These regulations apply to public and private wells to protect both public health and groundwater; however, ongoing maintenance, testing, and mitigation is the responsibility of the private well owner.

2.2.3 Well Construction and Age

Wells constructed before July 1974 pre-date the Minnesota Well Code. The Well Code outlines requirements for well construction, repair, maintenance, and abandonment guidelines to protect groundwater quality and public health. Older supply wells, not built according to the Well Code, have increased risk of well failure and increased risk of providing a pathway for groundwater contamination.

2.2.4 Geography

Should a well need mitigation, the location or geography of a well may present challenges based on the proximity to treatment providers. A well located in a rural area may not have access to a vendor that can easily supply a certain treatment option or necessary maintenance.

Land use in itself creates different challenges; agricultural areas present the concern for contamination from nitrates and pesticides. Rural areas with failing septic systems can introduce bacteria into well water.

2.2.5 Geology/Hydrology

Minnesota has abundant water resources that are distributed among six groundwater provinces in the state based on bedrock and glacial geology. Each province is distinguished by the combination of physical attributes (thickness, lateral extent, permeability, and porosity type) which contribute to making wells more or less susceptible to contamination. Each province has a unique combination of groundwater sources and availability for drinking water. The following describes the characteristics and unique environmental risks for each province and groundwater provinces are displayed on **Figure 1**.

Eastern Central Minnesota (Twin City Basin and North Province 1):

Groundwater resources in this region resides in the surficial and buried sand and gravel aquifers and these unconsolidated aquifers are underlain by thick and extensive Paleozoic (sandstone and carbonate) and Precambrian (sandstone) aquifers. The most prominent glacial deposits are till, outwash, and valley-train and lake deposits of the Superior lobe and Des Moines lobe. The Superior lobe advanced from the northeast and is mostly reddish brown to brown sand and gravel, in contrast to till of the Des Moines lobe, which advanced from the northwest and is mostly yellowish brown to gray clay. Large outwash sand and gravel deposits fanned out in front of the ice sheets during both their advancing and retreating stages. The sedimentary rocks in the area were deposited in transgressing and regressing Cambrian and Ordovician seas prior to the glaciers. Transgression resulted in deep water filling the basin and consequent deposition of fine-grained limestone and shale sediments. Regressions resulted in shallow water in the basin and consequent deposition of more coarse-grained siltstone and sandstone sediments. Environmental risks include nitrate contamination from agriculture practices in more rural areas to industrial chemical contaminants in more urban areas, including and widespread occurrence of per- and polyfluoroalkyl substances (PFAS). The lack of protective overburden and confining layers in many areas of the sand plains exacerbates aquifer sensitivity. In areas that till overburden is present the impacts are less; however, man-made structures such as landfills and unregulated wells allow the penetration and migration of these agricultural and industrial chemicals to the underlying bed rock aquifers.

South Central Minnesota (Glacial Till Plains and Cretaceous Aquifer Province 2) and Western, Minnesota (Glacial Till Plains and Cretaceous Aquifer Province 5):

Groundwater resources are constrained by thick, clay loam deposits with limited surficial and buried sand aquifers. Thick clay loam areas limit recharge to underlying buried sand aquifers and deeper Paleozoic (sandstone and carbonate) aquifers. Typically, these thick, clay loam deposits are associated with the advancement of the Des Moines Lobe of the Laurentide ice Sheet. The Des Moines Lobe advanced from central Canada and across North Dakota, and the till is comprised of fragments of shale and limestone carried from the Canadian source which are a potential source for arsenic. While these confining till units provide protection from rapid surface contamination, they also concentrate naturally occurring constituents such as arsenic. Unconsolidated aquifers in Province 2 are underlain by good bedrock aquifers comprising thick, laterally extensive sequences of sandstone, siltstone, and limestone and dolostone of sedimentary origin. Groundwater occurs in granular pore spaces, partings, joints, fractures, and dissolution features. Unconsolidated aquifers in Province 5 are underlain by limited bedrock aquifers. The uppermost bedrock is mostly hard crystalline igneous and metamorphic rocks. Groundwater mostly occurs in smaller fractures that may not yield useable quantities of water. In southwestern Minnesota and other scattered locations, Cretaceous age sandstone aquifers are interbedded with thick shale above the hard, fractured bedrock. Environmental risks include arsenic along with agricultural chemicals leaching where permeable deposits exist in the till, and industrial or agricultural contaminants reaching buried aquifers through improperly sealed wells.

Southeastern Minnesota (Driftless Area and Karst Province 3):

Groundwater resources in this region primarily reside in the extensive Carbonate bedrock aquifers. Carbonate aquifers series spanning from Cambrian to Devonian in age are highly productive aquifers. These aquifers exhibit extreme vulnerability due to shallow bedrock and karst features that allow rapid infiltration with minimal attenuation of contaminants. Environmental risks include nitrate contamination from row-crop agriculture and manure application, microbial pathogens from septic systems and livestock operations, and chemical contaminants transported through geologic features. The lack of protective overburden and confining layers in many areas exacerbates aquifer sensitivity and increases risk to aquifer contamination.

Central Minnesota (Glacial Drift and Paleozoic Sandstone Aquifers Province 4):

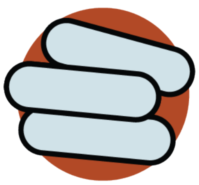
Groundwater resources in this region primarily reside in the extensive surficial sand and gravel aquifers derived from glacial outwash deposits. The glacial deposits are hydraulically connected to underlying Paleozoic sandstone and shale aquifers. These aquifers are underlain by Precambrian bedrock, which exhibit aquifer characteristics with high permeability and high recharge potential, making them reliable drinking water sources. However, the same hydrogeologic characteristics increase susceptibility to surface contamination. Environmental risks include nitrate and pesticide infiltration from agricultural land use, microbial contamination from septic systems, and widespread occurrence of PFAS. Generally, these aquifers have a high-risk factor susceptible to surface contaminants.

Northeastern Minnesota (Arrowhead/Shallow Bedrock Province 6):

Groundwater resources in this region primarily resides in fractured Precambrian crystalline bedrock and to a lesser extent Cretaceous bedrock where limited overburden is present. Yields are low, and recharge is dependent on localized fracture networks. Because of the minimal soil and sediment cover overlying bedrock, the aquifer system offers little natural filtration. Environmental risks include the potential mobilization of metals such as manganese and arsenic from bedrock, as well as contamination from local industrial operations. Surface water bodies, which are heavily used for public water supplies, are also vulnerable to metals, acid mine drainage, and adverse nutrient loading from shoreline development.

3.0 TOP FIVE CONTAMINANTS IN MINNESOTA PRIVATE WELL WATER

The top five COCs present in the Minnesota private well water are discussed below, including sources of contamination, occurrences in Minnesota, health risks associated with each COC, private wells that are typically at risk to COC contamination, and current MDH guidance for when COCs are detected or exceed a concentration limit established by MDH or EPA. A map with all known private wells with coordinate data is depicted on **Figure 1**.



3.1 Coliform bacteria

Biological organisms are among the oldest health threats to drinking water quality; they are responsible for most waterborne diseases. Organisms known to cause disease include bacteria, protozoa, and viruses. Coliforms are bacteria that are always present in the digestive tracts of animals, including humans, and are found in their wastes. They are also found in plant and soil material. They are easily transmitted to drinking water if the feces of an animal contaminate a water supply. Coliform bacteria cannot be identified in water by look, taste, or smell. Coliform bacteria in drinking water supplies are typically identified in three categories:

- Total coliforms include bacteria that are found in the soil, in water that has been influenced by surface water, and in human or animal waste.
- Fecal coliforms are the group of the total coliforms that are considered to be present specifically in the gut and feces of warm-blooded animals. Because the origins of fecal coliforms are more specific than the origins of the more general total coliform group of bacteria, fecal coliforms are considered a more accurate indication of animal or human waste than the total coliforms.
- *Escherichia coli* (*E. coli*) is the major species in the fecal coliform group. Of the five general groups of bacteria that comprise the total coliforms, only *E. coli* is generally not found growing and reproducing in the environment. Consequently, *E. coli* is considered to be the species of coliform bacteria that is the best indicator of fecal pollution and the possible presence of pathogens.

MDH recommends intervention when any coliform bacteria are detected in drinking water.

3.1.1 Source of Contamination

Some potential sources of contamination include sewers, septic systems, feedlots, animal yards, and surface runoff.

3.1.2 Minnesota Occurrence

There is limited data related to the occurrence of coliform bacteria in private well water in Minnesota. A private well must test negative for coliform bacteria before use. Therefore, MDH is only notified of wells that do not contain coliform bacteria. According to one Centers for Disease Control (CDC) study completed in the Midwest (CDC, 1998), approximately 27% of private wells sampled in Minnesota had coliform bacteria present. The presence of coliform bacteria is generally related to well conditions and construction methods; however, geographic distribution of wells impacted with coliform bacteria may be related to common sources and pathways for coliform bacteria, such as locations with high density of livestock production, karst areas, or floodplains. Location data of individual wells with coliform bacteria detections is not currently available.

3.1.3 Health Risks

While most coliform bacteria do not cause disease, their presence suggests there may be disease-causing microorganisms in water. These microorganisms can cause diarrhea, dysentery, salmonella, hepatitis, cryptosporidiosis, and giardiasis. Symptoms include diarrhea, vomiting, cramps, nausea, headaches, fever, fatigue, and even death sometimes. Infants, children, elderly people, and people with weakened immune systems are more likely to get sick or die from disease-causing microorganisms in drinking water.

3.1.4 Private Wells at Risk

Some types of wells are at higher risk of being contaminated with harmful microorganisms, such as:

- Wells constructed before 1974 (when the Minnesota Well Code was developed);
- Hand-dug wells;
- Wells at the bottom of old frost pits;
- Wells with damaged or leaking casings or fittings;
- Shallow wells;
- Wells close to sewers, septic systems, animal feedlots, or any other potential source (**Section 3.1.1**); or
- Wells in areas prone to flooding.

3.1.5 MDH Guidance

MDH recommends the following for well owners when any coliform bacteria are detected in drinking water samples:

- Drinking water should be obtained from a safe alternative source (like bottled water) until the problem is addressed. If other COCs are not detected in the water, the water can be boiled before using it for drinking or cooking.
- The well and water system can be disinfected with a chlorine solution (this can be completed by the well owner or by a licensed well contractor).
  - Following disinfection, the well should be tested again via an accredited laboratory.
  - If there are still coliform bacteria present, a licensed well contractor should be contacted to address the issue.

3.2 Nitrate

Nitrate is a naturally occurring compound and also has many human-made and agricultural sources, such as fertilizers, manure, agricultural runoff, dairy lagoons, and liquid waste discharged from septic tanks. Nitrate is in some lakes, rivers, and groundwater in Minnesota. You cannot taste, smell, or see nitrate in water. Elevated nitrates in the body makes it harder for red blood cells to carry oxygen, which can be very dangerous for infants and some adults. The MDH HRL, which is based on the EPA MCL for nitrate as nitrogen, is 10 milligrams per liter (mg/L).

3.2.1 Source of Contamination

Nitrate occurs naturally in the environment and comes from natural processes, like plant decay and lightning; however, natural concentrations of nitrate in Minnesota groundwater are usually low. Human-made sources typically cause higher concentrations of nitrate in groundwater. These sources include fertilizers, sewers, septic systems, animal feedlots, animal waste, landfills, and urban drainage. Most synthetic fertilizer applications to agricultural land occurred after 1980. Since approximately half of all applied nitrogen drains from agricultural fields to contaminate surface and groundwater, nitrate concentrations in water resources have also increased (Ward et al., 2018).

3.2.2 Minnesota Occurrence

Within the past 20 years, Minnesota State Agencies have generated multiple sources of nitrate data for private wells over the past few decades. The Minnesota Department of Agriculture (MDA) completed a Township Testing Program for Nitrate between 2013 and 2019. They offered nitrate testing to more than 90,000 private well owners in over 300 townships. The program found that 9.1% of private wells sampled had nitrate concentrations above EPA standard for nitrate in drinking water. Per Minnesota law, new private wells require nitrate testing following installation. MDH mapped nitrate testing results in new wells between 1992 and 2022. They categorized results based on wells that exceed the EPA standard (10 mg/L), and wells impacted by nitrate contamination (3 mg/L to 10 mg/L). Approximately 5% of new wells in Minnesota are impacted by nitrate contamination. A statewide map of nitrate detections in private wells is depicted in **Figure 2**.

3.2.3 Health Risks

Consuming too much nitrate can affect how blood carries oxygen and cause methemoglobinemia (also known as a blue baby syndrome). Bottle-fed babies under six months old are at the highest risk of getting this illness. Methemoglobinemia can result in serious illness or death. It can cause the lips and skin to turn a bluish color but may be difficult to detect in infants. Symptoms will often resolve once the nitrate source is removed.

The following conditions may also put people at higher risk of developing nitrate-induced methemoglobinemia: anemia, cardiovascular disease, lung disease, sepsis, glucose-6-phosphate-dehydrogenase deficiency, and some metabolic problems.

Recent studies describe possible health impacts of long-term exposure to nitrate in drinking water at concentrations below the current EPA standard. Potential health impacts include associations with thyroid problems, adverse pregnancy outcomes, and cancers (particularly colorectal).

3.2.4 Private Wells at Risk

Some types of wells are at a higher risk of being contaminated with nitrate, such as:

- Wells constructed before 1974 (when the Minnesota Well Code was developed);
- Hand-dug wells;
- Wells at the bottom of old frost pits;
- Wells with damaged or leaking casings or fittings;
- Shallow wells;
- Wells in sand, karst, and fractured bedrock aquifers;

- Wells close to sewers, septic systems, animal feedlots, or any other potential source (**Section 3.2.1**);
- Wells in areas highlighted in **Section 3.2.2**; or
- Wells in areas prone to flooding.

3.2.5 MDH Guidance

MDH recommends the following for well owners if nitrate concentrations are detected at concentrations exceeding the EPA standard of 10 mg/L:

- Drink from a safe alternative source (like bottled water) until the problem is addressed.
- Make sure babies under six months old do not drink the well water.
- Do not try to boil nitrate out of the water. Boiling will make nitrate more concentrated.
- Have a licensed well contractor inspect the well and repair any damage (if found).
- Find and remove any potential sources of nitrate contamination near the well.
- If the two previous steps do not fix the problem, contact a water treatment specialist to select and install a certified home water treatment system. Even with home treatment, MDH recommends that babies under six months do not drink the water (safety precaution if water treatment fails).
  - Periodically test water (via an accredited laboratory) to make sure the treatment system is working properly.
  - Follow manufacturer's recommendations for maintaining the system.
- The well should be tested again (via an accredited laboratory) following well repair, removal of potential nitrate sources, or installation of home water treatment.

3.3 Arsenic

Arsenic occurs naturally in rocks and soil across Minnesota and can dissolve into groundwater. The amount of arsenic released from geologic sources into groundwater depends on the chemical form of the arsenic, geochemical conditions in the aquifer, and the biogeochemical processes that occur in the surrounding formation. Long-term exposure to arsenic can cause cancer in people. Arsenic concentrations can vary between wells, even within a small area. Arsenic cannot be identified by taste, see, or smell in water. The EPA MCL for arsenic is 10 micrograms per liter (µg/L), but because arsenic is a carcinogen the MCL goal is 0 µg/L.

3.3.1 Source of Contamination

Arsenic contaminates groundwater naturally by dissolving from rocks and sediments. While most arsenic in Minnesota's environment occurs naturally, some comes from human activities such as mining, agricultural, and industrial uses. In the past, arsenic was an ingredient in some pesticides, was used as a wood preservative, and was added to animal feed (USGS, 2019).

3.3.2 Minnesota Occurrence

Per Minnesota law since 2008, new private wells require arsenic testing following installation. MDH mapped arsenic testing results in new wells between 2008 and 2022. Arsenic has been detected in approximately 48.9% of new wells. About 11.6% of private wells have arsenic concentrations higher than the EPA standard of 10 µg/L.

Some areas of Minnesota are more likely to have arsenic in the groundwater due to the way glaciers moved across Minnesota, such as the Des Moines Lobe Till. MDH mapped the arsenic testing results throughout Minnesota by county along with the Des Moines Lobe Till. Note that arsenic is often present outside the Des Moines Lobe Till. A statewide map of arsenic detections in private wells is depicted in **Figure 3**.

3.3.3 Health Risks

Consuming water with even low concentrations of arsenic over a long time period is associated with diabetes and an increased risk of cancers of the bladder, lungs, liver, and other organs. 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. Health impacts of arsenic may take many years to develop.

3.3.4 Private Wells at Risk

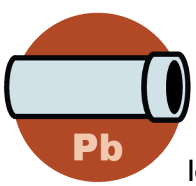
Most wells are at risk as arsenic is detected in groundwater throughout the state, especially in wells located within the Des Moines Lobe Till. Predicting arsenic in groundwater is difficult. One well may have high arsenic concentrations while a neighboring well may not have any arsenic. Well construction is not a factor. Wells in areas highlighted in **Section 3.3.2**. may be more at risk for elevated arsenic concentrations.

3.3.5 MDH Guidance

MDH recommends the following for well owners when arsenic is detected in private well drinking water at any concentration:

- Installing a treatment unit.
- Using a different drinking water source.

MDH highly recommends private well owners take action if arsenic concentrations are above 10 µg/L.



3.4 Lead

Lead is a poisonous metal that can cause long-term health and behavioral problems. With respect to drinking water, the main way to come in contact with lead in Minnesota is when plumbing materials that contain lead corrode, especially where the water has high acidity or low mineral content that corrodes pipes and fixtures. Lead cannot be detected in drinking water by color, taste, or smell. MDH, EPA and the CDC agree that there is no known safe blood lead level, especially in children.

3.4.1 Source of Contamination

Groundwater in Minnesota usually does not contain detectable concentrations of lead. However, pipes and other components in household well water systems and plumbing may contain lead. If they do, lead may dissolve into the water. The longer the water stands idle in the plumbing pipes and components, the more lead can dissolve into the water. Specific components of the water system that may contain lead include:

- Lead pipes are typically the worst contributor to elevated lead concentrations.

- Lead solder was used in the past to join copper pipes but has been illegal in Minnesota since 1985.
- Brass components such as faucets, coolers, and valves. Although brass usually contains low lead concentrations of 8 percent or less, it can still dissolve lead into the water, especially during the first few months of use. If you have new brass plumbing components installed in your plumbing system, be sure to flush the water before drinking. The federal Reduction of Lead in Drinking Water Act requires that most pipe, pipe and plumbing fittings, and fixtures installed in potable water-supply systems after January 2014 must contain no more than 0.25 percent lead.
- Lead “packers” above the well screen were commonly used in wells drilled before 1980. Lead “packers” were sometimes used in wells drilled until 1993 (when they were prohibited).
- Some submersible pumps manufactured before 1995 may contain leaded-brass components. Since January 1995, all submersible pump manufacturers in America have agreed not to use leaded-brass components in submersible pumps.

3.4.2 Minnesota Occurrence

There is limited data related to the occurrence of lead in private well water systems in Minnesota as lead testing for private wells isn’t a requirement. MDH tested 1,400 wells in southeast Minnesota and about 40% contained lead. Location data of individual wells with lead detections is not currently available.

3.4.3 Health Risks

Exposure to lead can cause serious health problems for everyone. There is no safe level of lead. MDH recommends lead concentrations in water be as close to zero as possible. MDH has not determined a level of lead in water that poses a negligible risk to health.

Coming in contact with too much lead can damage the brain, kidneys, and nervous system. Contact includes drinking, breathing, eating, or touching food, water, and other materials that contain lead. Adults can have increased risks of heart disease, high blood pressure, kidney, or nervous system problems. In children, lead can also slow development or cause learning, behavior, and hearing problems. For example, children can have decreases in IQ and attention spans.

Babies, children under six years old, and pregnant women are at the highest risk of being affected by lead.

- Babies drink more water for their size than older children and adults.
- Babies’ and children’s developing brains and organs can be injured or damaged more easily and their bodies are not very good at getting rid of harmful substances.
- Lead can pass from mother to baby during pregnancy.

3.4.4 Private Wells at Risk

Lead primarily enters private well water via well and plumbing components that contain lead. Wells and water system components installed before the following dates are most at risk for lead contamination:

- Brass components in faucets, coolers, and valves (any date),

- Lead pipes and solder installed before 1985,
- Wells installed before 1980, and
- Well pumps installed before 1995.

3.4.5 MDH Guidance

MDH recommends the following steps for well owners to reduce a household's exposure to lead in drinking water when any lead is detected or the presence of lead in plumbing is suspected:

- Let water run for at least one minute before using it for drinking or cooking. The more time water has been sitting in your home's pipes, the more lead it may contain.
- Use cold water for drinking, making food, and making baby formula. Hot water releases more lead from pipes than cold water.
- Test water and follow an accredited laboratory's instructions for sample collection.
  - First draw sample shows how much lead is in your water after the water sits in your plumbing system for at least 6 hours.
  - Flushed samples show how much lead is in your water after letting the water run for a minute or two.
- Hire a plumber to find the source of lead in your plumbing system and consider replacing that part of the system.
- Hire a certified well contractor to find the source of lead in well components and replace it accordingly.
- Contact a water treatment specialist to select and install a certified home water treatment system.
  - Periodically test water (via an accredited laboratory) to make sure the treatment system is working properly.
  - Follow manufacturer's recommendations for maintaining the system.

3.5 Manganese

Manganese occurs naturally in rocks and soil across Minnesota and is often found in Minnesota groundwater and surface water. The human body needs some manganese to stay healthy, but too much can cause neurological effects, especially in babies and children. At concentrations greater than 50 µg/L, manganese may cause a noticeable color, odor, or taste in water. The MDH HRL for manganese is 100 µg/L.

3.5.1 Source of Contamination

Manganese occurs naturally in rocks and soil across Minnesota and is often found in Minnesota ground and surface water. Your body needs some manganese to stay healthy, but too much can be harmful..

3.5.2 Minnesota Occurrence

There is limited data related to the occurrence of manganese from private wells in Minnesota as manganese testing for private wells isn't a requirement. The Minnesota Groundwater Association completed an assessment of manganese in Minnesota groundwater in 2012 (MDH, 2012). The statewide distribution of manganese in groundwater is highly variable but there are areas with more consistent trends. Southeastern Minnesota tend to have lower manganese concentrations (less than 50 µg/L) and southwestern Minnesota tends to have higher manganese concentrations (greater than 1,000 µg/L). Higher concentrations of manganese can be found in glacial aquifers. The assessment indicated 48.9% of wells in the assessment exceeded 100 µg/L and 20.3% exceed 300 µg/L. A statewide map of manganese detections in private wells is depicted in **Figure 4**.

3.5.3 Health Risks

Children and adults who drink water with high concentrations of manganese for a long time may have problems with memory, attention, and motor skills. Infants (babies under one year old) may develop learning and behavior problems if they drink water with too much manganese in it.

3.5.4 Private Wells at Risk

Higher concentrations of manganese can be found in glacial aquifers. Wells in areas highlighted in **Section 3.5.2**. may be more at risk for elevated manganese concentrations.

3.5.5 MDH Guidance

MDH provides the following guidance for safe drinking water concentrations based on whether or not an infant in the household drinks private well water:

- If there's an infant who drinks tap water or drinks formula made with tap water, a safe level of manganese in water is 100 µg/L or less.
- If you have an infant who never drinks tap water or formula made with tap water, a safe level of manganese in your water is 300 µg/L or less.
- If everyone in your household is more than one year old, a safe level of manganese in your water is 300 µg/L or less.

MDH provides the following guidance if manganese concentrations exceed the applicable standard:

- Use an alternative water source when using water to make formula or juice for a baby.
- Test your water again after taking action.

