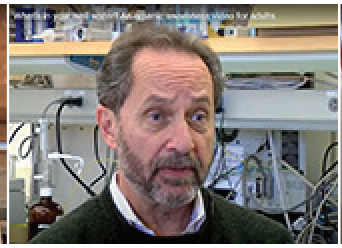

Arsenic Water Treatment for Private Wells in New Jersey

Arsenic Overview

Arsenic is the second most common contaminant to exceed primary drinking water standards in New Jersey private wells. As of 2018, water from over 49,000 private wells has been tested for arsenic under the New Jersey Private Well Testing Act (PWTA) (NJDOH, 2023). The Piedmont Physiographic Province (fig. 1) has been identified as the highest risk area for arsenic with 17% of the province's

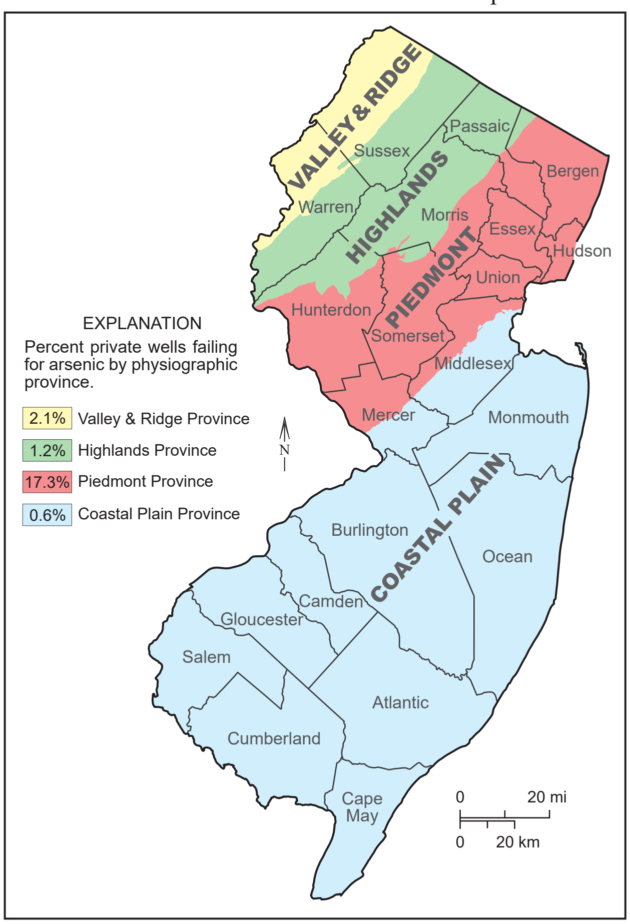

Figure 1. Arsenic exceedance in private wells by physiographic province.

private wells failing to meet the standard known as the maximum contaminant level (MCL) standard. Arsenic exceeding the MCL can also be found in the other physiographic provinces but at lower rates: Valley and Ridge (2%), Highlands (1%), and Coastal Plain (1%). Research by the New Jersey Geological & Water Survey (NJGWS) indicates arsenic is naturally occurring in arsenic bearing minerals in various geologic formations (NJDEP, 2004), and no association between private wells and known contaminated sites has been identified in New Jersey. The only contaminant to exceed arsenic's prevalence in New Jersey private wells is gross alpha, a measure of radioactivity in water, which is also naturally occurring.

Arsenic is a toxic element and exposure via well water increases the risk of a wide range of adverse health effects. These include cancer of the skin, bladder, lung, liver, and kidneys, as well as heart disease, peripheral neuropathy, skin disorders, diabetes, respiratory disease, and cognitive deficits in children (IPCS, 2001, Tolins et. al. 2014).

The New Jersey drinking water standard for arsenic is 5 micrograms per liter (µg/L). Since arsenic is a known human carcinogen via drinking water, the US Environmental Protection Agency has set an MCL-Goal for arsenic at 0 µg/L. The MCL-Goal is defined by USEPA as the level of contaminant in drinking water below which there is no known or expected risk to health and which allows a margin of safety.

Arsenic concentrations in New Jersey private wells range from less than 1 µg/L to 254 µg/L. The highest concentrations are found in the Highlands and Piedmont Physiographic Provinces.