3.6 Co-Occurrence of Contaminants

The occurrence of COCs detailed in this document are dependent on a variety of factors previously discussed, including well construction, geographic location, and geologic conditions; however, COCs commonly exist in in the same conditions and location, resulting in the potential for a well to impacted with multiple COCs.

Arsenic and manganese are common in sediments of the glacial aquifer system in Minnesota and dissolve into the groundwater via similar pathways. Manganese often co-occurs with dissolved iron too (Warner, K.L., and Ayotte, J.D., 2014). Additionally, a Minnesota county reported a positive correlation between arsenic and manganese and iron (Dakota County, 2020).

Bacteria in groundwater can indicate the presence of surface sources of contamination. The presence of bacteria in a well can indicate that the well may have a defect (e.g. a crack in the casing) that can create a pathway for contaminants from the surface to enter into the well water. In agricultural areas of Minnesota, there's a higher likelihood of surface runoff containing bacteria and nitrate from animal yards or fertilized fields. Therefore, there's a plausible pathway for these two contaminants to co-occur. Additionally, according to an MDA study, there's generally a correlation between the presence of pesticide and nitrate in Minnesota groundwater (MDA, 2006).

4.0 APPLICABLE LAWS AND REGULATIONS

4.1 Federal

The Safe Drinking Water Act (SDWA) was originally passed by Congress in 1974 to protect public health by regulating the nation's public drinking water supply. The law was amended in 1986 and 1996 and requires many actions to protect drinking water and its sources, such as rivers, lakes, reservoirs, springs, and ground water wells. It's important to note the SDWA does not regulate private domestic groundwater wells which serve fewer than 25 individuals. SDWA authorizes the EPA to set national health-based standards for drinking water to protect against both naturally occurring and man-made contaminants that may be found in drinking water. The EPA, states, and water systems then work together to make sure that these standards are met.

EPA develops health-based rules and guidance to evaluate potential human health risks from exposures to chemicals in groundwater. Federal rules and standards include the following:

- EPA MCLs,
- EPA MCL Goals,
- EPA Health Advisories.

4.2 State

The "Minnesota Well Code", Minnesota Statutes, chapter 103I and Minnesota Rules, chapter 4725, sets standards for well and boring construction, sealing, and maintenance to protect groundwater quality and public health. MDH-licensed well and borings contractors must notify MDH or delegated well programs before they construct a new well. In Minnesota, a person or contractor who provides services to construct, repair, and seal regulated wells and borings must be licensed by the Minnesota Department of Health (MDH). MDH-licensed well contractors must notify MDH or delegated well programs before they construct a new well.

4.2.1 Minnesota Rules, Chapter 4725: Wells and Borings

The Minnesota Rules describe required licensing and registration for well contractors, required permits and notifications, construction, and use.

- 4725.3725: Treatment chemicals must meet the requirements of American National Standards Institute (ANSI)/NSF International (NSF) Standard 60 as determined by a person accredited by ANSI. Sodium or calcium hypochlorite may be used if registered by the EPA according to the Federal Insecticide, Fungicide, and Rodenticide Act, Section 3(c)(7)(A), as an antimicrobial pesticide for use in potable water. Treatment chemicals must be neutralized or removed from the well, boring, and any connected piping systems prior to use of the well or boring.
- 4725.4750: Materials used in construction of a private groundwater well that contact water must not exceed eight percent lead and solders and flux must not contain more than 0.2 percent lead.
- 4725.5650: A water sample must be collected within 30 days of construction and analyzed for total coliform bacteria, arsenic, and nitrate-nitrogen. The well owner must be informed that the well may not be used for human consumption until water samples indicate an absence of total coliform bacteria, and arsenic and nitrate-nitrogen analysis have been completed.

4.2.2 Minnesota Statutes, Chapter 103I: Wells, Borings, and Underground Uses

The Minnesota Statutes provide jurisdiction to the Commissioner of Health and local authorities, describe required well construction, sealing, and licensure.

- 103I.241: The property owner of a well may pursue civil damages against a person whose action or inaction caused well contamination up to six years after the owner becomes aware of the contamination.
- 103I.111: A political subdivision may adopt ordinances that are consistent with and more restrictive than standards in state law or rule.

4.2.3 Minnesota Statutes, Chapter 103H: Groundwater Protection

MDH develops health-based rules and guidance to evaluate potential human health risks from exposures to chemicals in groundwater. State rules and standards include the following:

- MDH HBVs: the concentration of a chemical (or a mixture of chemicals) that is likely to pose little or no risk to human health.
- MDH HRLs: The concentration of a chemical (or a mixture of chemicals) that is likely to pose little or no risk to human health. The limit is derived the same way a health-based value is but it is then promulgated.
- MDH Risk Assessment Advice (RAAs): The concentration of a chemical (or a mixture of chemicals) that is likely to pose little or no risk to human health, similar to HBVs or HRLs. RAAs are generally based on more limited information than HBVs and HRLs or use an alternative risk assessment method.

MDH develops its health-based guidance (HRLs, HBV, RAA) by considering health impacts to the most sensitive and most exposed populations across all stages of human development. Drinking water that is contaminated above the standard or guidance may pose some level of health risk to some people's drinking the water. The current HRLs and/or MDH recommendation for each contaminant will be utilized to compare the data for any of the selected alternatives. These standards should be considered the goal when any mitigation effort is implemented for a private well. The following table presents selected standards for the contaminants identified in **Section 3.0**:

COC	Basis for Lowest Criteria	Standards/Limit
Coliform bacteria	MDH Recommendation	ANY
Nitrate (as nitrogen)	HRL	10 milligrams per liter (mg/L)
Arsenic	MDH Recommendation	2 micrograms per liter (µg/L)
Lead	MDH Recommendation	ANY
Manganese	HRL	100 µg/L

4.3 Local

Local standards are also in place in some areas of the state; some counties and cities in Minnesota have assumed some of the responsibility for regulating well construction through a delegation agreement with MDH. Delegated well programs may have additional requirements beyond those in Minnesota laws and rules to account for complex geology or other well construction considerations, and some local requirements may be stricter. A construction or sealing permit is usually required by a delegated well program.

4.3.1 Southeast

- Blue Earth County – Ordinance Chapter 6, Article III Water Supply Wells: The Water Well Program requires permits for new wells, annual well maintenance permit, a well reconstruction permit, and a well sealing permit (no charge).
- Dakota County – Ordinance No. 114 Well and Water Supply Management. Dakota County offers a well seal grant. Dakota County reimburses the well owner 50% of the cost to seal the well up to $3,000.00. A permit is required for well construction, sealing, and annual maintenance. Annual permits are required for unused wells along with an explanation of why the well cannot be sealed. The Dakota County board may grant variances. Dakota County operates a database of locations where wells are permitted and not permitted in the Prairie du Chien aquifer.
    - Dakota County GIS Map
- Goodhue County – Water Quality Ordinance. A permit is required for groundwater well construction and abandonment.
- Olmstead Couty – Ordinance Chapter 3200 Water Well and Water Supply Ordinance. A permit is required for groundwater well construction, sealing, reconstruction. A maintenance permit is required for wells that are not sealed, operable, in use, or are disconnected from a power supply. Per county ordinance 3205.03, A notification is required before initiating well construction, when well casing is available for inspection, when pre-grout nitrate nitrogen test has been completed and results are within county nitrate nitrogen standards, when grouting the well casing begins, when the well is disinfected and ready to be sampled, prior to sealing. Water wells not in use must be sealed within three years. Groundwater permits include water supply well construction permit ($659), water supply well reconstruction construction permit, water supply well maintenance permit, water supply renewal fee maintenance permit, well sealing permit ($319), variance application. Exceptions to the Olmstead County Water Supply Ordinance may be permitted when individual property characteristics make ordinance adherence difficult, unreasonably expensive, or impractical. State surcharges apply for water well construction and water well sealing.
- Wabasha County – Water Quality Ordinance #26: A permit is required for groundwater well construction or sealing.
- Waseca County – Water Supply Well Ordinance: The well contractor is required to notify the well inspector when construction, reconstruction, or sealing will begin. Waseca County may provide comments and recommendations to the MDH on each variance request. All copies of MDH well records and water sample analysis reports are required to be submitted to Waseca County within 30 days of construction, reconstruction, or sealing. A maintenance permit is required for unused, unsealed wells.
- Winona County – Water Quality Ordinance #28: a permit is required for water well maintenance. A notification is required for well construction and well sealing.

4.3.2 Other Counties or Cities

- Le Sueur County – Water Supply Well Ordinance: A permit is required for groundwater well construction, sealing, and reconstruction. Le Sueur County may provide comments and recommendations to variances proposed to MDH.

- City of Minneapolis - Ordinance Chapter 48.260 Wells and Borings: Approval from the City of Minneapolis prior to private well construction or sealing is required. A well sealing notification is required. The City of Minneapolis allows variance requests upon approval of the State Commissioner of Health.
- City of Bloomington – Ordinance Chapter 15, Article VIII, Division D: A permit is required for groundwater well construction or sealing. Annual maintenance permits are required to be obtained and renewed for owners of water supply wells.

5.0 PRIVATE WELL MITIGATION IDENTIFICATION AND SCREENING PROCESS

Potential technologies for addressing contaminants in private wells were identified through conversations with the MDH as well as through research into common treatment options developed for the remediation of contaminated supply wells. Ongoing studies and historical data provided by MDH were also used to assist in identifying feasible technologies for treating impacted wells. Considerations of mitigation technologies included evaluating options for private well owners lacking electricity; however, options for those private well owners are limited with respect to the COCs evaluated in this document. **Table 1** presents summaries of the mitigation options for private wells drinking water.

A qualitative approach was used to screen treatment technologies using a ranking system where each treatment technology was evaluated on the criteria below. Ratings are based on achievement of criterion: low achievement, moderate achievement, and high achievement. More specific scoring is discussed below. Mitigation options identified in the research phase were screened against a set of criteria that are applicable regardless of which COC requires mitigation, including:

- Technology availability,
- Ease of installation,
- Convenience,
- O&M, including:
  - Life expectancy
  - Serviceability
  - Parts Availability
  - Waste generation
- Cost, including estimated 30-year costs, and
- Additional considerations such as well conditions, hydrogeology, and other environmental conditions.

Many mitigation treatment systems evaluated in this document can be installed either point-of-entry (POE), which treats all water entering the home, or point-of-use (POU), which is a smaller under-the-counter system that treats water at the specific faucet. POE systems are typically more complicated to install, have more daily treatment capacity, and are more expensive compared to POU systems. The installation, daily treatment volumes, and cost implications associated with POE systems vs POU should be considered on an individual well owner basis and their desired outcomes.

Screening results of mitigation options for each COC are presented in **Table 2A-E** and **Table 3A-E**. Effectiveness on specific COCs, protectiveness, and performance of the options are discussed in **Section 6.0** rather than being presented here as criteria are contaminant specific.

Technology availability, Installation and O&M: Technology availability is evaluated based on the vendor support across the State and how common each mitigation option is. Installation evaluates how easy a mitigation option would be to install in a home in general. If plumbing or electrical needs to be moved in some cases, this is taken into consideration. The operation and maintenance evaluation criteria looks at the life expectancy, serviceability, parts availability and waste products of each technology. It should be noted that any mitigation option that requires continued operation of a private well would also require operations and maintenance of the well. Scoring is assigned with a number (1–3), based on the achievement level, as defined below for each qualifier:

Technology Availability Scoring:

- 1 is assigned if the alternative water source, repair, or mitigation option is dependent on vendor availability.
- 2 is assigned if the option is mostly available throughout the State.
- 3 is assigned if the option is readily available throughout the State.

Ease of Installation Scoring:

- 1 is assigned if the alternative water source, repair, or mitigation option is difficult to install (professional installation needed).
- 2 is assigned if the option is moderately easy to install.
- 3 is assigned if the option is easy to install (most well owners can do this themselves).

Convenience Scoring:

- 1 is assigned if the option requires significant service requirements, frequent home visits by professionals or product deliveries, high electricity costs, or is difficult to use.
- 2 is assigned if the option requires moderate service requirements, occasional home visits by professionals or product deliveries, moderate electricity costs, or is moderately difficult to use.
- 3 is assigned if the option requires infrequent service, little to no visits by professionals or product deliveries, or requires little to no electricity usage

O&M Scoring:

- 1 is assigned if a high amount of maintenance is expected or is difficult to operate.
- 2 is assigned if a moderate amount of maintenance is anticipated or is moderately difficult to operate.
- 3 is assigned if a minimal amount of maintenance is estimated or is easy to operate.

Cost: Relative costs for mitigation options are based on estimates from providers across Minnesota. The general cost evaluation considered installation costs (as necessary) and any operation and/or maintenance costs for one year (unless otherwise stated). Capital cost and annual cost utilized the same scoring evaluations as defined below. Estimated 30-year costs are based on an extrapolation of capital costs, O&M cost, replacement costs based on estimated lifespan of the option, for a 30-year time period and does not account for inflation. Scoring is assigned with a number (1–3), based on the estimated cost:

Capital and Annual O&M Cost Scoring:

- 1 is assigned if the alternative water source, repair, or mitigation option is estimated to be greater than $5,000.
- 2 is assigned if the option is estimated to be between $1,000 and $5,000.
- 3 is assigned if the option is estimated to be less than $1,000.

Estimated 30-Year Cost Scoring:

- 1 is assigned if the 30-year cost for alternative water source, repair, or mitigation option is estimated to be greater than $50,000.
- 2 is assigned if the 30-year cost for option is estimated to be between $10,000 and $50,000.
- 3 is assigned if the 30-year cost for option is estimated to be less than $10,000.

Additional Considerations: This criterion addresses variability in well construction, hydrogeologic settings, and other environmental factors. Because these conditions can differ significantly, the criterion is not ranked but is intended to identify factors that should be evaluated when selecting an appropriate mitigation option.

The following sections describe the technologies that were screened using the ranking system.

5.1 Alternative Water Source

5.1.1 Bottled Water

One alternative water source option is the use of bottled water supplied by a commercial vendor. Bottled water provides a reliable and immediate means of obtaining safe drinking water; however, it can become costly over time and would require ongoing delivery. For purposes of this evaluation, equipment setup/rental, and one year of continued delivery is assumed.

Bottled Water Applicability				
Coliform Bacteria	Nitrate	Arsenic	Lead	Manganese
Yes	Yes	Yes	Yes	Yes

Technology Availability

Throughout Minnesota, vendors such as Culligan and Premium Waters can provide bottled water. Due to various vendors being available across the State, the ranking for availability is determined to be *Readily Available*.

Ease of installation

In most cases, the vendor would provide the rental cooler, and the bottles would be delivered by the vendor monthly. The equipment will be set up by the vendor once delivered; Ease of installation is ranked as *Easy*.

Convenience

Bottled water requires delivery to the well owner by the vendor on a routine or as needed basis. This often requires the well owner to be on site during delivery, typically during business hours, and to actively track, manage, and schedule deliveries. Additionally, bottled water delivery services may be limited in some parts of the State. As a result, the this mitigation option is dependent on reliable vendor service to maintain a drinking water supply and requires a high level of effort to manage delivery by the well owner. Adequate storage space is also needed for the water cooler unit and extra 5-gallon water bottles. Well owners may find that these items add clutter or are not aesthetically desirable within living areas and may be inconvenient for smaller homes. While operation of the rental cooler is easy, each bottle weighs approximately 45 pounds, making bottle change outs physically difficult for many users. Additionally, safe drinking water is limited only to the cooler location, Requiring well owners to move to that location for any water used in drinking or cooking. This increases the likelihood of accidental use of untreated tap water out of habit or by visitors who are unaware of the cooler. Overall, the convenience of bottled water is *low*.

Operations and maintenance

Life expectancy: Life expectancy of bottled water delivery does not apply; delivery would continue for as long as is necessary.

Serviceability: Serviceability depends on the vendors delivery setup, monthly delivery is typical.

Parts Availability: Parts needed to install and/or maintain a rental cooler for dispensing water are typically readily available.

Waste generation: There is no waste associated with bottled water, the used bottles would be collected and recycled by the vendor.

Overall, a high amount of maintenance is needed for bottled water due to monthly delivery requirements.

Cost

Per estimates from Culligan, bottled water delivery is estimated to cost $585 for a family of four annually. The estimated 30-year cost is $17,550.

Additional Considerations

Bottled water delivery services would require the well owner to be present for water deliveries on a routine basis, which may pose an issue for residents working outside the home. Other mitigation options do not require the well owner to be home on a routine basis.

5.1.2 New Well Installation

Another alternative water source option is installing a new drinking water supply well. A licensed driller would be contracted to install a new well per the Minnesota Well Code. Additionally, the existing well would require sealing by a licensed driller. While this approach requires higher upfront costs and regulatory approvals it offers a long-term, sustainable water source that reduces reliance on outside vendors.

New Well Applicability				
Coliform Bacteria	Nitrate	Arsenic	Lead	Manganese
Yes	Yes	No	No	No

Technology Availability

Licensed drillers are available throughout Minnesota. Although installing a new well would be dependent on the driller's schedule, most drillers have expansive mobilization zones. The ranking for availability is determined to be *Mostly Available*.

Ease of installation

A licensed driller is necessary to install a new well. Location and geology must be taken into consideration as well. A new well installation can take a long time to implement due to required permits, potential inspections, and water testing requirements. In addition, the existing well would need to be properly abandoned and sealed in accordance with state and local regulations.
A new well is rated *Moderate* to *Difficult* for ease of installation.

Convenience

Installation of a new well would require the private well owner to be on site during construction and connection of the well. Significant access and clear space are needed for drilling equipment, and access to the selected well location may be difficult for the contractor. The installation process can cause temporary disturbance to landscaping as well as increased noise and traffic at the property. However, once installed, the new well would supply safe drinking water to the entire household at high volumes and high flow rates, with only infrequent service and maintenance required. While the upfront installation process is relatively inconvenient and disruptive, the long-term use of a new well is highly convenient for the homeowner. Overall, the convenience of new well installation is *moderate*.

Operations and maintenance

Life expectancy: The overall life expectancy of a well is 25–50 years. Although the well shaft can last decades, components of the well system may need to be replaced sooner. The well pump typically lasts 8–15 years and the pressure tank lasts between 5–15 years. Factors affecting the well's lifespan include geological conditions, water quality, construction quality, and maintenance/upkeep.

Serviceability: Licensed well drillers are widely available throughout the state to provide new well installation service as well as maintenance.

Parts Availability: Parts needed to install and/or maintain a well are usually readily available.

Waste generation: The primary waste from the well installation would be drill cuttings, and wastewater. The amount of waste generated is highly dependent upon the depth and diameter of the well and the geology of the area that will be drilled.

Overall, a *moderate* amount of maintenance is needed for a new well; however, it should be noted that any mitigation option the requires continued operation of a private well would also require operations and maintenance of the well.

Cost

Per estimates from multiple contractors, new well installation is, on average, estimated to cost $20,000, and the cost of sealing of the existing well can cost between $3,000 and $6,500, depending on available well construction information; however, the cost of well installation and sealing varies significantly based on factors such as topography, geology, and ease of access. The estimated 30-year cost is $25,000, which does not include the cost of electricity.

Additional Considerations

Hydrogeology and aquifer characteristics:

- Aquifer type/depth, particularly consider whether it is a confined or unconfined aquifer.
- Ensure groundwater availability can sustain the demand, this includes considering recharge rates.
- Groundwater quality factors:
    - Consider potential naturally occurring contaminants in the area.
    - Review possible microbiological risks (such as coliform bacteria from surface infiltration).
    - Review water chemistry (pH, hardness, corrosivity, dissolved solids).
    - Check available current or historical laboratory results from nearby wells or sources.

Potential contamination sources:

- Review surrounding area for the following:
    - Septic systems and/or drain fields,
    - Agricultural land,
    - Industrial or commercial facilities, and
    - Landfills, waste sites or abandoned wells.

Geology and surface conditions:

- Determine soil's permeability.
- Determine potential for flooding or for surface water intrusion.

Environmental protection and land use regulations:

- Check for setback requirements in proposed well location.
- Check for protected natural areas nearby.
- Consider whether future development will affect water quality.

Climate and long-term sustainability:

- Consider how and if drought or seasonal variability could affect the recharge rate.
- Determine the fluctuation of the water table overtime.
- Determine how the well will impact the aquifer or nearby wells or surface water.

5.1.3 Connection to Public Water Supply

Another alternative water source option for the well owner is connecting to the public water supply. This option typically requires coordination with the local utilities and the installation of a service line from the residence to the municipal system. Connection fees and possible infrastructure costs would apply. If connected to the public water supply, the homeowner gains access to a reliable, regulated source of drinking water that is routinely monitored.

Public Water Applicability				
Coliform Bacteria	Nitrates	Arsenic	Lead	Manganese
Yes	Yes	Yes	Yes	No

Technology availability

There are not always readily available utility lines to connect to. Due to the variability, this is rated as *Dependent on Availability*.

Ease of installation

Since the connection to public water supplies is highly dependent upon location and vicinity to a public water supply and generally requires a significant amount of earth work for trenching and installation. In addition, the existing well would need to be properly abandoned and sealed in accordance with state and local regulations. The ease of installation is rated as *Moderate* to *Difficult*.

Convenience

Public water supply connection requires significant excavation and disturbance to a well owner's property and would require the well owner to be on site during connection. Once connected, the public water supply provides a continuous, reliable source of treated and tested water to the entire household with essentially no operational requirements for the homeowner. Although generally reliable, public water systems can experience occasional service outages or advisories. While the upfront installation process is inconvenient and disruptive, the long-term use of connecting to private water supply is highly convenient for the homeowner and can improve property value. Overall, the convenience of public water supply connection is *moderate*.

Operation and maintenance

Life expectancy: The overall life expectancy of connecting to a public water supply would be indefinite.

Serviceability: Public water supplies are serviced by the public water supply provider up to the property owner's connection, typically near the property boundary. Property owners are typically responsible for maintaining public water supply lines from the connection at the property boundary up to the point of entry in the home. Commercial plumbers are widely available to service the private portion of the public water supply line.

Parts Availability: Parts needed to install and/or maintain a connection to a public water supply should be mostly available, though requires significant earth work and contractors.

Waste generation: The primary waste from the hookup would be soil and construction materials generated during trenching and connection. The amount of waste generated is highly dependent upon the distance from the public water supply connection point to the home and the geology of the area that will be trenched; however, much of the soil removed for water supply line installation can be reused.

Once connected, a minimal amount of maintenance is needed for a public water supply connection.

Cost

Per estimates from the MDH Infrastructure Unit, connection to public water supply is estimated to cost, on average, $25,000. Monthly water service fees cost, on average, $30.00. Factors such as location, availability, and geology can greatly increase the cost for public water supply connection. For highly remote locations, if available, connection to public water supply can cost over $75,000, along with monthly water service fees of over $175.00. The estimated 30-year cost is $35,800 to $138,000.

Additional Considerations

Source water protection:

- Determine if the source water is in proximity to potential contamination sources, or whether there other water quality concerns that exist.
- Consider potential vulnerabilities in the source water watershed or aquifer such as a shallow aquifer or geology conducive to quick recharge.

Infrastructure and location:

- Distance to the closest existing water main.
- Soil and geology conditions could affect trenching and pipe installation.
- Topography such as sloping can complicate the route and/or pressure requirements.

Environmental impact of construction:

- Ensure no wetlands, streams, or protected habitats will be disturbed during pipeline installation.
- If possible avoid tree removal causing erosion and/or utilize sedimentation control during trenching.
- Account for restoration requirements needed after installation.

Water system capacity and sustainability:

- Consider the public system capacity to provide additional demand without stressing the source.

- Account for seasonal fluctuations in the water supply if they exist.

Regulatory and safety considerations:

- Ensure a cross connection control to prevent contamination of the public supply from the private plumbing is created.
- Properly abandon the old well if needed.

Community and environmental health:

- Consider equitable access to safe and reliable water.

5.2 Investigation/Repairs

5.2.1 Plumbing System Investigation

A plumbing system investigation can be conducted to determine whether lead is present in a home's water distribution system. This process typically includes reviewing as-built records to assess the likelihood of lead service lines or plumbing materials in the system. Property age is also taken into consideration. Physical inspection of visible piping would also be completed. The investigator may check pipe composition at the service connection, joints, and fixtures as well as evaluate solder and fittings that could contain lead. The EPA provides basic guidance to identify potential presence of lead-containing plumbing system components: Protect Your Tap: A Quick Check for Lead. It should be noted that this guidance does not help private well owners identify potentially lead containing components in private well pumps or well casings. In most cases, if lead-containing plumbing system components are identified, the recommendation is to contact a licensed plumber for additional investigation and/or replacement of lead components.

Plumbing System Investigation Applicability				
Coliform Bacteria	Nitrate	Arsenic	Lead	Manganese
No	No	No	Yes	No

Technology availability

Licensed plumbers and replacement plumbing supplies are widely available throughout Minnesota.

Ease of installation

A licensed plumber is necessary to investigate the system. The ease of the repair (if necessary) would depend on what the actual issue is. The investigation/repair is rated *moderate* for ease of installation.

Convenience

Plumbing system investigation requires the well owner to be on-site during the investigation and replacement of lead-containing elements, likely during business hours. Replacement of lead-containing elements of the water system may require excavation of underground lines, removal of the well pump, and access to internal areas of the household. Once complete, safe water is supplied to the entire household in unlimited amounts at high volumes and flow rates. Overall, the convenience of plumbing system investigation and repairs is *moderate to high*.

Operation and maintenance

Life expectancy: Removal of the lead pipe is considered a permanent solution and does not require additional operations and maintenance.

Serviceability: Licensed plumbers are widely available throughout the state to conduct the investigation and complete a repair (if needed).

Parts Availability: Parts needed are typically readily available.

Waste generation: The primary waste would be any pipe, fittings, or other components that would need to be replaced.

Once investigation and repairs are complete, no additional operations and maintenance is required to reduce/prevent lead contamination; therefore, a *minimal* amount of maintenance is needed.

Cost

Plumbing system investigation is estimated to cost, on average, $150.00 for the initial investigation and $5,000.00 to replace a lead service line. Costs may significantly increase if additional lead components are identified in the water supply system. The estimated 30-year cost is $150 - $5,000, which assumes lead components are identified and permanently removed.

Additional Considerations

The following water quality factors can influence whether lead from plumbing materials can dissolve into the water:

- Low pH increases corrosion potential.
- Soft water tends to be more corrosive.
- Low alkalinity can promote corrosion.
- Oxidation reduction potential can affect corrosion and lead solubility.
- Higher oxygen concentrations can accelerate corrosion.
- High concentrations of chloride and sulfate concentrations can increase corrosivity.
- Warmer water can enhance corrosion and lead release.

Plumbing system characteristics/age of the system:

- Lead solder in copper plumbing was commonly used prior to 1986.
- Brass or bronze fixtures may contain lead fixtures.
- Older systems are more likely to have lead components.
- Water residing in pipes for long periods of time can increase lead leaching.

Usage and exposure conditions:

- Low water use or longer periods of stagnation raise the risk.
- Hot water tends to dissolve more lead.

5.2.2 Well Repairs and Disinfection

Another option is having a licensed well contractor inspect and repair your well. Common repairs in wells are completed by a licensed well driller and include well cap repair/replacement, well casing repair/extension, grout/seal/packer repairs, piping, pitless adapter repairs, and/or wellhead protection measures (such as regrading land to divert runoff, improving drainage, or removing contamination sources located too close to the well). Per MDH, a well must be disinfected whenever it is opened for repairs; therefore, disinfection is coupled with a well repair option.

Well Repair and Disinfection Applicability				
Coliform Bacteria	Nitrate	Arsenic	Lead	Manganese
Yes	Yes	No	No	No

Technology Availability

Licensed drillers are available throughout Minnesota. Although scheduling well repairs would be dependent on the driller's schedule, most drillers have expansive mobilization zones. The ranking for availability is determined to be *Mostly Available*.

Ease of installation

A licensed driller is necessary to repair a well. The repairs that are necessary must be taken into consideration. Repairs to a well is rated *Moderate* to *Difficult* for ease of installation.

Convenience

Well repairs and disinfection require the well owner to be present on-site for activities completed by the licensed driller during business hours. The process can temporarily interrupt water use while the well is being repaired and disinfected, and follow-up sampling is often required to confirm successful treatment. However, once the repairs and disinfection are successfully completed , the well can provide safe water to the entire household at high volumes and flow rates with minimal ongoing intervention from the homeowner. Overall, the convenience of well repairs and disinfection is *moderate to high*.

Operations and maintenance

Life expectancy: The overall life expectancy of repairing a well system is highly dependent upon the current well age and what the repair is that is needed.

Serviceability: Licensed well drillers are widely available throughout the state to provide well repair services; however, the type of wells repairs required is highly dependent on the age and condition of the individual well, ranging from replacing damaged or corroded fittings to replacing or repairing well casings.

Parts Availability: Parts needed are typically readily available.

Waste generation: The primary waste would be any components that would need to be replaced.

Once repairs are complete, a *Moderate* amount of maintenance is needed for the repaired well; however, it should be noted that any mitigation option that requires continued operation of a private well would also require operations and maintenance of the well.

Cost

Well repair costs range, on average, from $150.00 for well cap replacement to $4,500.00 for full well casing replacement. In extreme cases where major rehabilitation is needed, well repairs can cost up to $20,000. The estimated 30-year cost is $17,150 to $55,000, assuming at least one $5,000 repair over 30 years.

Additional Considerations

Hydrogeologic setting:

- Consider whether the existing well still works within the current aquifer.

Soil and geology:

- The geology may limit repair techniques available.

Water quality:

- Consider current water quality of the aquifer, including any contaminants that may remain after repair.

Climate/seasonal factors:

- If freeze-thaw, or flooding damaged the well, determine if repairs can strengthen the well and withstand seasonal conditions.

Regulatory requirements:

- Ensure the repairs meet standards for rehabilitation and sanitary protection.

5.3 Mitigation

5.3.1 Disinfection

Disinfection of a water supply well is the process of treating the well and its distribution system to eliminate harmful microorganisms such as bacteria, viruses, and other pathogens that may be present. Chlorine is commonly used for disinfection; chlorine is introduced into the well and circulated throughout the system to ensure contact with all components including the well casing, pump, and plumbing lines. After contact, the system is flushed until chlorine is no longer detected. Chlorine test strips should be used to verify that water coming from the outside faucet or yard hydrant is free of any chlorine solution. Additional information on disinfecting a well is included on MDH's Well Disinfection pdf (MDH, 2019).

Disinfection Applicability				
Coliform Bacteria	Nitrate	Arsenic	Lead	Manganese
Yes	No	No	No	No

Technology availability

Supplies needed to disinfect a well, bleach, are *Readily Available* throughout Minnesota.

Ease of installation

Well disinfection instructions are provided by MDH; therefore, a homeowner can follow the instructions and disinfect the well themselves, or a licensed well contractor can be hired to do it. Disinfection of a well is rated Easy for ease of installation.

Convenience

Well disinfection can be completed by the well owner and procedures are readily available. Once complete, safe water is supplied to the entire household in unlimited amounts at high volumes and flow rates. Overall, the convenience of well disinfection is *high*.

Operation and maintenance

Life expectancy: MDH recommends testing for coliform bacteria annually, with disinfection completed based on those results. Disinfection should be completed following any coliform detection; it is also recommended to test between 2–4 weeks following disinfection to see if additional disinfection is needed.

Serviceability: Serviceability is possible throughout the state. If disinfection is completed by the well owner, bleach is readily available. If a licensed driller is needed for assistance, licensed well drillers are available throughout the state.

Parts Availability: Parts needed are readily available.

Waste generation: The primary waste would be the chlorinated water that is flushed from the system; MDH recommends not discharging chlorinated water into or near a septic system, onto landscaping, or any water bodies, since bleach solution will harm them.

Following disinfection, a *minimal* amount of maintenance is needed.

Cost

Disinfection of a private well is estimated to cost $275.00. Well owners can also purchase chlorine solution for $20.00 and perform the disinfection themselves. The estimated 30-year cost is $2,500 to $8,500.

Additional Considerations

Groundwater chemistry:

- High pH can reduce chlorines effectiveness; the typical pH of drinking water is between 6.50 and 8.5.
- Disinfection reactions occur more slowly in the cold water.
- Iron or manganese can react with chlorine and reduce effectiveness.
- Suspended particles can make disinfection less effective.

Hydrogeologic conditions:

- Chlorine can move more rapidly and may not contact all surfaces evenly if the geology is permeable.
- A shallow water table could yield a faster dilution or a loss of disinfectant.

Well construction/condition:

- Compromised integrity of the casing and the grout, like cracks, can allow disinfectants to escape.
- Well depth and diameter affect the chlorine dosage.
- Scale buildup in the well can reduce chlorine effectiveness.
- Ensure compatibility between materials (pump/plumbing),some materials can corrode or degrade when exposed to chlorine solutions.

Site and surrounding environmental conditions:

- Consider the proximity to any surface water, septic system, or possible contamination source.
- Heavy rain or freezing conditions can complicate disinfection.

Water system operating conditions:

- A stagnant well requires more contact time.
- Lines may require extended contact time or flushing if there is a storage/distribution component.

5.3.2 Reverse Osmosis

Reverse osmosis (RO) is a water treatment process that uses a semi-permeable membrane to remove dissolved salts, metals, microorganisms, and other contaminants from water. Under pressure water molecules pass through the membrane while impurities are left behind and flushed away as waste. RO systems are highly effective at reducing health related contaminants such as nitrates, lead, arsenic, and certain organic compounds; however, RO systems typically require routine maintenance including filter and membrane replacement. Specific to arsenic treatment, pre-oxidation treatment may be required to assist in converting trivalent arsenic to pentavalent arsenic prior to RO treatment. RO systems also produce a waste stream that must be managed.

Reverse Osmosis Applicability				
Coliform Bacteria	Nitrate	Arsenic	Lead	Manganese
No	Yes	Yes	Yes	Yes

Technology availability

Throughout Minnesota, vendors can provide RO systems. Due to various vendors being available across the State, the ranking for availability is determined to be *Readily Available*.

Ease of installation

In many cases, the well owner could install an under the sink system themselves if they have basic plumbing skills; professional installation is recommended for whole-house systems. Ease of installation is ranked as *Easy to Moderate*.

Convenience

Installation of an RO system requires the well owner to be on site for installation activities during business hours. RO systems are typically installed at the POU; therefore, safe water is only provided from one POU location in the household and at low to moderate volumes and flow rates, depending on storage tank size. If the storage tank is depleted, it can take several hours for treated water tank to fully recharge, and reduced water pressure may occur during this period. As a result, homeowners must plan water usage accordingly. RO units also require under-sink cabinet space for filters and storage tank, which may be inconvenient in homes with limited cabinet space. RO systems require occasional replacement of filters, which can be completed by the well owner. Overall, the convenience of RO is *moderate*.

Operation and maintenance

Life expectancy: Typical life expectancy of a reverse osmosis system is 10–15 years. Sediment filters and carbon filters should be replaced every 6–12 months. Sediment filters remove dirt and assist in preventing damage to other filters, carbon filters remove certain contaminants that will reduce membrane efficiency. The RO membrane lasts 2–5 years, but lifespan will vary based on water quality and if there are high concentrations of contaminants. The post-filter or polishing filter should be replaced every 12 months.

Serviceability: Serviceability, such as replacement of filters, is typically easy to complete by the homeowner. If professional help is needed, providers are mostly available throughout the state.

Parts Availability: Parts needed are usually readily available.

Waste generation: The primary waste would be the rejected water; a typical under-sink RO system produces four gallons of rejected water for every gallon of purified water. Rejected water is discharged to the sanitary sewer or septic system, which may reintroduce the contaminant to the environment through the septic drain field. RO filters/membranes also require disposal when replaced.

Following setup, a *Moderate* amount of maintenance is needed.

Cost

The cost of installing an under-sink RO system is around $1,250 for full installation of a system, storage tank, and faucet cutout. RO systems may require pre-treatment to maximize effectiveness, such as water softening, pre-oxidation, or iron filtration, depending on water quality conditions. Thes pre-treatment measures can add substantial costs, ranging from $80 to $280, requiring replacement every 6-12 months. The estimated 30-year cost is $8,500 to $33,500, assuming one replacement unit over 30 years.

Additional Considerations

Water quality:

- Pre- and or post-treatment needs will be impacted by the aquifer water quality, analytes to consider include dissolved solids, nitrates, arsenic, manganese, lead, iron, hardness, or bacteria.
- pH and alkalinity will affect membrane lifespans and scaling potential.
- High turbidity will clog RO membranes, sediment filtration is required.
- Colder water decreases RO efficiency.

Hydrogeologic conditions:

- Aquifer recharge rates can impact RO efficiency.
- Sudden drops in the water table could impact pump or system pressure.
- Hardness will require stronger pre-treatment.

Site and installation conditions:

- There are multiple components to an RO system including tanks and filters which require maintenance access.
- Discharge water must be properly disposed.
- The area should be properly ventilated and in a moisture-controlled location.

Wastewater management and environmental impact:

- Confirm that local regulations allow discharge to septic systems, storm drains, or surface infiltration.
- Consider soil permeability and drainage at discharge site.
- Concentrated reject water could affect soil and vegetation (salt accumulation potential).

Infrastructure and power conditions:

- Ensure there is sufficient/stable pressure to support membrane function.
- Ensure there is a power source for pumps and controls.
- Ensure the system is compatible with existing plumbing.

Regulatory and environmental compliance:

- Consider proximity to a local groundwater protection zone.
- Acquire necessary permits for discharge, if needed.

5.3.3 Anion Exchange

An anion exchange system uses a positively charged ion exchange resin to capture and remove negatively charged anions, such as nitrates and arsenic. The contaminated water flows through the resin bed and ions are exchanged for less harmful or desirable ions like hydroxide or chloride. When the resin becomes saturated, the resin is no longer effective and requires a regeneration process, usually with a brine or alkaline solution, to remove the captured anions and restore its capacity for future use.

Anion Exchange Applicability				
Coliform Bacteria	Nitrate	Arsenic	Lead	Manganese
No	Yes	Yes	No	No

Technology availability

This treatment system isn't readily available as it is mostly used for commercial or industrial facilities. Water service companies have bulk resin available for this technology; however, a company that would install a system for residential purposes has not been identified in Minnesota. The ranking for availability is considered low.

Ease of installation

In most cases, professional installation is recommended for an anion exchange system. Ease of installation is ranked as *Moderate*.

Convenience

Installation of an anion exchange system requires the well owner to be on site for installation activities during business hours. Anion exchange systems are typically installed at the POU; therefore, safe water is only provided from one POU location in the household, though it is provided at relatively high volumes and flow rates. Anion exchange systems require occasional replacement of media, which is typically completed by a professional service provider, which may not be readily available. Overall, the convenience of anion exchange is *low to moderate*.

Operation and maintenance

Life expectancy: Typical life expectancy of the resin in an anion exchange system is 4–8 years. Water quality, operating conditions, regeneration efficiency, and resin type can affect the lifespan and resin changeout frequency; therefore, annual water testing, at minimum, is required to determine when resin changeout is required.

Serviceability: Since residential anion exchange systems are not typical, service would be completed by a specialized professional.

Parts Availability: Commercial and industrial parts needed are usually readily available; however, since residential applications are less comment, parts may be more limited.

Waste generation: The primary waste would be spent resin and the regeneration wastewater.

Following setup, a *Minimal to Moderate* amount of maintenance is needed.

Cost

The cost of installing a water softener-style anion exchange system is around $2,000 for full installation of a system. Once resin is depleted, well owners will need to purchase more resin to maintain effective COC removal at an approximate cost of $550 – $900. The resin changeout frequency depends on water quality factors and COC concentrations. The estimated 30-year cost is $18,000 to $29,500.

Additional Considerations

Water quality and chemistry:

- Ensure the concentrations of specific anions (nitrate, arsenic, sulfate, PFAS, etc.) are within design limits for the resin.
- High concentrations of sulfate, chloride, etc. can reduce efficiency of nitrate or arsenic removal.
- High total dissolved solids can reduce exchange efficiency.
- The pH range for optimal performance is from 6–9.
- Is there iron, manganese, and/or organics? These can foul the resin and should be removed with pre-treatment prior to entering the exchange unit.

Hydrogeologic conditions:

- Consider the aquifer recharge rate.
- Colder water may reduce treatment efficiency.

Waste disposal and environmental impact:

- Determine if local regulations allow discharge to septic systems, storm drains, or surface infiltration.
- Consider soil permeability and drainage at discharge site.
- Concentrated regeneration water could affect soil and vegetation (salinization).

Infrastructure and space considerations:

- Ensure there is sufficient/stable pressure to support the system.
- Space for the resin tanks, brine tanks, and pre-treatment, post-treatment (if needed) are necessary.
- Ensure the system is compatible with existing plumbing.

Regulatory and environmental compliance:

- Determine if local groundwater protection zones exist nearby.
- Acquire any necessary permits needed for discharge.

5.3.4 Distillation

Distillation is a process of boiling well water and collecting the condensed steam to produce nearly pure water, effectively removing heavy metals, dissolved solids, bacteria, and viruses. A distiller heats the water, causing it to boil and turn it into steam. The steam rises and comes into contact with a cool surface, where it condenses back into liquid. The collected pure water drips into a collection container. While highly effective, it leaves the water with a "flat" taste due to the removal of natural minerals. It requires an appliance that may not be practical for all homeowners.

Distillation Applicability				
Coliform Bacteria	Nitrates	Arsenic	Lead	Manganese
No	Yes	Yes	Yes	Yes

Technology availability

Countertop treatment systems are available at most home improvement stores. The well owner should consider that these countertop systems require electricity and only produce six gallons of water per day. Larger units may be available with certain vendors; however, these solutions may be for commercial use. The ranking for availability is determined to be *Mostly Available*.

Ease of installation

The countertop units are simple to install, larger units may require professional installation. Ease of installation is ranked as *Easy to Moderate*.

Convenience

Distillation systems are typically standalone countertop units that require counter space and a nearby electrical connection. These systems require filling of the unit reservoir as needed by the well owner in relatively small quantities. Distillation systems produce treated water very slowly at a typical rate of six gallons per day. As a result, treated water availability is limited, and frequent refilling may be required to meet household needs. Drinking water taste may be objectionable and may require additives to replace mineral loss. Additionally, distillation units may generate noticeable heat and operational noise during use, which may be disruptive in living areas. Overall, the convenience of distillation is *very low*.

Operation and maintenance

Life expectancy: Smaller, well maintained water distillers can last 10–15 years or even longer with proper care. Periodic descaling and filter preplacement is necessary. Distillation systems require relatively high amounts of energy to operate and distillation systems produce drinkable water at a relatively slow rate.

Serviceability: Basic maintenance is relatively easy to complete by home owner. If professional help is needed, providers are mostly available throughout the state.

Parts Availability: Parts needed are usually readily available.

Waste generation: The primary waste would be the distiller concentrate or brine.

Following setup, a *Minimal to Moderate* amount of maintenance is needed. This includes descaling the distiller as well as replacing the activated carbon sachet filters.

Cost

Per estimates from contractors, the cost of a large water distiller with a capacity of 7–12 gallons is approximately $1,500. Well owners can also purchase smaller counter top water distillers with a capacity of 1–6 gallons at home improvement stores for $150.00. It is recommended to descale the distiller and replace the carbon filter media every 1–3 months. This can add a cost of $20.00 each year for replacement carbon filters. Distillation is an energy-intensive process and results in significantly more energy use compared to other mitigation options. Average monthly energy costs for distillation are approximately $80, assuming production of 4 gallons per day using a 750-watt water distiller at $0.15 per kilowatt hour. The estimated 30-year cost is $32,100 to $50,000, which includes electricity costs and assumes one replacement unit over 30 years.

Additional Considerations

Source water quality:

- High concentrations of total dissolved solids may increase scale formation in the boiling chamber.

- If volatile organic compounds are present, they may not effectively be removed without a vent or carbon filter.

Temperature and climate conditions:

- Colder environments may reduce condenser efficiency while hotter spaces can increase strain on the system.
- Proper ventilation is necessary.
- Protection from freeze potential is necessary.

Water source and supply characteristics:

- Cooler water may slow the distillation rate; warmer water will increase efficiency.
- Water pressure should be stable enough to supply water to the distiller as required.
- High sediment or high turbidity may require prefiltration to keep the integrity of the heating element.

Site and infrastructure conditions:

- Sufficient power should be available.
- Proper drainage for the brine water will have to be established.
- The installation location should be dry, level, well ventilated, and protected from dust pests, and temperature extremes.
- The system should be accessible for cleaning and servicing.

Environmental and regulatory considerations:

- Confirm that the system meet drinking water standards.
- Consider ensuring the system is energy efficient and sustainable.
- Acquire any necessary permits needed for wastewater discharge.

5.3.5 Adsorptive Media

Adsorptive media is a type of granular material used in a filter system to remove specific contaminants from the water. Water flows through a bed of the media, which has a large surface area that attracts and holds onto certain unwanted substances through a process called adsorption. Common types of adsorptive media are iron-based (iron oxide or ferric hydroxide), activated alumina (aluminum oxide), activated carbon (carbon filters are evaluated as a separate mitigation option), or zeolite (porous, natural mineral).

Adsorptive Media Applicability				
Coliform Bacteria	Nitrates	Arsenic	Lead	Manganese
No	No	Yes	No	No

Technology availability

The systems are *Readily Available* across the state.

Ease of installation

POU units are simple to install, larger units may require professional installation. Ease of installation is ranked as *Easy to Moderate*.

Convenience

Installation of an absorptive media system requires the well owner to be on site for installation activities during business hours. Absorptive media systems are typically installed at the POU; therefore, safe water is only provided from one POU location in the household, though it is provided at moderately high volumes and flow rates. Absorptive media systems require occasional replacement of filters, which can be completed by the well owner, and may require some under sink or countertop space for the unit. Overall, the convenience of absorptive media systems is *moderate*.

Operation and maintenance

Life expectancy: External components may last for years, the media would need to be replaced regularly to remain effective. Media replacement time is highly dependent upon contaminant level and type. It is recommended to monitor the water quality annually to confirm that the media is performing effectively.

Serviceability: Service, such as replacement of media filters, is typically easy to complete by well owners. If professional help is needed, providers are mostly available throughout the state.

Parts Availability: Parts needed are usually readily available.

Waste generation: The primary waste would be the exhausted media and wastewater from backwashing.

Following setup, a *Moderate* amount of maintenance is needed. Filter media should be replaced every 2–4 years depending on the type of media and water quality.

Cost

The cost of an Adsorptive Media filtration system ranges from $2,800 for a 4 gallon-per-minute (gpm) capacity system to $5,900 for a 10 gpm capacity system. This range only reflects the actual system unit cost and does not include installation and furnishing costs. Media will need to be replaced every 2–4 years depending on water quality. One cubic foot of arsenic filter media costs $1,470.00. The estimated 30-year cost is $11,800 to $36,000.

Additional Considerations

Source water quality:

- The media to be used will be dependent on the type and concentration of the contaminant.
- Iron, manganese, sulfate, phosphate or silica can interfere with adsorption capacity.
- Temperature affects adsorption and media lifespan.
- Excess solids can clog the media bed and reduce flow rates.

Hydrogeologic and well conditions:

- Water needs proper contact time in adsorption unit; therefore, the well yield and flow must be adequate to meet household demand.
- Seasonal variations could affect water consistency and treatment.
- Agricultural runoff or septic systems can introduce competing contaminants.
- Consider if there co-occurring metals or contaminant in the water.

Site and environmental setting:

- The system should be protected from temperature extremes.
- There should be adequate drainage and no risk of flooding.

- The system should be accessible for media replacement, sampling, and maintenance.

Operational and waste disposal considerations:

- Determine if the spent media is considered hazardous following treatment.
- Determine if the backwash water complies with wastewater/stormwater requirements.
- Sufficient power should be available.

Environmental protection and sustainability:

- The system should meet drinking water standards.
- Consider system energy efficiency and sustainability.

5.3.6 Carbon Filters

Carbon filters contain activated carbon, a material made from organic sources like coconut shells, coal, or wood that is processed to be highly porous. As water passes through the filter, contaminants are attracted to and are trapped in the pores through adsorption. One type of very common POU treatment systems are gravity-fed countertop carbon filtration systems, which do not require electricity; however, effective treatment of the COCs evaluated in this document is limited and requires specialized carbon filters that may not be available for gravity-fed systems.

Activation is crucial to the carbon functioning: the raw carbon is heated to burn off impurities, then it is superheated to 'activate' it (this process creates pores and increases the surface area.

Carbon Filter Applicability				
Coliform Bacteria	Nitrates	Arsenic	Lead	Manganese
No	No	No	Yes	No

Technology availability

The systems are *Readily Available* across the State. Gravity-fed carbon filtration systems can be found in most home improvement retailers.

Ease of installation

POU units are simple to install, larger units may require professional installation. Ease of installation is ranked as *Easy to Moderate*.

Convenience

Installation of a POU carbon filter system requires the well owner to be on site for installation activities during business hours. Carbon filter POU provides safe water from one POU location in the household, though it is provided at relatively high volumes and flow rates. Gravity fed carbon filter systems are filled on an as needed basis by the well owner in small quantities, and these systems process water at a relatively slow rate of approximately 2 to 3 gallons per hour. Carbon filter systems require occasional replacement of filters, which can be completed by the homeowner, and may require some under sink or countertop space for the unit. Overall, the convenience of carbon filter systems is *moderate to low*.

Operation and maintenance

Life expectancy: External components may last for years; the carbon media would need to be replaced regularly to remain effective. Carbon replacement time is highly dependent upon contaminant level and type. It is recommended to monitor the water quality annually to confirm that the carbon is performing effectively.

Serviceability: Service, such as replacement of carbon filters and backwashing, is typically easy to complete by well owners. If professional help is needed, providers are mostly available throughout the state.

Parts Availability: Parts needed are usually readily available.

Waste generation: The primary waste would be the exhausted carbon and wastewater from backwashing.

Following setup, a *Moderate* amount of maintenance is needed.

Cost

Gravity-fed home carbon filter systems rang in costs from $30 to $250. The cost to furnish and install a 90-pound granulated activated carbon filter is approximately $3,300.00. This includes the cost to furnish and install the system as well as the tubing and additional piping needed for a household. The estimated 30-year cost is $3,800 to $24,000.

Additional Considerations

Source water quality:

- If there are competing ions, such as iron, manganese, sulfate, phosphate or silica, these can interfere with adsorption capacity.
- The temperature can affect adsorption and media lifespan.
- If the water is turbid, excess solids can clog the media bed and reduce flow rates.

Hydrogeologic and well conditions:

- Water needs proper contact time in carbon filters, the well yield and flow needs to meet the household's demands.
- Seasonal variations can affect water consistency and how well the filters work.
- Nearby agricultural runoff or septic systems can introduce competing contaminants.
- Co-occurring metals or contaminants in the water can also compete with the filters' effectiveness.

Site and environmental setting:

- If the system is located outdoors, it must be protected from temperature extremes.
- The system needs to be set up away from any drainage or flooding risk.
- The system needs to be accessible for carbon replacement, sampling, and maintenance needs.

Operational and waste disposal considerations:

- The spent carbon should be sampled to ensure it is not considered hazardous following treatment.
- The backwash water should be sampled to ensure it complies with wastewater/stormwater requirements.
- Ensure there is sufficient power available for the system.

Environmental protection and sustainability:

- The water should be tested to ensure the system meets drinking water standards.
- Consider system energy efficiency and sustainability.

5.3.7 Oxidizing Media Filtration

Oxidizing media filtration is a water treatment method that converts dissolved contaminants like iron, manganese, and hydrogen sulfide into solid particles. A common oxidation/filtration process used in Minnesota is a Greensand filter. Greensand Plus is a catalytic media; manganese-coated green sand (Greensand Plus) is used to speed up the oxidation process. Following this oxidation process, the water now containing the solids passes through a filter media bed. The media traps the particles. The system periodically runs a backwash cycle to flush the particles and build up out.

Oxidizing Media Applicability				
Coliform Bacteria	Nitrates	Arsenic	Lead	Manganese
No	No	Yes	No	Yes

Technology availability

Greensand is *Mostly Available* throughout Minnesota. Some home improvement stores carry greensand filters. Local water quality contractors do not recommend greensand filters due to the likelihood of the greensand filter media staining basement floors and concrete foundations.

Ease of installation

Professional installation is highly recommended; this is rated as *Moderate* for ease of installation.

Convenience

Installation of an oxidizing media filtration system requires the well owner to be on site for installation activities during business hours. Oxidizing media systems, such as greensand filters, are typically installed at the POE; therefore, safe water is provided to the entire household at relatively high volumes and flow rates. Oxidizing media systems require occasional replacement of media, which can be completed by the well owner. Overall, the convenience of oxidizing media filtration systems is *moderate to high*.

Operation and maintenance

Life expectancy: Greensand filter media can last anywhere from 4 to 8 years; life expectancy depends on the usage and conditions. Replacement of the media is said to be fairly easy.

Serviceability: Service, such as replacement of greensand filters, is typically easy to complete by well owners. If professional help is needed, providers are mostly available throughout the state.

Parts Availability: Greensand filters are a relatively specialized component; however, external parts needed are mostly available.

Waste generation: The primary waste would be the exhausted media, the contaminant particles and wastewater from backwashing.

Following setup, a *Moderate* amount of maintenance is needed.

Cost

The cost of an oxidizing media filtration system ranges from $2,600 for a 1–3 bathroom household to $3,300 for a 3–6 bathroom household. This does not include the cost of installation and furnishing, although it is possible to install this system without a licensed plumber. Quotes were not provided by Minnesota plumbing service contractors due to the requirement of having a water quality test performed before a system can be selected and fitted. The estimated 30-year cost is $10,400 to $34,000, assuming one replacement unit over 30 years.

Additional Considerations

Source water quality:

- Pre-oxidation may be required if there are high concentrations of hydrogen sulfide.
- The pH should be between 6.8–8.0 for optimal for manganese removal.
- There must be adequate oxygen concentrations for the system to work properly.
- High turbidity may clog the media.

Hydrogeologic and well conditions:

- The well yield must be enough for sufficient backwashing.
- The temperature should be considered, cold water slows oxidation.
- Iron components in the well or plumbing can cause recontamination or oxidation within the system.

Site and environmental setting:

- There must be proper drainage for the backwash water containing oxidized metals.
- Consider the proximity to any surface water, wetlands, or possible contamination sources.
- There must be sufficient power for the system to run.
- Ensure the unit is protected from freezing conditions.

Regulatory and environmental compliance:

- The system should be tested to ensure it meets drinking water standards.
- Consider the system's energy efficiency and sustainability.

5.3.8 Ozonation & Filtration

Ozonation uses ozone, an oxidizing gas, to break down contaminants like iron, manganese, and bacteria, while filtration physically removes the resulting solid particles and other impurities from the water.

Ozonation & Filtration Applicability				
Coliform Bacteria	Nitrates	Arsenic	Lead	Manganese
No	No	No	No	Yes

Technology availability

There are a few water treatment companies across the State that can provide ozonation systems, availability is rated as *Mostly Available.*

Ease of installation

Professional installation is needed for installation. Ease of installation is ranked as *Moderate*.

Convenience

Installation of an ozonation and filtration system requires the well owner to be on site for installation activities during business hours. Ozonation and filtration systems are typically installed at the POU; therefore, safe water is provided only at that specific location in the household and at moderate volumes and flow rates. Ozone units produce low-level noise during operation, which may be noticeable and inconvenient depending on the installation location. Routine operation is simple, though the system requires periodic filter replacements, which can generally be completed by the homeowner. Overall, the convenience of ozonation and filtration is *moderate*.

Operation and maintenance

Life expectancy: The life expectancy for ozone generators are about 3–10 years; this varies significantly by manufacturer and quality of the equipment.

Serviceability: Service typically requires a professional.

Parts Availability: Parts needed are mostly available.

Waste generation: The primary waste would be the oxidized contaminant particles, the spent media, and the backwash water.

Following setup, a *moderate* amount of maintenance is needed. Check valves should be cleaned annually and filter media should be changed every 5–7 years.

Cost

The cost of an Ozone Backwashing filter is approximately $4,400.00 for a 10 gpm capacity filter. The estimated 30-year cost is $10,500 to $25,000, assuming one replacement unit over 30 years.

Additional Considerations

Water quality:

- Natural organic matter that may be present can react to ozone and form byproducts like bromate.
- The pH should be monitored to ensure it is neutral; high pH reduces ozone oxidation efficiency.
- Colder water holds ozone longer but slows reaction kinetics.
- If the water is turbid, excess sediment can overload filters and shield contaminants from oxidation.

Hydrogeologic conditions:

- The aquifer composition may affect the system's efficiency.
- Stable flow is necessary for consistent ozone contact time.
- Seasonal water fluctuations can affect contaminant concentrations and system sizing.

Site conditions:

- Location should be evaluated to ensure there is enough space for the system (ozone generation, contact tanks, filtration units) and ventilation.
- Ensure the system is protected from freezing conditions.
- There must be sufficient power for the system to run.
- Ensure there is proper drainage for discharge.
- Ozone can affect plumbing materials.

Environmental safety and byproduct management:

- Ensure there is off-gas control; ozone is a respiratory irritant.
- Monitoring is needed for byproduct formation (such as bromate, aldehydes, or other oxidation byproducts).
- Environmental regulations must be followed for media disposal; used media may accumulate metals or oxidized compounds.

Regulatory and ecological considerations:

- The installation must meet regulatory requirements.
- Nearby wetlands, surface waters or adjacent wells that may be impacted should be considered.

Maintenance and monitoring environment:

- Ensure the equipment is accessible for maintenance.
- Confirm there are pre- and post-treatment sampling locations to monitor the system.

5.3.9 Water Softening

A water softener removes the contaminant or minerals by adding salt. The salt (sodium chloride or potassium chloride) replaces the positively charged contaminant or minerals.

Water Softening Applicability				
Coliform Bacteria	Nitrates	Arsenic	Lead	Manganese
No	No	No	No	Yes

Technology availability

Water softeners are *Readily Available* across the state.

Ease of installation

Units are simple to install; larger units may require professional installation. Ease of installation is ranked as *Easy to Moderate*.

Convenience

Installation of a water softening system requires the well owner to be on site for installation activities during business hours. Water softening systems are typically installed at the POE, allowing the entire household to receive treated water at relatively high volumes and flow rates. Routine operation of the system is simple; however, the homeowner must periodically add salt to the tank. Handling standard 40-pound bags of salt can be difficult for some users. Overall, the convenience of water softening systems is *moderate to high*.

Operation and maintenance

Life expectancy: A water softener is expected to last 10–15 years; life expectancy depends on the water hardness, system efficiency and household usage. The brine tanks and salt concentrations should be checked monthly.

Serviceability: Serviceability by the homeowner, including adding salt and cleaning the brine tank are easy. If professional help being needed, providers are regularly available throughout state.

Parts Availability: Parts needed are readily available.

Waste generation: Waste from water softening systems is minimal.

Following setup, a *Moderate* amount of maintenance is needed.

Cost

The cost of water softening ranges from $2,000 to $5,000 depending on water quality and hardness. High iron concentrations in well water require additional filters which can increase costs. The estimated 30-year cost is $5,500 to $19,000.

Additional Considerations

Source water quality:

- Hardness levels will determine resin capacity and regeneration frequency.
- High levels of manganese (or iron) can foul the resin; pre-treatment may be required.
- Confirm there is enough pressure/flow for softener operation and backwash.
- Cold water can slow softening.

Site and drainage conditions:

- Ensure there is proper drainage for the regeneration of brine water.
- Consider the proximity to any surface water, septic system or possible contamination source.
- Confirm the equipment is clear of flood risks.

Disposal and environmental discharge:

- Ensure regeneration brine disposal will comply with local and state discharge regulations.
- Direct discharge to the ground surface, storm drains or septic systems should be avoided; can be harmful to groundwater or drain fields.
- Check if connection to a sanitary sewer or dedicated brine holding tanks is an option for discharging.

Equipment location and climate:

- The system should be in a temperature-controlled environment, avoid freezing.
- Ensure there is ventilation and access for maintenance.
- Confirm there is electricity available to power the system.

Hydrogeologic and environmental sensitivity:

- If there are any nearby wetlands lakes or streams, Care should be taken to prevent salt-rich discharge from reaching these.

5.3.10 Aeration & Filtration

Aeration is a pre-treatment process that introduces air into the well water to remove dissolved gases and oxidize dissolved metals. Air is forced through the water, which causes the dissolved gases and other volatile compounds to be released. The gas-infused air is then vented to the outside. For dissolved minerals, such as manganese, the aeration oxidizes them, causing them to convert from a dissolved state into a solid particle. After aeration, the water is sent through a filtration system to trap and remove the solid particles created during the aeration process. Common filtration methods are sediment filtration, iron filters, carbon filtration, reverse osmosis and/or water softeners.

Technology availability

A vendor that supplies aeration systems/equipment for residential hookup was not identified in Minnesota, because of this, the availability is rated as *Not Available*.

Ease of installation

Since a vendor could not be identified, this is not rated.

Convenience

Since a vendor could not be identified, this is not rated.

Operation and maintenance

Since a vendor could not be identified, this is not rated.

Cost

Cost estimates for residential hookup was not researched.

5.3.11 Continuous Chlorination

Continuous chlorination is a water treatment method where chlorine is added continuously to water as it flows through a plant or pipeline to disinfect it and provide a residual disinfectant throughout the distribution system. This method kills harmful microorganisms, oxidizes iron and manganese, and reduces odors, ensuring water quality from the treatment plant all the way to the consumer's tap. This technology is not applicable for residential use in Minnesota.

Technology availability

A vendor that supplies continuous chlorination equipment for residential hookup was not identified in Minnesota, because of this, the availability is rated as *Not Available*.

Ease of installation

Since a vendor could not be identified, this is not rated.

Convenience

Since a vendor could not be identified, this is not rated.

Operation and maintenance

Since a vendor could not be identified, this is not rated.

Cost

Cost estimates for residential hookup was not researched.

6.0 COMPARATIVE ANALYSIS BY CONTAMINANT

This section details the qualitative approach to evaluating the effectiveness, protectiveness, and performance of mitigation options, specific to each COC. Ratings are based on achievement of criterion: low achievement; moderate achievement; and high achievement. More specific scoring is discussed below.

Effectiveness is evaluated in terms of removal performance, reliability, and long-term studies completed on the mitigation method. Protectiveness is evaluated by how well a mitigation option reduces risk to human health and ensures the drinking water consistently meets drinking water criteria. Scoring is assigned with a number (1–3), based on the achievement level, as defined below for each qualifier:

<u>Effectiveness on COC Scoring:</u>

- 1 is assigned if the alternative water source, repair, or mitigation option is less effective at removing the subject contaminant.
- 2 is assigned if the option is moderately effective at removing the subject contaminant.
- 3 is assigned if the option is highly effective at removing the subject contaminant.

<u>Protectiveness and Performance Scoring:</u>

- 1 is assigned if the alternative water source, repair, or mitigation option provides a low achievement of protectiveness against the subject contaminant.
- 2 is assigned if the option provides a moderate achievement of protectiveness against the subject contaminant.
- 3 is assigned if the option provides a high achievement of protectiveness against the subject contaminant.

Table 1 presents the applicable mitigation options for each COC that were carried through for evaluation. Screening results of mitigation options for each COC are presented in **Table 2A-E** and **Table 3A-E**. **Table 4** presents the mitigation option scores for all options evaluated for each COC. The following sections present the mitigation screening evaluations for each COC, with higher score values indicating better performing options.

6.1 Coliform Bacteria

Alternative water sources, well repairs and mitigation options were evaluated as alternatives for use against coliform bacteria contamination in private supply wells. **Table 2A** presents the comparative analysis summary of alternatives evaluated for coliform bacteria. **Table 3A** presents numerical comparisons of the evaluated alternatives.

Exhibit 6-1
Coliform Bacteria Technology Screening Summary

Bottled Water	New Well	Public Water Supply	Well Repair & Disinfection	Disinfection
22	19	18.5	21	25.5

<u>6.1.1 Alternative Water Source – Bottled Water</u>

Effectiveness on contaminant of concern

Bottled water would be *Highly effective* at reducing coliform bacteria since this is removing the source risk.

Overall protectiveness and performance

Bottled water provides a *High Achievement* of protectiveness. Current good manufacturing practices (CGMPs) are Food and Drug Administration (FDA)-mandated regulations ensuring bottled water is safe and sanitary by requiring bottlers to process and bottled water under sanitary conditions, protect water sources from contaminants, use quality control processes for chemical and bacteriological safety, and conduct regular sampling and testing of water.

6.1.2 Alternative Water Source – New Well Installation

Effectiveness on contaminant of concern

A new well would be *Highly Effective* at reducing coliform bacteria. Wells installed in accordance with established Well Code greatly reduce the likelihood of bacteria contamination; however, there is still a possibility for bacteria to be introduced depending on what the source of the bacteria is.

Overall protectiveness and performance

A new well provides a *High Achievement* of protectiveness. A new well would be installed according to the MN Well Code, ensuring the well would not have a high exposure to bacteria.

6.1.3 Alternative Water Source – Public Water Supply Connection

Effectiveness on contaminant of concern

A public water supply connection is Highly Effective at reducing coliform bacteria; there is a possibility for bacteria to be found in public water supplies; however, testing and monitoring efforts make the presence of bacteria less likely.

Overall protectiveness and performance

A public water supply connection provides a *High Achievement* of protectiveness. Public water supplies can have bacteria exposure if contamination occurs, but they are generally safe due to treatment processes like chlorination. Bacteria can enter the system through breaks in pipes, during repairs, or by growing in stagnant water inside homes.

6.1.4 Investigation/Repairs – Well Repairs And Disinfection

Effectiveness on contaminant of concern

Well repairs are *Highly Effective* at reducing the coliform bacteria; following well repairs, disinfection is needed to flush the well/system of any residual bacteria.

Overall protectiveness and performance

Well repairs would provide a *High Achievement* of protectiveness. Regardless of repairs, if the well is still subject to flooding or agricultural runoff, there is still a potential for bacteria to be reintroduced to the repaired well.

6.1.5 Mitigation – Disinfection

Effectiveness on contaminant of concern

Disinfection is *Moderately to Highly Effective* at reducing coliform bacteria from a well when done properly. Disinfectants offer strong protection against most bacteria by destroying them on inanimate surfaces, but their effectiveness is not absolute.

Overall protectiveness and performance

Disinfection provides a *Moderate Achievement* of protectiveness. The level of protection depends on the type of bacteria, the disinfectant's chemical properties, and correct application.

6.1.6 Technology Screening Results Summary

Estimated costs of each alternative are discussed in **Section 5.0**. **Table 2A** and **Table 3A** document the alternative screening process and results for coliform bacteria. The following options were determined to be the most cost-effective, effective for mitigating coliform bacteria, protective, and available in Minnesota:

- **Disinfection** scored highest for mitigating coliform bacteria. Disinfection may not be a permanent solution for a well owner as root problem of the bacteria may not be solved; however, disinfection is easy to implement and cost effective. Note that this mitigation option does not mitigate nitrates, which is a common co-contaminant.
- **Bottled water** scored second highest for mitigating coliform bacteria; however, bottled water should be considered a temporary solution. This mitigation option does also mitigate nitrates.
- **Well repairs and disinfection** are the next best option for mitigating coliform bacteria. Well repairs in most cases would be more feasible than connecting to a public water supply. This mitigation option may also mitigate nitrates.
- **Public water supply connections** scored the second lowest for mitigating coliform bacteria. Although a public water supply connection would provide a high protection against bacteria, public water supply connections are expensive and highly dependent on the building location with respect to the available connection. This mitigation option does also mitigate nitrates.
- A **new well installation** scored the lowest of the evaluated alternatives but should still be considered if the other options have been ruled out. This mitigation option may also mitigate nitrates.

6.2 Nitrates

Alternative water sources, well repairs and mitigation options were evaluated as alternatives for use against nitrate contamination in private supply wells. **Table 2B** presents the comparative analysis summary of alternatives evaluated for nitrates. **Table 3B** presents numerical comparisons of the evaluated alternatives.

Exhibit 6-2
Nitrate Technology Screening Summary

Bottled Water	New Well	Public Water Supply	Well Repair & Disinfection	Reverse Osmosis	Anion Exchange	Distillation
22	17.5	18	18.5	23	20.5	20

6.2.1 Alternative Water Source – Bottled Water

Effectiveness on contaminant of concern

Bottled water is *Highly Effective* at reducing nitrates. This rating is given because the source risk is removed.

Overall protectiveness and performance

Bottled water provides a *High Achievement* of protectiveness. CGMPs are FDA-mandated regulations ensuring bottled water is safe and sanitary by requiring bottlers to process and bottled water under sanitary conditions, protect water sources from contaminants, use quality control processes for chemical and bacteriological safety, and conduct regular sampling and testing of water.

6.2.2 Alternative Water Source – New Well Installation

Effectiveness on contaminant of concern

A new well built to code is *Moderately Effective* at reducing nitrates; it's crucial to identify a nitrate-free aquifer or eliminate the source of nitrate contamination first.

Overall protectiveness and performance

Provides a *Moderate* to *High Achievement* of protectiveness. A new well would be installed according to the MN Well Code, ensuring the well would not have a high exposure to nitrates; however, accessible nitrate-free aquifers may not be available in some portions of the State, such as areas in southeast Minnesota.

6.2.3 Alternative Water Source – Public Water Supply Connection

Effectiveness on contaminant of concern

A public water supply connection is *Highly Effective* at reducing nitrates; testing and monitoring efforts ensure nitrates are not present at unsafe levels in public water supplies.

Overall protectiveness and performance

A public water supply would provide a *High Achievement* of protectiveness as the water would be monitored.

6.2.4 Investigation/Repairs – Well Repairs and Disinfection

Effectiveness on contaminant of concern

Well repairs are *Moderately to Highly Effective* at reducing nitrates, assuming the target aquifer is not contaminated. Old or damaged wells are more susceptible to contamination; necessary repairs would eliminate this risk.

Overall protectiveness and performance

Well repairs provide a *Moderate Achievement* of protectiveness. Regardless of repairs, if the well is still subject to flooding or agricultural runoff, there is still a potential for nitrates to be re-introduced to the repaired well or target aquifer.

6.2.5 Mitigation – Reverse Osmosis

Effectiveness on contaminant of concern

RO is *Highly Effective* at reducing nitrates. RO forces water under pressure through a semi-permeable membrane with microscopic pores that block dissolved ions like nitrate from passing through, leaving behind the contaminants (Fresh Water Systems, 2020).

Overall protectiveness and performance

RO provides a *High Achievement* of protectiveness. RO can remove anywhere from 83–92% of nitrates (Fresh Water Systems, 2020).

6.2.6 Mitigation – Anion Exchange

Effectiveness on contaminant of concern

Anion exchange is *Highly Effective* at reducing nitrates. Positively charged resin beads attract negatively charged nitrate ions from water, effectively exchanging them for other ions like chloride (Aqua Energy Expo, 2025).

Overall protectiveness and performance

Anion exchange provides a *High Achievement* of protectiveness. Ion exchange can remove more than 90% of the nitrates (Wastewater Digest, 2003).

6.2.7 Mitigation – Distillation

Effectiveness on contaminant of concern

Distillation is *Highly Effective* at reducing nitrates. Nitrates are non-volatile and have a higher boiling point than water and do not vaporize with it.

Overall protectiveness and performance

Distillation provides a *High Achievement* of protectiveness. Distillation units are capable of removing nitrates from the treated water (University of Nebraska-Lincoln, 2013).

6.2.8 Technology Screening Results Summary

Estimated costs of each alternative are discussed in **Section 5.0**. **Table 2B** and **Table 3B** document the alternative screening process and results for nitrates. The following options were determined to be the most cost-effective, effective for mitigating nitrates, protective, and available in Minnesota:

- **Bottled water** scored highest for mitigating nitrates; however, bottled should be considered a temporary solution. For a more permanent solution, the remaining options should be considered. This mitigation option does also mitigate coliform bacteria, which is a common co-contaminant.
- **Reverse osmosis** scored second highest for mitigating nitrates. Reverse osmosis is readily available from water treatment providers. This mitigation option does not mitigate coliform bacteria.
- **Anion exchange** scored next highest for nitrate mitigation. Water service companies have bulk resin available for this technology; however, availability of providers that would install a system for residential purposes in Minnesota may be very limited. This mitigation option does not mitigate coliform bacteria, which is a common co-contaminant.
- **Distillation** scored next highest for mitigating nitrates due to slow and limited water production as well as high energy consumption. This mitigation option does also mitigate coliform bacteria.
- **Public water supply connections, well repairs and disinfection,** and **new well installations** are the next best options for mitigating nitrates. Although a public water supply connection would provide a high protection against nitrates, public water supply

connections are expensive and highly dependent on the building location with respect to the closest available connection. Well repairs in most cases would be more feasible but may not address nitrate contamination. Installation of a new well may be highly effective; however, a nitrate-free aquifer must be available and up-front costs for installation of a new are significantly higher than other mitigation options. These mitigation options do also mitigate coliform bacteria.

6.3 Arsenic

Alternative water sources and mitigation options were evaluated as alternatives for use against arsenic contamination in private supply wells. **Table 2C** presents the comparative analysis summary of alternatives evaluated for arsenic. **Table 3C** presents numerical comparisons of the evaluated alternatives.

Exhibit 6-3
Arsenic Technology Screening Summary

Bottled Water	Public Water Supply	Reverse Osmosis	Anion Exchange	Distillation	Absorptive Media	Oxidizing Media Filtration
22	18.5	22	18.5	20	21	19.5

6.3.1 Alternative Water Source – Bottled Water

Effectiveness on contaminant of concern

Bottled Water is *Highly Effective* at reducing arsenic. This rating is given because the source risk is removed.

Overall protectiveness and performance

Bottled water provides a *High Achievement* of protectiveness. CGMPs are FDA-mandated regulations ensuring bottled water is safe and sanitary by requiring bottlers to process and bottled water under sanitary conditions, protect water sources from contaminants, use quality control processes for chemical and bacteriological safety, and conduct regular sampling and testing of water.

6.3.2 Alternative Water Source – Public Water Supply Connection

Effectiveness on contaminant of concern

A public water supply connection is *Highly Effective* at reducing arsenic; testing and monitoring efforts ensure arsenic is not present at unsafe levels in public water supplies.

Overall protectiveness and performance

A public water supply connection would provide a *High Achievement* of protectiveness because the water is monitored and tested frequently.

6.3.3 Mitigation – Reverse Osmosis

Effectiveness on contaminant of concern

RO is *Highly Effective* at removing pentavalent arsenic but is less effective at removing trivalent arsenic, unless pre-oxidation pretreatment is implemented. Pre-oxidation treatment assists in converting trivalent arsenic to pentavalent arsenic prior to treatment via RO; however, this pre-treatment step increases the cost of installation.

Overall protectiveness and performance

RO provides a *High Achievement* of protectiveness. Several reports have evaluated the effectiveness of point-of-use RO filtration units in laboratory settings or in formal field-testing programs and have reported that these filters can reduce arsenic concentrations by up to 80% to 99% (Ward, M. H., et al., 2018).

6.3.4 Mitigation – Distillation

Effectiveness on contaminant of concern

Distillation is ‘highly effective’ at reducing trivalent arsenic and pentavalent arsenic. Non-volatile contaminants like arsenic are left behind in the boiling chamber.

Overall protectiveness and performance

Provides a *High Achievement* of protectiveness. Distillation units are capable of removing virtually all arsenic from the treated water.

6.3.5 Mitigation – Adsorptive Media

Effectiveness on contaminant of concern

Adsorptive media is *Highly Effective* at removing pentavalent arsenic but is *Less Effective* at removing trivalent arsenic. Pre-oxidation treatment may assist in converting trivalent arsenic to pentavalent arsenic prior to treatment via adsorptive media.

Overall protectiveness and performance

Adsorptive media would provide a *High Achievement* of protectiveness when properly selected, installed, and maintained.

6.3.6 Mitigation – Oxidizing Media Filtration

Effectiveness on contaminant of concern

Oxidizing Media Filtration is *Moderately Effective* at removing pentavalent arsenic but is *Less Effective* at removing trivalent arsenic. Oxidizing Media Filtration effectiveness is improved when iron concentrations in water are relatively high and arsenic concentrations are relatively low. Pre-oxidation treatment is usually required to convert trivalent arsenic to pentavalent arsenic prior to treatment.

Overall protectiveness and performance

Adsorptive media would provide a *Moderate Achievement* of protectiveness requiring optimal conditions and pretreatment to achieve optimal performance.

6.3.7 Mitigation – Anion Exchange

Effectiveness on contaminant of concern

Anion exchange is *Highly Effective* at removing pentavalent arsenic but is *Not Effective* for removing trivalent arsenic. To use anion exchange for complete arsenic removal, any trivalent arsenic present must first be oxidized to pentavalent arsenic.

Overall protectiveness and performance

Provides a *Moderate to High Achievement* of protectiveness, reliability is heavily influenced by the water's chemical characteristics.

6.3.8 Technology Screening Results Summary

Estimated costs of each alternative are discussed in **Section 5.0. Table 2C** and **Table 3C** document the alternative screening process and results for arsenic. The following options were determined to be the most cost-effective, effective for mitigating arsenic, protective and available in Minnesota:

- **Bottled water** scored highest for mitigating arsenic; however, bottled water should be considered a temporary solution. This mitigation option does also mitigate manganese, which is a common co-contaminant.
- **Reverse osmosis** scored second highest for mitigating arsenic, systems are more readily available from water treatment providers across the State. If trivalent arsenic is in the water, pre-oxidation would be required, which would add to the cost. This mitigation option does also mitigate manganese.
- **Adsorptive media** scored third highest for mitigating arsenic. If trivalent arsenic is present, pre-oxidation would be required to convert the trivalent arsenic to pentavalent arsenic. This mitigation option may not mitigate manganese.
- **Distillation** scored the fourth highest due to slow and limited water production as well as high energy consumption. This mitigation option does also mitigate manganese.
- **Oxidizing media filtration** scored fifth highest as it requires optimal concentrations of both arsenic (must be relatively low) and iron (must be relatively high) to be effective.
- **Public water supply connection and anion exchange** are ranked last for mitigating arsenic. Although a public water supply connection would provide a high protection against arsenic, public water supply connections are expensive and highly dependent on the building location with respect to an available connection. Anion exchange water service companies have bulk resin available for this technology; however, availability of providers that would install a system for residential purposes in Minnesota may be very limited. A public water supply connection does also mitigate manganese; however, anion exchange does not mitigate manganese.

6.4 Lead

Alternative water sources, investigation, and mitigation options were evaluated as alternatives for use against lead contamination in private supply wells. **Table 2D** presents the comparative analysis summary of alternatives evaluated for lead. **Table 3D** presents numerical comparisons of the evaluated alternatives.

Exhibit 6-4
Lead Technology Screening Summary

Bottled Water	Public Water Supply	Plumbing System Investigation	Reverse Osmosis	Distillation	Carbon Filters
22	18.5	24.5	23	20	22

6.4.1 Alternative Water Source – Bottled Water

Effectiveness on contaminant of concern

Bottled water is *Highly Effective* at reducing lead. This rating is given because the source risk is removed.

Overall protectiveness and performance

Bottled water provides a *High Achievement* of protectiveness. CGMPs are FDA-mandated regulations ensuring bottled water is safe and sanitary by requiring bottlers to process and bottled water under sanitary conditions, protect water sources from contaminants, use quality control processes for chemical and bacteriological safety, and conduct regular sampling and testing of water.

6.4.2 Alternative Water Source – Public Water Supply Connection

Effectiveness on contaminant of concern

A public water supply connection is *Highly Effective* at reducing lead; testing and monitoring efforts ensure lead are not present at unsafe levels in public water supplies. The plumbing system would still need to be investigated to rule out any lead contamination coming from within the home's system.

Overall protectiveness and performance

A public water supply provides a *High Achievement* of protectiveness against lead because it is monitored and tested frequently.

6.4.3 Investigation/Repairs – Plumbing System Investigation

Effectiveness on contaminant of concern

This would be *Highly Effective*; once the lead component is located, the system could be upgraded to remove the lead exposure from the system.

Overall protectiveness and performance

This would provide a high achievement of protectiveness once the lead component is located and removed.

6.4.4 Mitigation – Carbon Filters

Effectiveness on contaminant of concern

Carbon filters are *Highly Effective* at removing lead through adsorption; however, not all filters are designed to remove lead; a specific micron size is required (RTI International). Gravity-fed countertop filtration systems are unlikely to provide required micron size filter.

Overall protectiveness and performance

A certified carbon filter that meets ANSI/NSF Standard 53 can be *Highly Protective* against lead contamination. Gravity-fed countertop filtration systems are unlikely to provide required ANSI/NSF Standard 53 filter.

6.4.5 Mitigation – Reverse Osmosis

Effectiveness on contaminant of concern

Reverse osmosis is *Highly Effective* at removing lead. An RO system's semipermeable membrane has extremely tiny pores that physically block lead particles and dissolved ions from passing through while allowing water molecules to go through (ESP Water, 2025).

Overall protectiveness and performance

RO would provide a high achievement of protectiveness. Independent studies and field applications show that RO can remove up to 95–99% of lead from contaminated water (AMPAC, 2025).

6.4.6 Mitigation – Distillation

Effectiveness on contaminant of concern

Distillation is *Highly Effective* at reducing lead. Non-volatile contaminants like lead are left behind in the boiling chamber.

Overall protectiveness and performance

Provides a high achievement of protectiveness. Lead's boiling point is extremely high (3,180°F), so it is left behind as a solid residue in the boiling chamber.

6.4.7 Technology Screening Results Summary

Estimated costs of each alternative are discussed in **Section 5.0. Table 2D** and **Table 3D** document the alternative screening process and results for lead. The following options were determined to be the most cost-effective, effective for mitigating lead, protective and available in Minnesota:

- **Bottled water** scored highest for mitigating lead; however, bottled water should be considered a temporary solution.
- **Plumbing system investigation** scored second highest for mitigating lead. Removal of lead-containing elements in the drinking water system would eliminate the source of lead contamination permanently.
- **Reverse osmosis** scored third highest for mitigating nitrates. Reverse osmosis is readily available from water treatment providers.
- **Carbon filters** scored fourth highest for mitigating lead; carbon filters are readily available from most water treatment vendors across the State. Initial installation is a bit higher than some other mitigation options.
- **Distillation** scored fifth highest due to slow and limited water production as well as high energy consumption.
- **Public water supply connections** scored the lowest for mitigating lead. Although a public water supply connection would provide a high protection against lead, public water supply connections are expensive and highly dependent on the building location with respect to an available connection. Additionally, lead-containing components in the home's plumbing system would still need to be removed to eliminate lead hazards.

6.5 Manganese

Alternative water sources and mitigation options were evaluated as alternatives for use against manganese contamination in private supply wells; however, it should be noted that at the time of publishing this document, none of the mitigation options evaluated in this document certified for manganese treatment. **Table 2E** presents the comparative analysis summary of alternatives evaluated for manganese. **Table 3E** presents numerical comparisons of the evaluated alternatives.

Exhibit 6-5
Manganese Technology Screening Summary

Bottled Water	Reverse Osmosis	Distillation	Ozonation & Filtration	Oxidizing Media Filtration	Water Softening
22	22	20	20.5	21.5	21.5

6.5.1 Alternative Water Source – Bottled Water

Effectiveness on contaminant of concern

Bottled water is *Highly Effective* at reducing manganese. This rating is given because the source risk is removed.

Overall protectiveness and performance

Bottled water provides a high achievement of protectiveness. CGMPs are FDA-mandated regulations ensuring bottled water is safe and sanitary by requiring bottlers to process and bottled water under sanitary conditions, protect water sources from contaminants, use quality control processes for chemical and bacteriological safety, and conduct regular sampling and testing of water.

6.5.2 Mitigation – Reverse Osmosis

Effectiveness on contaminant of concern

Reverse osmosis is *Moderately Effective* at removing low levels of manganese.

Overall protectiveness and performance

RO provides a *High Achievement* of protectiveness. More than 90% of manganese can be removed with RO. However, this method shouldn't be used for treating high levels of manganese, as too much manganese blocks and damages the membrane.

6.5.3 Mitigation – Water Softening

Effectiveness on contaminant of concern

Water softening is *Moderately Effective* at removing dissolved manganese. Optimal results require specific water conditions such as low concentrations of dissolved oxygen and pH above 6.7.

Overall protectiveness and performance

Provides a *Moderate Achievement* of protectiveness because manganese needs to be dissolved and levels must be low. Oxidized manganese can damage the softener.

6.5.4 Mitigation – Distillation

Effectiveness on contaminant of concern

Distillation is *Highly Effective* at reducing manganese. Non-volatile contaminants like manganese are left behind in the boiling chamber.

Overall protectiveness and performance

Distillation provides a *High Achievement* of protectiveness. Manganese's boiling point is extremely high (3,742°F), so it is left behind as a solid residue in the boiling chamber.

6.5.5 Mitigation – Oxidizing Media Filtration

Effectiveness on contaminant of concern

Oxidizing media filtration is *Highly Effective* at reducing manganese. Oxidizing media filtration first converts dissolved manganese into an insoluble, solid form through oxidation; the solids are then physically trapped by the filter media (PennState Extension, 2025).

Overall protectiveness and performance

This option would provide a *High Achievement* of protectiveness. Can be limited by several factors, including the incoming manganese concentration, water chemistry (especially pH), temperature, and the specific filter media and oxidant used.

6.5.6 Mitigation – Ozonation and Filtration

Effectiveness on contaminant of concern

Ozonation & filtration is *Highly Effective* at reducing manganese. Ozone oxidizes dissolved manganese; the solids are then trapped in the filter.

Overall protectiveness and performance

A well designed and properly operated system provides a *High Achievement* of protectiveness.

6.5.7 Technology Screening Results Summary

Estimated costs of each alternative are discussed in **Section 5.0. Table 2E** and **Table 3E** document the alternative screening process and results for manganese. The following options were determined to be the most cost-effective, effective for mitigating manganese, protective and available in Minnesota:

- **Bottled water** scored highest for mitigating manganese; however, bottled water should be considered a temporary solution. This mitigation option does also mitigate arsenic, which is a common co-contaminant.
- **Reverse osmosis** scored second for mitigating manganese. RO systems are usually readily available for installation across the state and provide a high protection against manganese. This mitigation option does also mitigate arsenic.
- **Oxidizing media filtration** scored third highest for mitigating manganese. Oxidizing media is not as readily available as an RO system would be in Minnesota. This mitigation option does not mitigate arsenic.
- **Water softening** and **ozonation and filtration** fourth highest for mitigating manganese. Water softening is ranked as moderately effective against manganese. The

installation/capital cost for ozonation and filtration is a bit higher than some other mitigation options. These mitigation options do not mitigate arsenic.

- **Distillation** scored second lowest for mitigating manganese due to slow and limited water production as well as high energy consumption. This mitigation option does also mitigate arsenic.

7.0 CONSIDERATIONS

The purpose of this Cost-Benefit Analysis was to identify and evaluate mitigation options for private well owners to address drinking water contaminated with five COCs identified by MDH. This analysis is intended to improve understanding of the actual costs of mitigating these contaminants on a per-well basis and to identify the most effective mitigation options under a range of scenarios. However, the following factors should be considered when evaluating the scalability, feasibility, and costs of implementing a statewide mitigation program:

- **Effectiveness for contaminant reduction:** The effectiveness of any mitigation option is highly dependent on the specific water chemistry of the well being treated. This variability should not be overlooked, and a comprehensive water chemistry evaluation should be incorporated into any state-funded program.
- **Overall protectiveness and performance:** Similar to treatment effectiveness, the protectiveness and performance of mitigation options depend on site-specific water chemistry and long-term operations and maintenance (O&M). Well owners must understand how each mitigation option functions and under what conditions it provides optimal protection.
- **Technology availability:** Availability of mitigation technologies may vary by geographic location, with remote areas potentially being the most difficult to serve. Economic considerations also influence availability, including the well owner’s ability to obtain replacement parts and manage ongoing operational costs.
- **Ease of installation:** Installation complexity varies widely among the mitigation options evaluated. Well owners should understand installation requirements, recognizing that individual comfort levels and technical abilities may affect implementation feasibility.
- **Convenience:** Convenience is subjective, and perceptions of ease of use will vary among well owners. To support informed decision-making and encourage long-term adoption of mitigation systems, targeted education and outreach may be necessary.
- **Operations and maintenance:** As with convenience, well owner education regarding required O&M is critical to ensuring informed decisions, sustained use of mitigation systems, and continued protection of drinking water quality.
- **Data management and tracking:** A statewide program would benefit from consistent data collection related to water quality results, system installation, O&M compliance, and performance outcomes. Establishing clear, standardized data management protocols may improve program transparency, evaluation, and future decision-making.
- **Administrative capacity and oversight:** Implementation of a statewide mitigation program would require administrative infrastructure for application review, contractor coordination, data management, and performance tracking. Administrative requirements may influence program costs and scalability.
- **Cost and available program funding:** Cost estimates presented in this analysis are based on actual product costs provided by industry professionals, suppliers, and retailers; however, individual water systems may have unique requirements that result in costs significantly different from those presented. While the State’s goal is to provide safe drinking water to all Minnesotans, implementing a comprehensive mitigation program for all private well owners would require substantial funding and may exceed available resources. The State should consider establishing priorities to address the most highly contaminated water supplies and the populations with the greatest need.

- **Broader public health and economic impacts:** In addition to direct mitigation costs, broader public health and economic effects should be considered when evaluating a statewide program. Potential impacts may include long-term reductions in health care expenditures, stabilization of property values, decreased reliance on bottled water, and other secondary economic or community effects. While these impacts may be more difficult to quantify, they may influence the overall cost-benefit evaluation.

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9.0 FIGURES

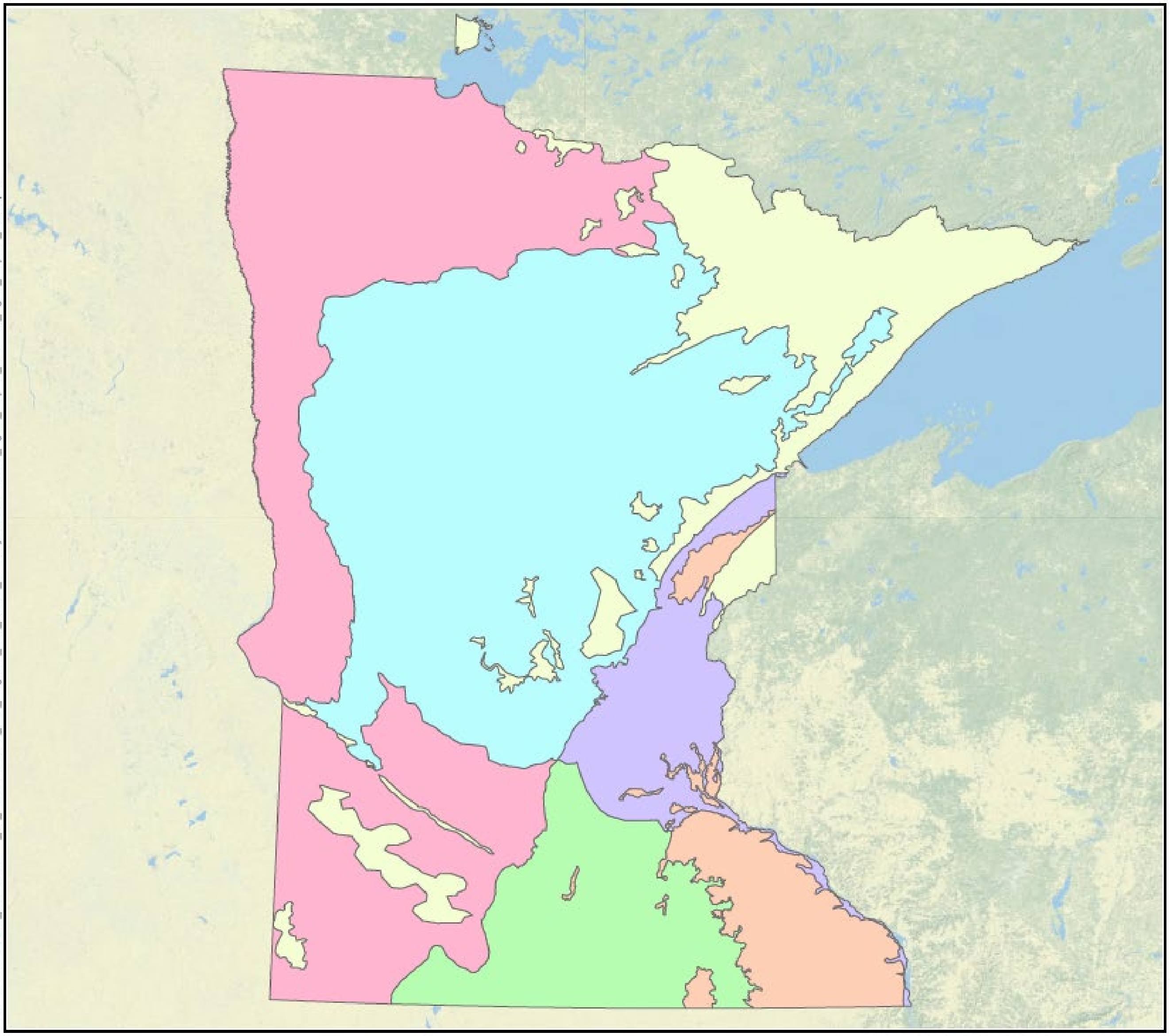

Figure 1

Minnesota Groundwater Province Map

Private Well Mitigation

Map Projection: NAD 1983 UTM Zone 15 N, Meters
Basemap: ESRI USA Topo Maps WMS

0 40 80 Miles

0 75 150 Kilometers

Groundwater Province

- Arrowhead/Shallow Bedrock
- Central
- East-Central
- Karst
- South-Central
- Western

Bay West

Drawn By: J.Q. Date Drawn/Revised:12/15/2025 Project No.J250426

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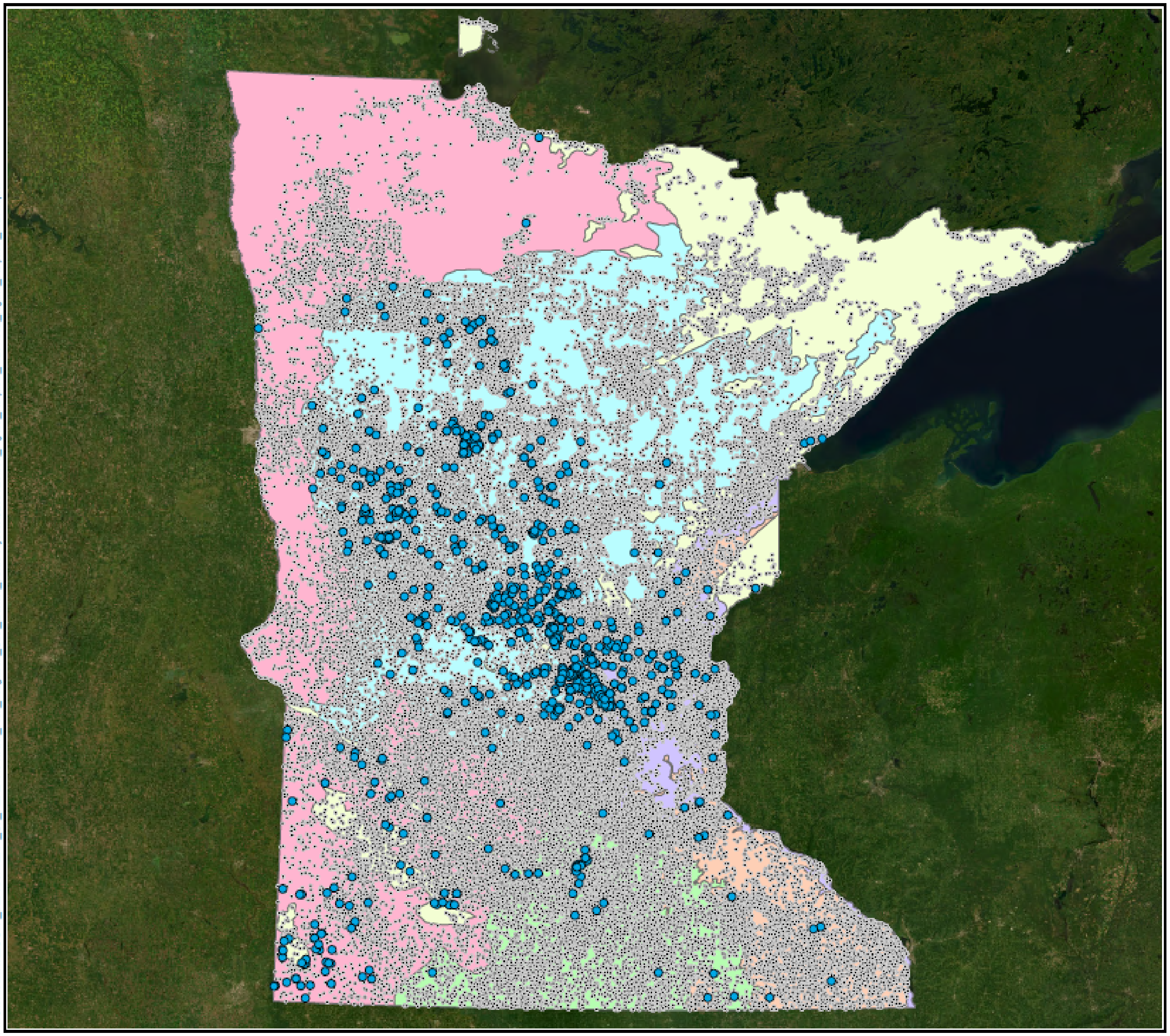
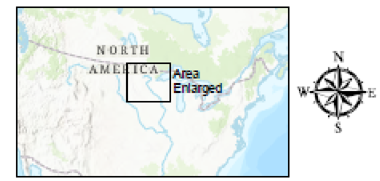
Figure 2

Nitrates in Private Wells Map

Private Well Mitigation





Map Projection: NAD 1983 UTM Zone 15 N, Meters
Basemap: ESRI World Imagery WMS

0 40 80 Miles

0 75 150 Kilometers

Private Well Exceeding Nitrate Criteria

Private Well Less Than Nitrate Criteria

Groundwater Province

- Arrowhead/Shallow Bedrock
- Central
- East-Central
- Karst
- South-Central
- Western

COC	Action level
Nitrates	10 mg/L

Notes:

Available data for private well distribution across the State, acquired from the Minnesota Department of Health, provides the best available information for known private wells but does not include a complete comprehensive list of all data for all private wells.

Nitrate data queried in August 2025 from the MDH WELLS database (samples taken after installation) and includes a limited number of results from the MDH Drinking Water Ambient Monitoring Program.

Bay West

Drawn By: J.Q. Date Drawn/Revised:12/15/2025 Project No.J250426

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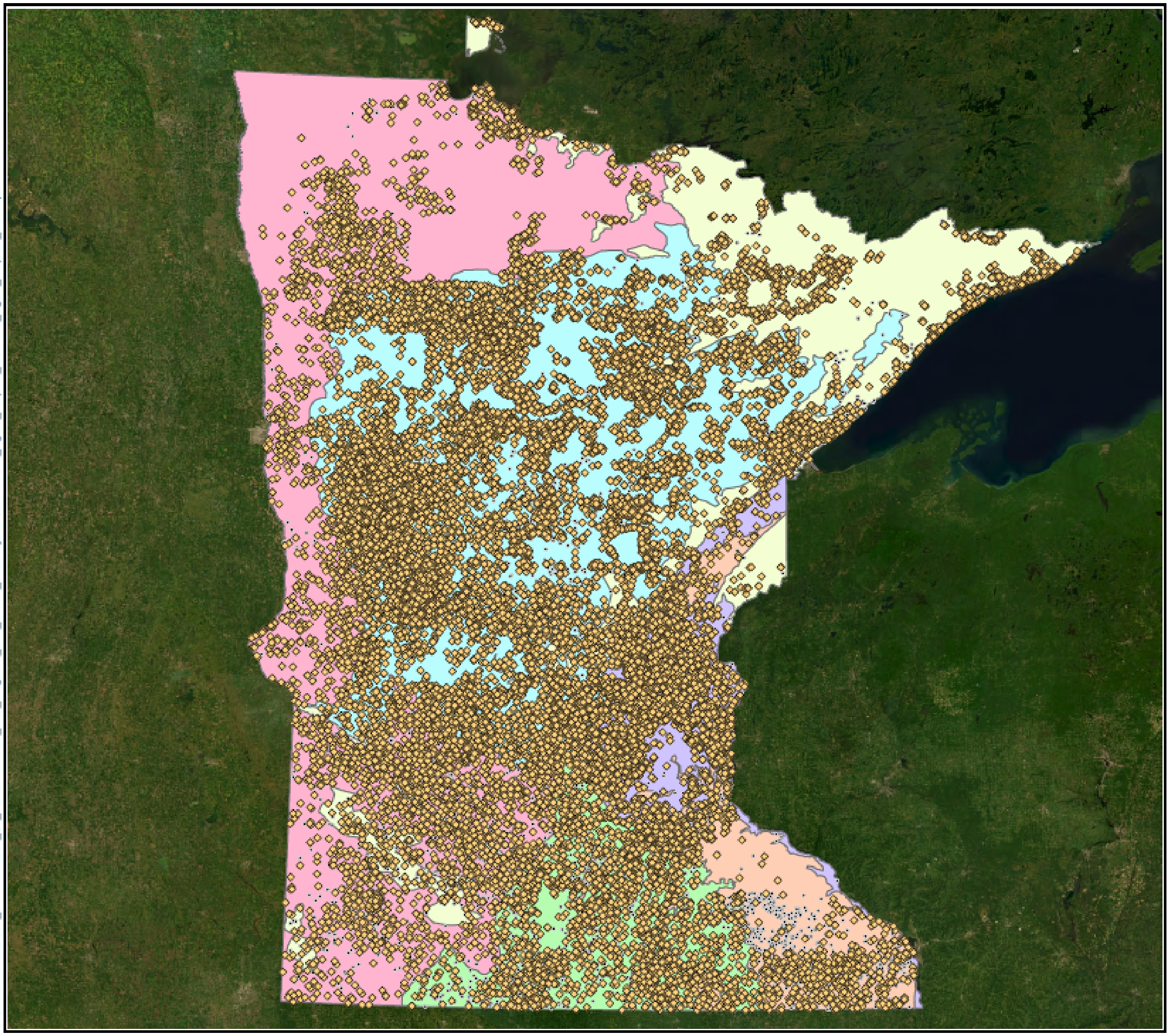
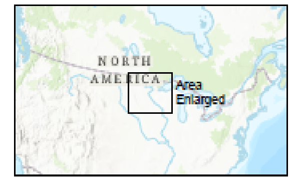


Figure 3

Arsenic in Private Wells Map

Private Well Mitigation



N W E S

Map Projection: NAD 1983 UTM Zone 15 N, Meters
Basemap: ESRI World Imagery WMS

0 40 80 Miles
0 75 150 Kilometers

- Private Well Exceeding Arsenic Criteria
- Private Well Less Than Arsenic Criteria

Groundwater Province

- Arrowhead/Shallow Bedrock
- Central
- East-Central
- Karst
- South-Central
- Western

COC	Action level
Arsenic	2 µg/L

Notes:

Available data for private well distribution across the State, acquired from the Minnesota Department of Health, provides the best available information for known private wells but does not include a complete comprehensive list of all data for all private wells.

Arsenic data queried in August 2025 from the MDH WELLS database (samples taken after installation) and includes a limited number of results from the MDH Drinking Water Ambient Monitoring Program.

Bay West

Drawn By: J.Q. Date Drawn/Revised:12/15/2025 Project No.J250426

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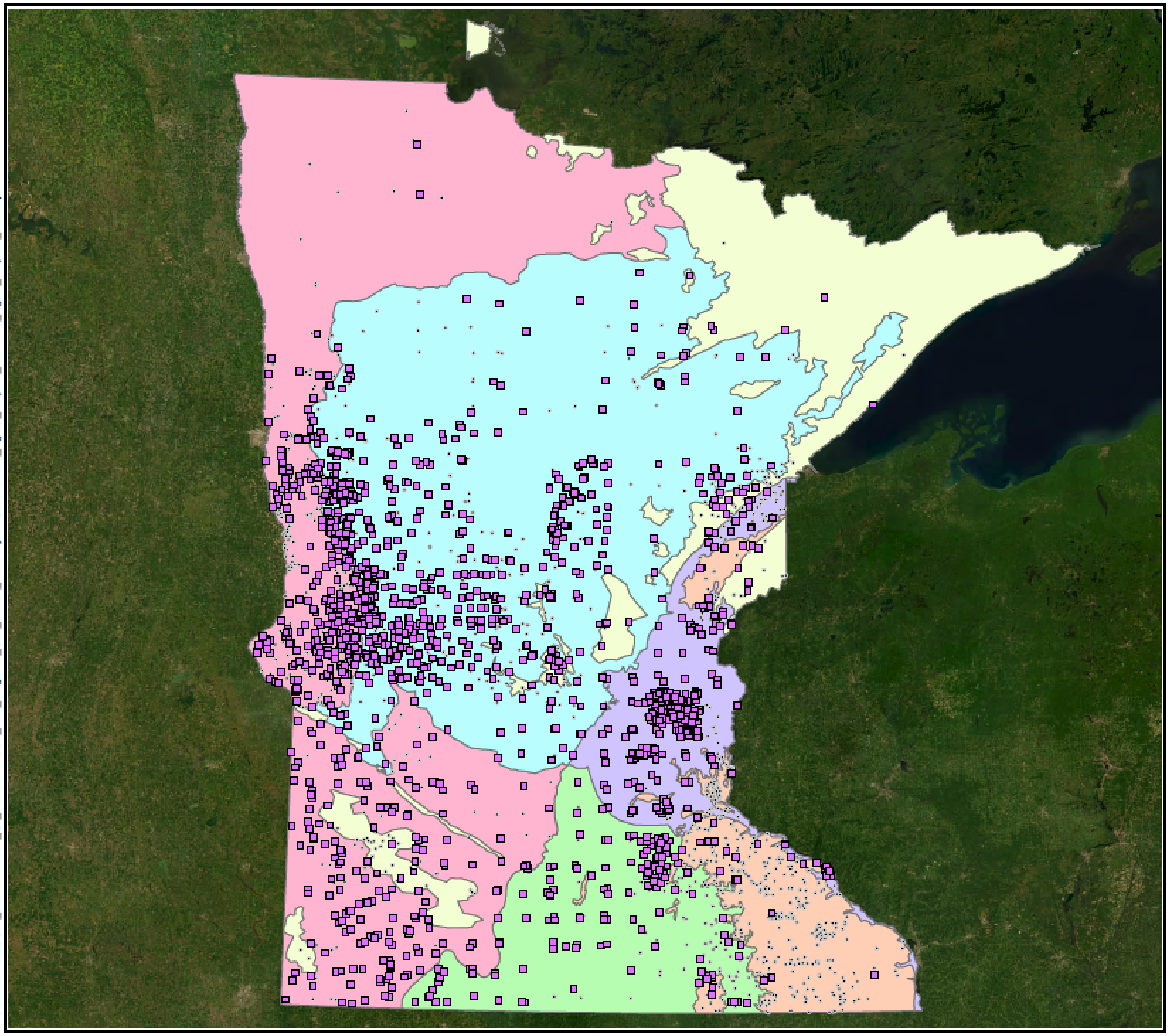

Figure 4

Manganese in Private Wells Map

Private Well Mitigation

Map Projection: NAD 1983 UTM Zone 15 N, Meters
Basemap: ESRI World Imagery WMS

0 40 80 Miles
0 75 150 Kilometers

- Private Well Exceeding Mangnese Criteria
- Private Well Less Than Manganese Criteria

Groundwater Province

- Arrowhead/Shallow Bedrock
- Central
- East-Central
- Karst
- South-Central
- Western

COC	Action level
Manganese	100 µg/L

Notes:
Available data for private well distribution across the State, acquired from the Minnesota Department of Health, provides the best available information for known private wells but does not include a complete comprehensive list of all data for all private wells.

Bay West

Drawn By: J.Q. Date Drawn/Revised:12/15/2025 Project No.J250426

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10.0 TABLES

Table 1: Technologies Screening Summary

Hyphen (-) means that the treatment is not appropriate for the contaminant

Treatment	Description	Rationale	C. Bacteria	Nitrates	Arsenic	Lead	Manganese
Bottled Water	Replace all drinking water sources in the home with bottled water. Well owner coordinates bottled water delivery. Water delivery service provides monthly delivery and rental cooler.	May be used as a single, long-term management remedy if conditions warrant and residents agree to terms. Available in many portions of the state. Well owners should contact the nearest water treatment company for water delivery.	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
New Well	Install replacement well that is constructed in accordance with well code and installed in an aquifer that can provide safe drinking water. Well owner hires a licensed driller that installs a new well per the Minnesota well code.	Long term management remedy if source of contamination is from the construction of the well or impacted aquifer. Licensed well drillers are readily available throughout the state.	**Yes**	**Yes**	**-**	**-**	**-**
Public Water Supply	If available, connect to a public or community water supply system. Well owner establishes connection to local public water supply and abandons private well.	Permanent remedy if source of contamination is from well owners immediate surrounding property and drilling another well/mitigation technologies are not feasible.	**Yes**	**Yes**	**Yes**	**Yes**	**-**
Plumbing System Investigation	Well owner hires a plumber to identify the source of lead in the plumbing system and work with plumber for replacement of parts that could solve the contamination in the system.	Permanent remedy if source of contamination is from the construction of the plumbing material. Homeowner should contact plumbing services for a lead pipe inspection or perform inspection themselves and work with licensed plumber to replace lead materials.	**-**	**-**	**-**	**Yes**	**-**

Treatment	Description	Rationale	C. Bacteria	Nitrates	Arsenic	Lead	Manganese
Well Repair & Disinfection	Well owner hires a licensed driller that inspects and performs maintenance including but not limited to sealing, drilling, and installing new casing.	Long term management remedy if contamination known to be directly related to well construction and not an impacted water source. Well repairs should be performed by a licensed driller.	**Yes**	**Yes**	**-**	**-**	**-**
Disinfection	Well owners or a licensed professional runs chlorine bleach through the well and all faucets and fixtures to disinfect the water. Well owners can follow instructions provided in "Well Disinfection" document by the Minnesota Department of Health: www.health.state.mn.us/communities/environment/water/wells/waterquality/disinfection.html	May be used when source of contamination is temporary (surface water, flooding, or storm pollution). When the source of contamination is fixed (contaminated groundwater or well damage), several well disinfections may not be enough to reduce bacteria in a well. Disinfection can be completed by well owner or registered well driller.	**Yes**	**-**	**-**	**-**	**-**
Reverse Osmosis	Water treatment service provider or well owner installs a reverse osmosis system that allows water to permeate through a membrane to remove larger contaminants from the water.	Reverse osmosis is readily available by multiple water treatment companies across the state and treats many of the target contaminants of concern. Systems can be installed point of use or point of entry. Systems should be installed by a licensed professional.	**-**	**Yes**	**Yes**	**Yes**	**Yes**

Treatment	Description	Rationale	C. Bacteria	Nitrates	Arsenic	Lead	Manganese
Anion Exchange	Water treatment service provider or well owner installs anion exchange water treatment that removes dissolved minerals by replacing the negative minerals with salt (sodium chloride or sodium potassium). Well owner responsible to replace salt.	This treatment system isn't as readily available as it is mostly used for commercial or industrial facilities. However, there is residential treatment solutions available in some areas of the state. System should be installed by a licensed professional.	**-**	**Yes**	**Yes**	**-**	**-**
Distillation	Water treatment service provider or well owner installs a countertop distillation system that removes contaminants by boiling water to create steam. The steam leaves the contaminant behind and then is condensed to distilled water.	This treatment system reduces most target contaminants of concern and countertop solutions are readily available at most home improvement stores. Well owner should consider that countertop treatments produce six gallons of water a day. Larger units may be available at water distiller companies; however, these solutions may be for commercial use. Systems can be installed by the well owner or licensed professional.	**-**	**Yes**	**Yes**	**Yes**	**Yes**
Adsorptive Media	Water treatment service provider or well owner installs an adsorptive media filtration system. The filtration system can be installed with specific filters to target particular contaminants. Filters have a charged media bed that attaches contaminants (oppositely charged ions) to the media and allows water to flow through.	If the only contaminant in well water is arsenic, this solution treats both arsenic III and V and is readily available throughout the state of Minnesota. Systems can be installed by the well owner or a licensed professional.	**-**	**-**	**Yes**	**-**	**-**

Treatment	Description	Rationale	C. Bacteria	Nitrates	Arsenic	Lead	Manganese
Ozonation & Filtration	Water treatment service provider or well owner installs an ozonation and filtration system. Ozone treats contaminated water by disinfection. Ozone is generated with electricity to change oxygen molecules in the air to ozone. The ozone is injected into water and changes contaminants into solid particles. The solids are then filtered out of the water.	This water treatment method is effective for mutliple target contaminants of concern; however, it is not available in all parts of the state. Limited number of suppliers and installers available for this technology and service may not be available in remote and rural areas of the state.	**-**	**-**	**-**	**-**	**Yes**
Oxidizing Media Filtration	Water treatment service provider or well owner installs an oxidation filtration system that oxidizes dissolved contaminants into solid particles. The system uses a media bed to filter contaminants out of the water.	Oxidizing media and filtration is not available in all of parts of Minnesota. It also rewuires a lot of maintenace from well owner and isnt as popular as a solution to treating arsenic and manganese in well water. Systems can be installed by the well owner or a licensed professional.	**-**	**-**	**Yes**	**-**	**Yes**
Carbon Filters	Water treatment service provider or well owner installs a carbon filtration system that passes water through a bed of porous carbon media that adsorbs and removes contaminants.	This system only treats lead, which requires a specific type of carbon filter. Lead is rare to occur in groundwater in Minnesota and well water is likely contaminated from plumbing material. POE system should be installed by a licensed professional. POU systems can be installed by home owner.	**-**	**-**	**-**	**Yes**	**-**

Treatment	Description	Rationale	C. Bacteria	Nitrates	Arsenic	Lead	Manganese
Water Softening	Water treatment service provider or well owner installs a water softener that removes the contaminant/minerals by adding salt. The salt (sodium chloride or potassium chloride) replaces the positively charged contaminant/minerals.	Treating contaminated water with water softeners is common throughout Minnesota and requires minimal maintenace by the well owner. Using a water softener treats manganese in the well water and no other contaminants of concern. Systems should be installed by a licensed professional.	-	-	-	-	**Yes**

Aeration and filtration were evaluated, but it was determined they were not available for residential use in Minnesota.
Continuous chlorination was evaluated, but it was determined it were not available for residential use in Minnesota.

Table 2A: Comparative Analysis Summary - Coliform Bacteria

Evaluation Criteria (c. bacteria)	Alternative Water Source - Bottled Water	Alternative Water Source - New Well Installation	Alternative Water Source - Public Water Supply Connection	Well Repairs & Disinfection	Mitigation - Disinfection
Effectiveness for reducing contaminants (Coliform Bacteria)	Bottled water is **highly effective** at reducing coliform bacteria.	A new well is **highly effective** at reducing coliform bacteria; there is a possibility for bacteria to be introduced to a new well.	A public water supply connection is **highly effective** at reducing coliform bacteria; there is a possibility for bacteria to be found in public water supplies; however, testing and monitoring efforts make bacteria presence very unlikely.	Well repairs are **highly effective** at reducing the coliform bacteria; following well repairs, additional mitigation such as disinfection may be needed to flush the well/system of any residual bacteria.	Disinfection on its own is **moderately to highly effective** at reducing coliform bacteria from a well when done properly. Disinfectants offer strong protection against most bacteria by destroying them on inanimate surfaces, but their effectiveness is dependent on the factors that led to bacteria infection and may require additional mitigation.

Evaluation Criteria (c. bacteria)	Alternative Water Source - Bottled Water	Alternative Water Source - New Well Installation	Alternative Water Source - Public Water Supply Connection	Well Repairs & Disinfection	Mitigation - Disinfection
Overall protectiveness and performance	Provides a **high achievement of protectiveness**. Current Good Manufacturing Practices are Food and Drug Administration-mandated regulations ensuring bottled water is safe and sanitary by requiring bottlers to process and bottled water under sanitary conditions, protect water sources from contaminants, use quality control processes for chemical and bacteriological safety, and conduct regular sampling and testing of water. Water supply is limited to what well owner orders each month.	Provides a **high achievement of protectiveness**. A new well would be installed according to the Minnesota well code, ensuring the well would not have a high risk of exposure to bacteria. Unlimited water supply as it is a point of entry solution.	Provides a **high achievement of protectiveness**. Public water supplies can have bacteria exposure if contamination occurs, but they are generally safe due to treatment processes like chlorination. Bacteria can enter the system through breaks in pipes, during repairs, or by growing in stagnant water inside homes. Unlimited water supply as it is a point of entry solution.	Provides a **high achievement of protectiveness**. Repairs may include replacement of parts or casing, resealing of grout around well, well pump repair, and/or full well system overhaul. Regardless of repairs, if the well is still subject to flooding or agricultural runoff, there is still a potential for bacteria to be re-introduced to the repaired well. Unlimited water supply as it is a point of entry solution.	Provides a **moderate achievement of protectiveness**. The level of protection depends on the type of bacteria, the disinfectant's chemical properties, and correct application. Unlimited water supply as it is a point of entry solution.
Technology Availability	Bottled water is available throughout the State of Minnesota; **readily available**.	Drillers are available around the State of Minnesota; dependent upon Driller availability, however most drillers have expansive mobilization zones, due to this: **mostly available**.	**Dependent** upon location of well and available public water supply to hookup to.	Drillers are **available** around the State of Minnesota; dependent upon Driller availability, however most drillers have expansive mobilization zones, due to this: mostly available.	Supplies to disinfect the well are **available** to well owners, a professional can also be hired; readily available

Evaluation Criteria (c. bacteria)	Alternative Water Source - Bottled Water	Alternative Water Source - New Well Installation	Alternative Water Source - Public Water Supply Connection	Well Repairs & Disinfection	Mitigation - Disinfection
Ease of installation	**Easy** to setup water dispenser, well owner can complete setup.	**Moderate to difficult** installation; dependent upon location, well depth, and geology.	**Moderate to difficult;** dependent upon location and vicinity to water supply hookup. Likely requires significant earth work to install lines from public water supply connection to home.	**Moderate to difficult;** dependent upon repairs needed.	Well owner can complete by following instruction; or a licensed driller can be hired; **Easy**
Convenience	Requires ongoing tracking, coordination, delivery, and storage of water bottles. Weight of water bottles may be prohibitive. Safe drinking water limited to bottled water cooler location with relatively low flow: **Low convenience.**	Requires access to new well location, space for large equipment, and potential disturbance to landscaping. Requires well owner to be on site during installation. Provides safe water to entire household at high flow rates and large quantities. **Moderate convenience.**	Requires significant earthwork and disturbance to landscaping. Requires well owner to be on site during installation. Provides safe water to entire household at high flow rates and unlimited quantities. **Moderate convenience.**	Requires well owner to be on site during repairs/disinfection and can temporarily interrupt water service. Provides safe water to entire household at high flow rates and large quantities. **Moderate to high convenience.**	Can be completed by well owner, Provides safe water to entire household at high flow rates and large quantities. **High convenience.**

Evaluation Criteria (c. bacteria)	Alternative Water Source - Bottled Water	Alternative Water Source - New Well Installation	Alternative Water Source - Public Water Supply Connection	Well Repairs & Disinfection	Mitigation - Disinfection
Operations and maintenance (O&M) •Life expectancy •Serviceability •Parts availability •Waste products	Life expectancy: N/A - Ongoing as long as necessary. Serviceability: Difficult - monthly delivery and coordination. Parts availability: Readily available. Waste: Not applicable - Bottles to be recycled by vendor **High.**	Life expectancy: 25-50 years is common; components may need replacing between 5-15 years. Serviceability: Licensed well drillers are widely available throughout the state. Parts availability: Usually readily available. Waste: Drill cuttings, wastewater, highly dependent on depth of well and geology. **Moderate.**	Life expectancy: forever Serviceability: Public water supply depends on location, commercial plumbers are common. Parts availability: Usually mostly available. Waste: Trenching, highly dependent on depth of well and geology. **Minimal.**	Life expectancy: Highly dependent upon the repair made and the well age. Assume 5-20 years Serviceability: Licensed well drillers are widely available, depends on type of repairs required. Parts availability: Usually readily available. Waste: Any components to be replaced. **Moderate.**	Life expectancy: Annual; as needed following coliform detection; recommended to test between 2-4 weeks following disinfection to see if additional disinfection is needed. Serviceability: Possible throughout the State Parts availability: Readily available. Waste: Flushed water **Minimal.**
Capital Cost	$77 for cooler setup	$25,000	$25,000 - $75,000	$150 - $20,000	$20 - $275
Annual O&M Cost	$585 for bottled delivery per year (family of 4)	Annual O&M costs minimal	$360 - $2,100 (based on monthly water service fees ranging from $30-$175)	$400 - $1,000	$80 - $275
Approximate 30 Year Cost	$17,550	$25,000	$35,800 - $138,000	$17,150 - $55,000 (assumes at least one $5,000 repair over 30 years)	$2,500 - $8,500

Table 2B: Comparative Analysis Summary – Nitrate

Evaluation Criteria for Nitrate	Alternative Water Source - Bottled Water	Alternative Water Source - New Well Installation	Alternative Water Source - Public Water Supply Connection	Well Repairs & Disinfection	Mitigation - Reverse Osmosis	Mitigation - Anion Exchange	Mitigation - Distillation
Effectiveness on range of contaminants (Nitrate)	Bottled water is **highly effective** at reducing nitrates.	A new well built to code is **moderately effective** at reducing nitrates; it's crucial to identify and eliminate the source of nitrate contamination first.	A public water supply connection is **highly effective** at reducing nitrates; testing and monitoring efforts ensure nitrates are not present at unsafe levels in public water supplies.	Well repairs are **moderately to highly effective** at reducing nitrates. Old or damaged wells are more susceptible to contamination; necessary repairs would eliminate this risk.	Reverse osmosis is **highly effective** at reducing nitrates.	Anion exchange is **highly effective** at reducing nitrates.	Distillation is **highly effective** at reducing nitrates.

Evaluation Criteria for Nitrate	Alternative Water Source - Bottled Water	Alternative Water Source - New Well Installation	Alternative Water Source - Public Water Supply Connection	Well Repairs & Disinfection	Mitigation - Reverse Osmosis	Mitigation - Anion Exchange	Mitigation - Distillation
Overall protectiveness and performance	Provides a **high achievement** of protectiveness. Current Good Manufacturing Practices are Food and Drug Administration-mandated regulations ensuring bottled water is safe and sanitary by requiring bottlers to process and bottled water under sanitary conditions, protect water sources from contaminants, use quality control processes for chemical and bacteriological safety, and conduct regular sampling and testing of water.	Provides a **moderate to high achievement** of protectiveness. A new well would be installed according to the Minnesota well code, ensuring the well would not have a high exposure to nitrates.	Provides a **high achievement** of protectiveness.	Provides a **moderate achievement** of protectiveness. Regardless of repairs, if the well is still subject to flooding or agricultural runoff, there is still a potential for nitrates to be re-introduced to the repaired well.	Provides a **high achievement** of protectiveness. Reverse osmosis can remove anywhere from 83-92% of nitrates.	Provides a **high achievement** of protectiveness. Ion exchange can remove more than 90% of the nitrates.	Provides a **high achievement** of protectiveness. Distillation units are capable of removing virtually all nitrates from the treated water.

Evaluation Criteria for Nitrate	Alternative Water Source - Bottled Water	Alternative Water Source - New Well Installation	Alternative Water Source - Public Water Supply Connection	Well Repairs & Disinfection	Mitigation - Reverse Osmosis	Mitigation - Anion Exchange	Mitigation - Distillation
Technology Availability	Bottled water is available throughout the State of Minnesota; **readily available**.	Drillers are available around the State of Minnesota; dependent upon driller availability; however, most drillers have expansive mobilization zones. Due to this, this is **mostly available**.	**Dependent** upon location of well and available public water supply to hookup to.	Drillers are available around the State of Minnesota; dependent upon driller availability; however, most drillers have expansive mobilization zones. Due to this, this is **mostly available**.	Vendors are available throughout the State of Minnesota; **readily available**	This treatment system isn't as readily available for private well applications (**low availability**) as it is mostly used for commercial or industrial facilities. However, there is residential treatment solutions available in some areas of the state.	This treatment system reduces nitrates; countertop solutions are **mostly available** at most home improvement stores. Well owner should consider that countertop treatments produce six gallons of water a day. Larger units may be available at water distiller companies; however, these solutions may be for commercial use.
Ease of installation	**Easy** to set up water dispenser; well owner can complete setup.	**Moderate to difficult** installation; dependent upon location and geology.	**Moderate to difficult**; dependent upon location and vicinity to water supply hookup. Likely requires significant earth work to install lines from public water supply connection to home.	**Moderate to difficult**; dependent upon repairs needed.	**Easy to moderate**, a licensed plumber may be needed for whole-house systems or if well owner does not have basic plumbing skills.	**Moderate**, a licensed plumber may need to relocate the supply lines	**Easy to moderate**, depending on unit size. Countertop models are simple to install, larger units may require plumbing and/or electrical modifications.

Evaluation Criteria for Nitrate	Alternative Water Source - Bottled Water	Alternative Water Source - New Well Installation	Alternative Water Source - Public Water Supply Connection	Well Repairs & Disinfection	Mitigation - Reverse Osmosis	Mitigation - Anion Exchange	Mitigation - Distillation
Convenience	Requires ongoing tracking, coordination, delivery, and storage of water bottles. Weight of water bottles may be prohibitive. Safe drinking water limited to bottled water cooler location with relatively low flow: **Low convenience**.	Requires access to new well location, space for large equipment, and potential disturbance to landscaping. Requires well owner to be on site during installation. Provides safe water to entire household at high flow rates and large quantities. **Moderate convenience.**	Requires significant earthwork and disturbance to landscaping. Requires well owner to be on site during installation. Provides safe water to entire household at high flow rates and unlimited quantities. **Moderate convenience.**	Requires well owner to be on site during repairs/disinfection and can temporarily interrupt water service. Provides safe water to entire household at high flow rates and large quantities. **Moderate to high convenience.**	Requires well owner to be on site during installation. Provides safe drinking water only to point of use location. Delivers water at moderate flow and moderate quantity. Filter replacement can be completed by owner. Convenience is **moderate**.	Requires well owner to be on site during installation. Provides safe drinking water only to point of use location. Delivers water at relatively high flow and relatively large quantity. Media replacement completed by professional, which may not be readily available. Convenience is **low to moderate**.	Typically requires countertop space to store unit. Requires frequent filling of reservoir. Produces treated water slowly and at low volumes. Units may also produce heat and noise during operation. May require additives to replace mineral loss for taste. Convenience is **very low**.

Evaluation Criteria for Nitrate	Alternative Water Source - Bottled Water	Alternative Water Source - New Well Installation	Alternative Water Source - Public Water Supply Connection	Well Repairs & Disinfection	Mitigation - Reverse Osmosis	Mitigation - Anion Exchange	Mitigation - Distillation
Operations and maintenance (O&M) •Life expectancy •Serviceability •Parts availability •Waste products	Life expectancy: N/A - Ongoing as long as necessary. Serviceability: Difficult - monthly delivery and coordination. Parts availability: Readily available. Waste: Not applicable - Bottles to be recycled by vendor **High.**	Life expectancy: 25-50 years is common; components may need replacing between 5-15 years. Serviceability: Licensed well drillers are widely available throughout the state. Parts availability: Usually readily available. Waste: Drill cuttings, wastewater, highly dependent on depth of well and geology. **Moderate.**	Life expectancy: forever Serviceability: Public water supply depends on location, commercial plumbers are common. Parts availability: Usually mostly available. Waste: Trenching, highly dependent on depth of well and geology. **Minimal.**	Life expectancy: Highly dependent upon the repair made and the well age. Assume 5-20 years Serviceability: Licensed well drillers are widely available, depends on type of repairs required. Parts availability: Usually readily available. Waste: Any components to be replaced. **Moderate.**	Life expectancy: 10-15 years; filters need to be replaced every 6-12 months, membrane replacement 2-5 years Serviceability: Filter replacements done by homeowner, larger repairs by done by professionals. Parts availability: Usually readily available. Waste: Rejectant stream. **Moderate**.	Life expectancy: 4-8 years for resin; Serviceability: Residential systems uncommon, service would be completed by a specialized professional. Parts availability: Usually readily available. Waste: Used resin, regeneration wastewater **Minimal to Moderate**.	Life expectancy: 10-15 years for smaller units; Serviceability: basic maintenance easy to complete by homeowner. Professional providers are mostly available throughout the state for larger repairs. Parts availability: Usually readily available. Waste: Distiller concentrate/brine **Minimal to Moderate**.
Capital Cost	$77 for cooler setup	$25,000	$25,000 - $75,000	$150 - $20,000	$1,250 - $1,900	$1,500 to $2,500	$150 - $1,500
Annual O&M Cost	$585 for bottled delivery per year (family of 4)	Annual O&M costs minimal	$360 - $2,100	$400 - $1,000	$200 - $990	$550 - $900 (from Ecolab quote and MDH home treatment pdf)	$100 - $600 + $960 in energy cost
Approximate 30 Year Cost	$17,550	$25,000	$35,800 - $138,000	$17,150 - $55,000 (assumes at least one $5,000 repair over 30 years)	$8,500 - $33,500 (assumes one replacement unit over 30 years)	$18,000 - $29,500	$32,100 - $49,800 (assumes one replacement unit over 30 years)

Table 2C : Comparative Analysis Summary – Arsenic

Evaluation Criteria for Arsenic	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Mitigation - Reverse Osmosis	Mitigation - Distillation	Mitigation - Adsorptive Media	Mitigation - Oxidizing Media Filtration	Mitigation - Anion Exchange
Effectiveness on range of contaminants (Arsenic)	Bottled water is highly effective at reducing arsenic.	A public water supply connection is highly effective at reducing arsenic; testing and monitoring efforts ensure arsenic are not present at unsafe levels in public water supplies.	Reverse osmosis is highly effective at reducing arsenic V, but is less effective at reducing arsenic III. Pre-oxidation treatment may assist in converting arsenic III to arsenic V prior to treatment via reverse osmosis.	Distillation is highly effective at reducing arsenic III and arsenic V.	Highly effective at reducing arsenic V, but is less effective at reducing arsenic III. Pre-oxidation treatment may assist in converting arsenic III to arsenic V prior to treatment via adsorptive media.	Oxidizing media filtration is **Moderately effective** at reducing arsenic, with optimal effectiveness achieved with pre-treatment, high iron concentrations and low arsenic concentrations.	Anion exchange is highly effective at reducing arsenic V, but is not effective for reducing arsenic III. To use anion exchange for complete arsenic removal, any arsenic III present must first be oxidized to arsenic V.

Evaluation Criteria for Arsenic	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Mitigation - Reverse Osmosis	Mitigation - Distillation	Mitigation - Adsorptive Media	Mitigation - Oxidizing Media Filtration	Mitigation - Anion Exchange
Overall protectiveness and performance	Provides a **high achievement** of protectiveness. Current Good Manufacturing Practices are Food and Drug Administration-mandated regulations ensuring bottled water is safe and sanitary by requiring bottlers to process and bottled water under sanitary conditions, protect water sources from contaminants, use quality control processes for chemical and bacteriological safety, and conduct regular sampling and testing of water.	Provides a **high achievement** of protectiveness.	Provides a **high achievement** of protectiveness. Several reports have evaluated the effectiveness of point-of-use reverse osmosis filtration units in laboratory settings or in formal field testing programs and have reported that these filters can reduce arsenic concentrations by up to 80% to 99%. (pmc.ncbi.nlm.nih.gov)	Provides a **high achievement** of protectiveness. Distillation units are capable of removing virtually all arsenic from the treated water.	Provides a **high achievement** of protectiveness when properly selected, installed, and maintained.	Provides a **Moderate achievement** of protectiveness. Can be limited by several factors, including the incoming arsenic and iron concentrations.	Provides a **moderate to high achievement** of protectiveness, reliability is heavily influenced by the water's chemical characteristics.

Evaluation Criteria for Arsenic	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Mitigation - Reverse Osmosis	Mitigation - Distillation	Mitigation - Adsorptive Media	Mitigation - Oxidizing Media Filtration	Mitigation - Anion Exchange
Technology Availability	Bottled water is available throughout the State of Minnesota; **readily available**.	**Dependent** upon location of well and available public water supply to hookup to.	Vendors are available throughout the State of Minnesota; **readily available**.	Countertop solutions are **mostly available** at most home improvement stores. Well owner should consider that countertop treatments produce six gallons of water a day. Larger units may be available at water distiller companies, however these solutions may be for commercial use.	Vendors are available throughout the State of Minnesota; **readily available**.	Some water treatment companies are **mostly available** throughout Minnesota.	This treatment system isn't as readily available (**low availability**) as it is mostly used for commercial or industrial facilities.
Ease of installation	**Easy** to setup water dispenser, well owner can complete setup.	**Moderate to difficult**; dependent upon location and vicinity to water supply hookup. Likely requires significant earth work to install lines from public water supply connection to home.	**Easy to moderate**, a licensed plumber may be needed for whole-house systems or if well owner does not have basic plumbing skills.	**Easy to moderate**, depending on unit size. Countertop models are simple to install, larger units may require plumbing and/or electrical modifications.	**Easy to moderate**, depending on unit size. POU units are simple to install, larger units may require professional installation.	**Moderate**, since professional installation is necessary for installation.	**Moderate**, a licensed plumber may need to relocate the supply lines.

Evaluation Criteria for Arsenic	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Mitigation - Reverse Osmosis	Mitigation - Distillation	Mitigation - Adsorptive Media	Mitigation - Oxidizing Media Filtration	Mitigation - Anion Exchange
Convenience	Requires ongoing tracking, coordination, delivery, and storage of water bottles. Weight of water bottles may be prohibitive. Safe drinking water limited to bottled water cooler location with relatively low flow: **Low convenience**.	Requires significant earthwork and disturbance to landscaping. Requires well owner to be on site during installation. Provides safe water to entire household at high flow rates and unlimited quantities. **Moderate convenience.**	Requires well owner to be on site during installation. Provides safe drinking water only to point of use location. Delivers water at moderate flow and moderate quantity. Filter replacement can be completed by owner. Convenience is **moderate**.	Typically requires countertop space to store unit. Requires frequent filling of reservoir. Produces treated water slowly and at low volumes. Units may also produce heat and noise during operation. May require additives to replace mineral loss for taste. Convenience is **very low**.	Requires well owner to be on site during installation. Provides safe drinking water only to point of use location. Delivers water at moderately high flow and quantity. Media replacement can be completed by owner. Convenience is **moderate**.	Requires well owner to be on site during installation. Typically installed at point of entry, producing safe water for entire household at high flow rates and volumes. Media replacement can be completed by owner. Convenience is **moderate to high**.	Requires well owner to be on site during installation. Provides safe drinking water only to point of use location. Delivers water at relatively high flow and relatively large quantity. Media replacement completed by professional, which may not be readily available. Convenience is **low to moderate**.

Evaluation Criteria for Arsenic	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Mitigation - Reverse Osmosis	Mitigation - Distillation	Mitigation - Adsorptive Media	Mitigation - Oxidizing Media Filtration	Mitigation - Anion Exchange
Operations and maintenance (O&M) **•Life expectancy** **•Serviceability** **•Parts availability** **•Waste products**	Life expectancy: N/A - Ongoing as long as necessary. Serviceability: Difficult - monthly delivery and coordination. Parts availability: Readily available. Waste: Not applicable - Bottles to be recycled by vendor **High.**	Life expectancy: forever Serviceability: Public water supply depends on location, commercial plumbers are common. Parts availability: Usually mostly available. Waste: Trenching, highly dependent on depth of well and geology. **Minimal.**	Life expectancy: 10-15 years; filters need to be replaced every 6-12 months, membrane replacement 2-5 years Serviceability: Filter replacements done by homeowner, larger repairs by done by professionals. Parts availability: Usually readily available. Waste: Rejectant stream. **Moderate**.	Life expectancy: 10-15 years for smaller units; Serviceability: basic maintenance easy to complete by homeowner. Professional providers are mostly available throughout the state for larger repairs. Parts availability: Usually readily available. Waste: Distiller concentrate/brine **Minimal to Moderate**.	Life expectancy: Many years for external components, media needs to be replaced regularly - annual monitoring recommended; Serviceability: Replacement of media filters by well owner is easy. Professional providers are mostly available throughout the state for larger repairs. Parts availability: Usually readily available. Waste: Exhausted media, wastewater **Moderate**.	Life expectancy: 4-8 years depnding on media, usage, and contaminants; Serviceability: Replacement of greensand filters is typically easy to complete by well owners. If professional help is needed, providers are mostly available throughout the state. Parts availability: Mostly available. Waste: Oxidized contaminant particles/spent media, backwash water **Moderate**.	Life expectancy: 4-8 years for resin; Serviceability: Residential systems uncommon, service would be completed by a specialized professional. Parts availability: Usually readily available. Waste: Used resin, regeneration wastewater **Minimal to Moderate**.
Capital Cost	\$77 for cooler setup	\$25,000 - \$75,000	\$1,250 - \$1,900 (pre-treatment may be required if arsenic III is present)	\$150 - \$1,500	\$2,800 - \$6,000 (pre-treatment may be required if arsenic III is present)	Source water quality, hydrogeologic/well conditions, site/environmental setting, regulatory/environmental compliance	\$1,500 to \$2,500 (pre-treatment may be required if arsenic III is present)

Evaluation Criteria for Arsenic	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Mitigation - Reverse Osmosis	Mitigation - Distillation	Mitigation - Adsorptive Media	Mitigation - Oxidizing Media Filtration	Mitigation - Anion Exchange
Annual O&M Cost	$585 for bottled delivery per year (family of 4)	$360 - $2,100	$200 - $990	$100 - $600 + $960 in energy cost	$300 - $1,000	$2,200 - $5,000 (estimate on installation cost if needed)	$550 - $900 (from Ecolab quote and MDH home treatment pdf)
Approximate 30 Year Cost	$17,550	$35,800 - $138,000	$8,500 - $33,500 (assumes one replacement unit over 30 years)	$32,100 - $49,800 (assumes one replacement unit over 30 years)	$11,800 - $36,000	$200 - $800	$18,000 - $29,900

Table 2D: Comparative Analysis Summary – Lead

Evaluation Criteria for Lead	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Plumbing System Investigation	Mitigation - Carbon Filters	Mitigation - Reverse Osmosis	Mitigation - Distillation
Effectiveness on range of contaminants (Lead)	Bottled water is highly effective at reducing lead.	A public water supply connection is highly effective at reducing lead; testing and monitoring efforts ensure lead are not present at unsafe levels in public water supplies. The plumbing system would still need to be investigated to rule out any lead contamination coming from within the home's system.	Plumbing investigation/replacement **highly effective**; once the lead component is located, the system could be upgraded to remove the lead exposure from the system.	Carbon filters are highly effective at reducing lead through adsorption. Not all filters are designed to remove lead; a specific micron size is required. (RTI International)	Reverse osmosis is highly effective at reducing lead. (ESP Water Products)	Distillation is highly effective at reducing lead.

Evaluation Criteria for Lead	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Plumbing System Investigation	Mitigation - Carbon Filters	Mitigation - Reverse Osmosis	Mitigation - Distillation
Overall protectiveness and performance	Provides a **high achievement** of protectiveness. Current Good Manufacturing Practices are Food and Drug Administration-mandated regulations ensuring bottled water is safe and sanitary by requiring bottlers to process and bottled water under sanitary conditions, protect water sources from contaminants, use quality control processes for chemical and bacteriological safety, and conduct regular sampling and testing of water.	Provides a **high achievement** of protectiveness.	Provides a **high achievement** of protectiveness once the lead component is located and removed.	A certified carbon filter that meets NSF/ANSI Standard 53 can be **highly protective** against lead contamination.	Provides a **high achievement** of protectiveness. Independent studies and field applications show that RO can remove up to 95-99% of lead from contaminated water.	Provides a **high achievement** of protectiveness. Lead's boiling point is extremely high (3,180°F), so it is left behind as a solid residue in the boiling chamber.
Technology Availability	Bottled water is available throughout the State of Minnesota; **readily available**.	Dependent upon location of well and available public water supply to hookup to.	Licensed plumbers are widely available around the State of Minnesota**.**	Off-the-shelf POU options are widley available. Professional vendors are available throughout the State of Minnesota; **readily available**	Vendors are available throughout the State of Minnesota; **readily available**	Countertop solutions are **mostly available** at most home improvement stores. Well owner should consider that countertop treatments produce six gallons of water a day. Larger units may be available at water distiller companies, however these solutions may be for commercial use.

Evaluation Criteria for Lead	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Plumbing System Investigation	Mitigation - Carbon Filters	Mitigation - Reverse Osmosis	Mitigation - Distillation
Ease of installation	**Easy** to set up water dispenser; well owner can complete setup.	**Moderate to difficult**; dependent upon location and vicinity to water supply hookup. Likely requires significant earth work to install lines from public water supply connection to home.	**Moderate**; dependent upon the lead-causing issue that would need to be replaced.	**Easy to moderate**, a whole-house filter would require professional installation. Gravity fed and POU options can be installed by well owner	**Easy to moderate**, a licensed plumber may be needed for whole-house systems or if well owner does not have basic plumbing skills.	**Easy to moderate**, depending on unit size. Countertop models are simple to install, larger units may require plumbing and/or electrical modifications.

Evaluation Criteria for Lead	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Plumbing System Investigation	Mitigation - Carbon Filters	Mitigation - Reverse Osmosis	Mitigation - Distillation
Convenience	Requires ongoing tracking, coordination, delivery, and storage of water bottles. Weight of water bottles may be prohibitive. Safe drinking water limited to bottled water cooler location with relatively low flow: **Low convenience**.	Requires significant earthwork and disturbance to landscaping. Requires well owner to be on site during installation. Provides safe water to entire household at high flow rates and unlimited quantities. **Moderate convenience.**	Requires the well owner to be on-site during the investigation and replacement of lead-containing elements. May require excavation of underground lines, removal of the well pump, and access to internal areas of the household. Safe water is supplied to the entire household in unlimited amounts at high volumes and flow rates. Convenience is **moderate to high**.	Point of use systems require well owner to be on site during installation. Gravity-fed systems are easy to operate and require countertop or refrigerator. Provides safe drinking water only to point of use location or from gravity-fed system. POU systems deliver water at moderate flow and moderate quantity. Gravity-fed systems provide safe water at low quantities and rates. Filter replacement can be completed by owner. Convenience is **moderate to low**.	Requires well owner to be on site during installation. Provides safe drinking water only to point of use location. Delivers water at moderate flow and moderate quantity. Filter replacement can be completed by owner. Convenience is **moderate**.	Typically requires countertop space to store unit. Requires frequent filling of reservoir. Produces treated water slowly and at low volumes. Units may also produce heat and noise during operation. May require additives to replace mineral loss for taste. Convenience is **very low**.

Evaluation Criteria for Lead	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Plumbing System Investigation	Mitigation - Carbon Filters	Mitigation - Reverse Osmosis	Mitigation - Distillation
Operations and maintenance (O&M) **•Life expectancy** **•Serviceability** **•Parts availability** **•Waste products**	Life expectancy: N/A - Ongoing as long as necessary. Serviceability: Difficult - monthly delivery and coordination. Parts availability: Readily available. Waste: Not applicable - Bottles to be recycled by vendor **High.**	Life expectancy: forever Serviceability: Public water supply depends on location, commercial plumbers are common. Parts availability: Usually mostly available. Waste: Trenching, highly dependent on depth of well and geology. **Minimal.**	Life expectancy: Permanent assuming the lead-containing elements are identified and removed. Serviceability: Professional plumbers are widley available. Parts availability: Usually readily available. Waste: Piping, fittings, or components to be replaced. **Minimal.**	Life expectancy: Many years for external components, carbon needs to be replaced regularly - annual monitoring recommended; Serviceability: Basic service is easy to complete by well owner. If professional help is needed, providers are mostly available throughout the state. Parts availability: Usually readily available. Waste: Spent carbon, wastewater **Moderate**.	Life expectancy: 10-15 years; filters need to be replaced every 6-12 months, membrane replacement 2-5 years Serviceability: Filter replacements done by homeowner, larger repairs by done by professionals. Parts availability: Usually readily available. Waste: Rejectant stream. **Moderate**.	Life expectancy: 10-15 years for smaller units; Serviceability: basic maintenance easy to complete by homeowner. Professional providers are mostly available throughout the state for larger repairs. Parts availability: Usually readily available. Waste: Distiller concentrate/brine **Minimal to Moderate**.
Considerations for well conditions, hydrogeology, and other environmental conditions	N/A	Source water protection, infrastructure and location, environmental impact of construction, water system capacity and sustainability, regulatory and safety considerations, community and environmental health.	Water chemistry, plumbing age and materials, water use/stagnation periods.	Source water quality, hydrogeologic/well conditions, site/environmental setting, operational/waste disposal considerations, environmental protection/sustainability	Water quality, hydrogeologic conditions, site and installation conditions, wastewater management/environmental impact, infrastructure/power conditions, regulatory/environmental compliance	Water quality, temperature/climate conditions, water source/supply characteristics, site/infrastructure conditions, regulatory/environmental compliance

Evaluation Criteria for Lead	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Plumbing System Investigation	Mitigation - Carbon Filters	Mitigation - Reverse Osmosis	Mitigation - Distillation
Capital Cost	$77 for cooler setup	$25,000 - $75,000	$150 - $5,000	$30 - $6,000	$1,250 - $1,900	$150 - $1,500
Annual O&M Cost	$585 for bottled delivery per year (family of 4)	$360 - $2,100	No annual cost if lead is removed from the system.	$60 - $600	$200 - $990	$100 - $600 + $960 in energy cost
Approximate 30 Year Cost	$17,550	$35,800 - $138,000	$150 - $5,000	$1,800 - $24,000	$8,500 - $33,500 (assumes one replacement unit over 30 years)	$32,100 - $49,800 (assumes one replacement unit over 30 years)

Table 2E: Comparative Analysis Summary – Manganese

Evaluation Criteria	Alternative Water Source - Bottled Water	Mitigation - Reverse Osmosis	Mitigation - Water Softening	Mitigation - Distillation	Mitigation - Oxidizing Media Filtration	Mitigation - Ozonation & Filtration
Effectiveness on range of contaminants (Manganese)	Bottled Water is **highly effective** at reducing manganese.	Reverse osmosis is **moderately effective** at reducing manganese.	Water softening is **moderately effective** at reducing dissolved manganese. Optimal results require specific water conditions such as low concentrations of dissolved oxygen and pH above 6.7.	Distillation is **highly effective** at reducing manganese.	Oxidizing media filtration is **highly effective** at reducing manganese.	Ozonation & filtration is **highly effective** at reducing manganese.
Overall protectiveness and performance	Provides a **high achievement** of protectiveness. Current Good Manufacturing Practices are Food and Drug Adminstration-mandated regulations ensuring bottled water is safe and sanitary by requiring bottlers to process and bottled water under sanitary conditions, protect water sources from contaminants, use quality control processes for chemical and bacteriological safety, and conduct regular sampling and testing of water.	Provides a **high achievement** of protectiveness. More than 90% of manganese can be removed with reverse osmosis. However, this method shouldn’t be used for treating high levels of manganese, as too much manganese blocks and damages the membrane.	Provides a **moderate achievement** of protectivenes; manganese needs to be dissolved and levels must be low. Oxidized manganese can damage the softener and will cause the resin to foul.	Provides a **high achievement** of protectiveness. Manganese's boiling point is extremely high (3,742°F), so it is left behind as a solid residue in the boiling chamber.	Provides a **high achievement** of protectiveness. Can be limited by several factors, including the incoming manganese concentration, water chemistry (especially pH), temperature, and the specific filter media and oxidant used.	A well-designed and properly operated system provides a **high achievement** of protectiveness.

Evaluation Criteria	Alternative Water Source - Bottled Water	Mitigation - Reverse Osmosis	Mitigation - Water Softening	Mitigation - Distillation	Mitigation - Oxidizing Media Filtration	Mitigation - Ozonation & Filtration
Technology Availability	Bottled water is available throughout the State of Minnesota; **readily available**.	Vendors are available throughout the State of Minnesota; **readily available**	Vendors are available throughout the State of Minnesota; **readily available**	Countertop solutions are **mostly available** at most home improvement stores. Well owner should consider that countertop treatments produce six gallons of water a day. Larger units may be available at water distiller companies, however these solutions may be for commercial use.	Some water treatment companies are **mostly available** throughout Minnesota.	Some water treatment companies are **mostly available** throughout Minnesota.
Ease of installation	**Easy** to setup water dispenser, well owner can complete setup.	**Easy to moderate**, a licensed plumber may be needed for whole-house systems or if well owner does not have basic plumbing skills.	**Easy to moderate**, a licensed plumber may need to relocate the supply lines	**Easy to moderate**, depending on unit size. Countertop models are simple to install, larger units may require plumbing and/or electrical modifications.	**Moderate**, since professional installation is necessary for installation.	**Moderate**, since professional installation is necessary for installation.

Evaluation Criteria	Alternative Water Source - Bottled Water	Mitigation - Reverse Osmosis	Mitigation - Water Softening	Mitigation - Distillation	Mitigation - Oxidizing Media Filtration	Mitigation - Ozonation & Filtration
Convenience	Requires ongoing tracking, coordination, delivery, and storage of water bottles. Weight of water bottles may be prohibitive. Safe drinking water limited to bottled water cooler location with relatively low flow: **Low convenience**.	Requires well owner to be on site during installation. Provides safe drinking water only to point of use location. Delivers water at moderate flow and moderate quantity. Filter replacement can be completed by owner. Convenience is **moderate**.	Requires well owner to be on site during installation. Typically installed at point of entry, producing safe water for entire household at high flow rates and volumes. Salt management is completed by well owner; however, handling salt bags may be difficult. Convenience is **moderate to high**.	Typically requires countertop space to store unit. Requires frequent filling of reservoir. Produces treated water slowly and at low volumes. Units may also produce heat and noise during operation. May require additives to replace mineral loss for taste. Convenience is **very low**.	Requires well owner to be on site during installation. Typically installed at point of entry, producing safe water for entire household at high flow rates and volumes. Media replacement can be completed by owner. Convenience is **moderate to high**.	Requires well owner to be on site during installation. Provides safe drinking water only to point of use location. Produces low-level noise during operation. Delivers water at moderate flow and moderate quantity. Filter replacement can be completed by owner. Convenience is **moderate**.

Evaluation Criteria	Alternative Water Source - Bottled Water	Mitigation - Reverse Osmosis	Mitigation - Water Softening	Mitigation - Distillation	Mitigation - Oxidizing Media Filtration	Mitigation - Ozonation & Filtration
Operations and maintenance (O&M) **•Life expectancy** **•Serviceability** **•Parts availability** **•Waste products**	Life expectancy: N/A - Ongoing as long as necessary. Serviceability: Difficult - monthly delivery and coordination. Parts availability: Readily available. Waste: Not applicable - Bottles to be recycled by vendor **High.**	Life expectancy: 10-15 years; filters need to be replaced every 6-12 months, membrane replacement 2-5 years Serviceability: Filter replacements done by homeowner, larger repairs by done by professionals. Parts availability: Usually readily available. Waste: Rejectant stream. **Moderate**.	Life expectancy: 10-15 years; resin typically lasts 7-10 years, salt/brine tank should be checked monthly Serviceability: Basic maintenance is easy. If professional help being needed, providers are regularly available throughout state. Parts availability: Usually readily available. Waste: Backwash water **Moderate**.	Life expectancy: 10-15 years for smaller units; Serviceability: basic maintenance easy to complete by homeowner. Professional providers are mostly available throughout the state for larger repairs. Parts availability: Usually readily available. Waste: Distiller concentrate/brine **Minimal to Moderate**.	Life expectancy: 4-8 years depnding on media, usage, and contaminants; Serviceability: Replacement of greensand filters is typically easy to complete by well owners. If professional help is needed, providers are mostly available throughout the state. Parts availability: Mostly available. Waste: Oxidized contaminant particles/spent media, backwash water **Moderate**.	Life expectancy: 3-10 years for ozone generator - varies significantly by manufacturer and quailty; Serviceability: Service typically requires a professional. Parts availability: Mostly available. Waste: Oxidized contaminant particles/spent media, backwash water **Moderate**.
Considerations for well conditions, hydrogeology, and other environmental conditions	N/A	Water quality, hydrogeologic conditions, site and installation conditions, wastewater management/environmental impact, infrastructure/power conditions, regulatory/environmental compliance	Water quality, site/drainage conditions, disposal/environmental discharge, equipment location/climate, hydrogeologic/environmental sensitivity	Water quality, temperature/climate conditions, water source/supply characteristics, site/infrastructure conditions, regulatory/environmental compliance	Source water quality, hydrogeologic/well conditions, site/environmental setting, regulatory/environmental compliance	Water quality, hydrogeologic conditions, site conditions, environmental safety/byproduct management, regulatory/ecological considerations, maintenance/monitoring environment
Capital Cost	$77 for cooler setup	$1,250 - $1,900	$2,000 - $5,000	$150 - $1,500	$2,200 - $5,000 (estimate on installation cost if needed)	$4,500 - $8,000 (estimate on installation cost)

Evaluation Criteria	Alternative Water Source - Bottled Water	Mitigation - Reverse Osmosis	Mitigation - Water Softening	Mitigation - Distillation	Mitigation - Oxidizing Media Filtration	Mitigation - Ozonation & Filtration
Annual O&M Cost	$585 for bottled delivery per year (family of 4)	$200 - $990	$50 - $300	$100 - $600 + $960 in energy cost	$200 - $800	$50 - $300
Approximate 30 Year Cost	$17,550	$8,500 - $33,500 (assumes one replacement unit over 30 years)	$5,500 - $19,000	$32,100 - $49,800 (assumes one replacement unit over 30 years)	$10,400 - $34,000 (assumes one replacement unit over 30 years)	$10,500 - $25,000 (assumes one replacement unit over 30 years)

Table 3A: Numerical Comparative Analysis Summary - Coliform Bacteria

Evaluation Criteria	Alternative Water Source - Bottled Water	Alternative Water Source - New Well Installation	Alternative Water Source - Public Water Supply Connection	Well Repairs & Disinfection	Mitigation - Disinfection
Effectiveness for reducing contaminants (Coliform Bacteria)	3	3	3	3	2.5
Overall protectiveness and performance	3	3	3	3	2
Technology Availability	3	2	1	2	3
Ease of installation	3	1.5	1.5	1.5	3
Convenience	1	2	2	2.5	3
Operations and maintenance (O&M) (Life expectancy, Serviceability, Parts availability, Waste products)	1	2	3	2	3
Capital Cost	3	1	1	2	3
Annual O&M Cost*	3	2.5	2.5	2.5	3
Approximate 30 Year Cost	2	2	1.5	2.5	3
Total Numerical Value	**22**	**19**	**18.5**	**21**	**25.5**

Notes
Scores are based on 1 = low achievement; 2 = moderate achievement; and 3 = high achievement
Scoring for effectiveness are based on 1 = not very effective, 2 = moderately effective, 3 = highly effective
Scoring for protectiveness are based on 1 = low achievement, 2 = moderate achievement, 3 = high achievement
Scoring for availability are based on 1 = dependent on vendor availability, 2 = mostly available, 3 = readily available
Scoring for installations are based on 1 = difficult, 2 = moderate, 3 = easy
Scoring for O&M is based on 1 = high maintenance, 2 = moderate maintenance, 3 = minimal maintenance
Scoring for capital and O&M cost are based on the following cost breakpoints: 1 = More than $5,000; 2= $1,000 to $5,000; 3 = less than $1,000
Scoring for 30 year costs are based on the following cost breakpoints: 1 = More than $50,000; 2= $10,000 to $50,000; 3 = less than $10,000

*Annual O&M costs were annualized whether or not incurred annually
See Table 2A for a discussion of each criterion.

Table 3B: Numerical Comparative Analysis Summary - Nitrate

Evaluation Criteria for nitrate	Alternative Water Source - Bottled Water	Alternative Water Source - New Well Installation	Alternative Water Source - Public Water Supply Connection	Well Repairs & Disinfection	Mitigation - Reverse Osmosis	Mitigation - Anion Exchange	Mitigation - Distillation
Effectiveness for reducing contaminants (nitrates)	3	2	3	2.5	3	3	3
Overall protectiveness and performance	3	2.5	3	2	3	3	3
Technology Availability	3	2	1	2	3	1	2
Ease of installation	3	1.5	1.5	1.5	2.5	2	2.5
Convenience	1	2	2	2.5	2	1.5	0.5
Operations and maintenance (O&M) (Life expectancy, Serviceability, Parts availability, Waste products)	1	2	3	2	2	2.5	2.5
Capital Cost	3	1	1	1.5	2	2	2.5
Annual O&M Cost*	3	2.5	2	2.5	3	3	2
Approximate 30 Year Cost**	2	2	1.5	2	2.5	2.5	2
Total Numerical Value	**22**	**17.5**	**18**	**18.5**	**23**	**20.5**	**20**

Notes
Scores are based on 1 = low achievement; 2 = moderate achievement; and 3 = high achievement
Scoring for effectiveness are based on 1 = not very effective, 2 = moderately effective, 3 = highly effective
Scoring for protectiveness are based on 1 = low achievement, 2 = moderate achievement, 3 = high achievement
Scoring for availability are based on 1 = dependent on vendor availability, 2 = mostly available, 3 = readily available
Scoring for installations are based on 1 = difficult, 2 = moderate, 3 = easy
Scoring for O&M is based on 1 = high maintenance, 2 = moderate maintenance, 3 = minimal maintenance
Scoring for capital and O&M cost are based on the following cost breakpoints: 1 = More than $5,000; 2= $1,000 to $5,000; 3 = less than $1,000
Scoring for 30 year costs are based on the following cost breakpoints: 1 = More than $50,000; 2= $10,000 to $50,000; 3 = less than $10,000

*Annual O&M costs were annualized whether or not incurred annually

See Table 2B for a discussion of each criterion.

Table 3C: Numerical Comparative Analysis Summary – Arsenic

Evaluation Criteria for Arsenic	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Mitigation - Reverse Osmosis	Mitigation - Distillation	Mitigation - Adsorptive Media	Mitigation - Oxidizing Media Filtration	Mitigation - Anion Exchange
Effectiveness for reducing contaminants (arsenic)	3	3	2	3	2	2	2
Overall protectiveness and performance	3	3	3	3	3	2	2.5
Technology Availability	3	1	3	2	3	2	1
Ease of installation	3	1.5	2.5	2.5	2.5	2	2
Convenience	1	2	2	0.5	2	2.5	1.5
Operations and maintenance (O&M) (Life expectancy, Serviceability, Parts availability, Waste products)	1	3	2	2.5	2	2	2.5
Capital Cost	3	1	2	2.5	1.5	2	2
Annual O&M Cost*	3	2.5	3	2	3	3	3
Approximate 30 Year Cost	2	1.5	2.5	2	2	2	2
Total Numerical Value	**22**	**18.5**	**22**	**20**	**21**	**19.5**	**18.5**

Notes
Scores are based on 1 = low achievement; 2 = moderate achievement; and 3 = high achievement
Scoring for effectiveness are based on 1 = not very effective, 2 = moderately effective, 3 = highly effective
Scoring for protectiveness are based on 1 = low achievement, 2 = moderate achievement, 3 = high achievement
Scoring for availability are based on 1 = dependent on vendor availability, 2 = mostly available, 3 = readily available
Scoring for installations are based on 1 = difficult, 2 = moderate, 3 = easy
Scoring for O&M is based on 1 = high maintenance, 2 = moderate maintenance, 3 = minimal maintenance
Scoring for capital and O&M cost are based on the following cost breakpoints: 1 = More than $5,000; 2= $1,000 to $5,000; 3 = less than $1,000
Scoring for 30 year costs are based on the following cost breakpoints: 1 = More than $50,000; 2= $10,000 to $50,000; 3 = less than $10,000

*Annual O&M costs were annualized whether or not incurred annually

See Table 2C for a discussion of each criterion.

Table 3D: Numerical Comparative Analysis Summary – Lead

Evaluation Criteria	Alternative Water Source - Bottled Water	Alternative Water Source - Public Water Supply Connection	Plumbing System Investigation	Mitigation - Carbon Filters	Mitigation - Reverse Osmosis	Mitigation - Distillation
Effectiveness for reducing contaminants (lead)	3	3	3	3	3	3
Overall protectiveness and performance	3	3	3	3	3	3
Technology Availability	3	1	3	3	3	2
Ease of installation	3	1.5	2	2.5	2.5	2.5
Convenience	1	2	2.5	1.5	2	0.5
Operations and maintenance (O&M) (Life expectancy, Serviceability, Parts availability, Waste products)	1	3	3	2	2	2.5
Capital Cost	3	1	2	1.5	2	2.5
Annual O&M Cost*	3	2.5	3	3	3	2
Approximate 30 Year Cost	2	1.5	3	2.5	2.5	2
Total Numerical Value	**22**	**18.5**	**24.5**	**22**	**23**	**20**

Notes
Scores are based on 1 = low achievement; 2 = moderate achievement; and 3 = high achievement
Scoring for effectiveness are based on 1 = not very effective, 2 = moderately effective, 3 = highly effective
Scoring for protectiveness are based on 1 = low achievement, 2 = moderate achievement, 3 = high achievement
Scoring for availability are based on 1 = dependent on vendor availability, 2 = mostly available, 3 = readily available
Scoring for installations are based on 1 = difficult, 2 = moderate, 3 = easy
Scoring for O&M is based on 1 = high maintenance, 2 = moderate maintenance, 3 = minimal maintenance
Scoring for capital and O&M cost are based on the following cost breakpoints: 1 = More than $5,000; 2= $1,000 to $5,000; 3 = less than $1,000
Scoring for 30 year costs are based on the following cost breakpoints: 1 = More than $50,000; 2= $10,000 to $50,000; 3 = less than $10,000

*Annual O&M costs were annualized whether or not incurred annually

See Table 2D for a discussion of each criterion.

Table 3E: Numerical Comparative Analysis Summary - Manganese

Evaluation Criteria	Alternative Water Source - Bottled Water	Mitigation - Reverse Osmosis	Mitigation - Water Softening	Mitigation - Distillation	Mitigation - Oxidizing Media Filtration	Mitigation - Ozonation & Filtration
Effectiveness for reducing contaminants (manganese)	3	2	2	3	3	3
Overall protectiveness and performance	3	3	2	3	3	3
Technology Availability	3	3	3	2	2	2
Ease of installation	3	2.5	2.5	2.5	2	2
Convenience	1	2	2.5	0.5	2.5	2
Operations and maintenance (O&M) (Life expectancy, Serviceability, Parts availability, Waste products)	1	2	2	2.5	2	2
Capital Cost	3	2	2	2.5	2	1.5
Annual O&M Cost*	3	3	3	2	3	3
Approximate 30 Year Cost	2	2.5	2.5	2	2	2
Total Numerical Value	**22**	**22**	**21.5**	**20**	**21.5**	**20.5**

Notes
Scores are based on 1 = low achievement; 2 = moderate achievement; and 3 = high achievement
Scoring for effectiveness are based on 1 = not very effective, 2 = moderately effective, 3 = highly effective
Scoring for protectiveness are based on 1 = low achievement, 2 = moderate achievement, 3 = high achievement
Scoring for availability are based on 1 = dependent on vendor availability, 2 = mostly available, 3 = readily available
Scoring for installations are based on 1 = difficult, 2 = moderate, 3 = easy
Scoring for O&M is based on 1 = high maintenance, 2 = moderate maintenance, 3 = minimal maintenance
Scoring for capital and O&M cost are based on the following cost breakpoints: 1 = More than $5,000; 2= $1,000 to $5,000; 3 = less than $1,000
Scoring for 30 year costs are based on the following cost breakpoints: 1 = More than $50,000; 2= $10,000 to $50,000; 3 = less than $10,000

*Annual O&M costs were annualized whether or not incurred annually

See Table 2E for a discussion of each criterion.

Table 4: COC Screening Results Summary

Category	Treatment	Coliform Bacteria	Nitrates	Arsenic	Lead	Manganese
Alternative Water Source	Bottled Water	22	22	22	22	22
Alternative Water Source	New Well	19	17.5	NE	NE	NE
Alternative Water Source	Public Water Supply	18.5	18	18.5	18.5	NE
Investigation/ Repairs	Plumbing System Investigation	NE	NE	NE	24.5	NE
Investigation/ Repairs	Well Repair & Disinfection	21	18.5	NE	NE	NE
Mitigation	Disinfection	25.5	NE	NE	NE	NE
Mitigation	Reverse Osmosis	NE	23	22	23	22
Mitigation	Anion Exchange	NE	20.5	18.5	NE	NE
Mitigation	Distillation	NE	20	20	20	20
Mitigation	Adsorptive Media	NE	NE	21	NE	NE
Mitigation	Aeration & Filtration	NE	NE	NE	NE	NE
Mitigation	Ozonation & Filtration	NE	NE	NE	NE	20.5
Mitigation	Oxidizing Media Filtration	NE	NE	19.5	NE	21.5
Mitigation	Carbon Filters	NE	NE	NE	22	NE
Mitigation	Water Softening	NE	NE	NE	NE	21.5