Arsenic Water Testing

Arsenic in well water is colorless, odorless, and tasteless. The only way to identify its presence is to have the water specifically tested for arsenic. Due to arsenic's high prevalence in the Piedmont Province, DEP recommends all private well owners in this part of the state should have their water tested for arsenic (nj.gov/dep/dsr/arsenic/guide.htm). Water testing labs can be found through an online search for "NJ private well water test" or a list of certified labs can be obtained via the NJDEP DataMiner (njems.nj.gov/DataMiner/Search/SearchByCategory). Use a lab that is certified to test drinking water for arsenic and can provide a method detection limit (MDL) of 1 µg/L.

If a well's arsenic level is below 2.5 µg/L you should re-test at least once every five years. If the arsenic level is greater than 2.5 µg/L, you should re-test once per year (Mailloux et. al. 2020). It should be noted EPA's public health based MCL-Goal for arsenic is 0 µg/L.

If the observed arsenic level is greater than 5 µg/L, DEP recommends that arsenic water treatment be installed after a retest confirms the reading (nj.gov/dep/dsr/arsenic/guide.htm). The re-sampling for arsenic should also test for pH, hardness, iron, manganese, nitrate, phosphate, radionuclides, sulfate, and silica, as their concentrations can have an impact on the efficiency and design of your arsenic treatment system.

Arsenic in New Jersey well water occurs in two species commonly referred to as arsenite (the reduced species - also referred to as As^{III}) and arsenate (the oxidized species - also referred to as As^{V}). The tests to determine these species are not widely available from commercial labs, and therefore arsenic is generally reported as total arsenic. Arsenite, due to its neutral charge, is much more difficult to remove from water than arsenate which is an anion (negatively charged). More information on arsenic species is provided in the "Potential Problems with Arsenic Water Treatment" section.

Arsenic Water Treatment

Treatment System Design

Arsenic removal requires special considerations. Water softeners and granular activated carbon do not remove arsenic. The New Jersey Geological & Water Survey (NJGWS) tested and evaluated treatment systems to determine the most efficient, cost effective, user friendly, and environmentally sound water treatment technologies to remove arsenic from residential well water in New Jersey.

Based on NJGWS testing, the best performing treatment technology for arsenic removal in New Jersey is a whole-house, two-tank, iron- or titanium-based adsorption system as shown in Table 1. This type of system can remove both arsenic species from all water in the home, is easy to operate and maintain, and the arsenic is not returned to the environment via regeneration. This type of system is called a "Point-of-Entry" (POE) system because the water treatment is installed where the water enters the home and all the water in the home is treated. The proper setup for this type of system is shown in Figure 2. The system consists of:

- a shut-off valve,
- a 5-micron sediment pre-filter,
- a raw water sample tap,
- two 10x40 inch or 9x48 inch tanks each containing at least

Table 1. Arsenic treatment options and cost survey options.

Treatment Type	Cost (2014)	Pro's	Con's
Whole-House (POE) Adsorption[1]	$2,495[3]	Treats all water in the home. All asenic exposure removed.	Relatively expensive start-up and maintenance costs for POE.
Point-of-Use (POU)[2] Adsorption[1]	$835/Unit[3]	May be less expensive han POE. Removes arsenate and arsenite.	Multiple units needed -- One for each faucet used for drinking or cooking. Arsenic exposure at untreated faucets.
Point-of-Use (POU)[2] Reverse Osmosis	$835/Unit[3]	May be less expensive than POE. Can remove other contaminants.	Does not effectively remove arsenite. Arsenic exposure at untreated faucets. Multiple units needed -- One for each faucet used for drinking or cooking.

[1]The most effective adsorptive media tested by NJDEP are granular ferric oxide titanium, and hybrid media that contain iron-impregnated resin. They all remove both arsenite and arsenate, but the capacity for arsenite is much less than for arsenate.
[2]POU units should be installed at each potential drinking water tap in the home, or a POE whole-house treatment system should be used.
[3]POE maintenance costs for media replacement once every 3-4 years will average about $300 per year. POU maintenance costs for annual cartridge replacements will average about $100 per year per unit. Costs have been estimated from an NJGWS and Columbia University Cost Survey which was conducted in 2014. Costs may vary with time and market conditions.

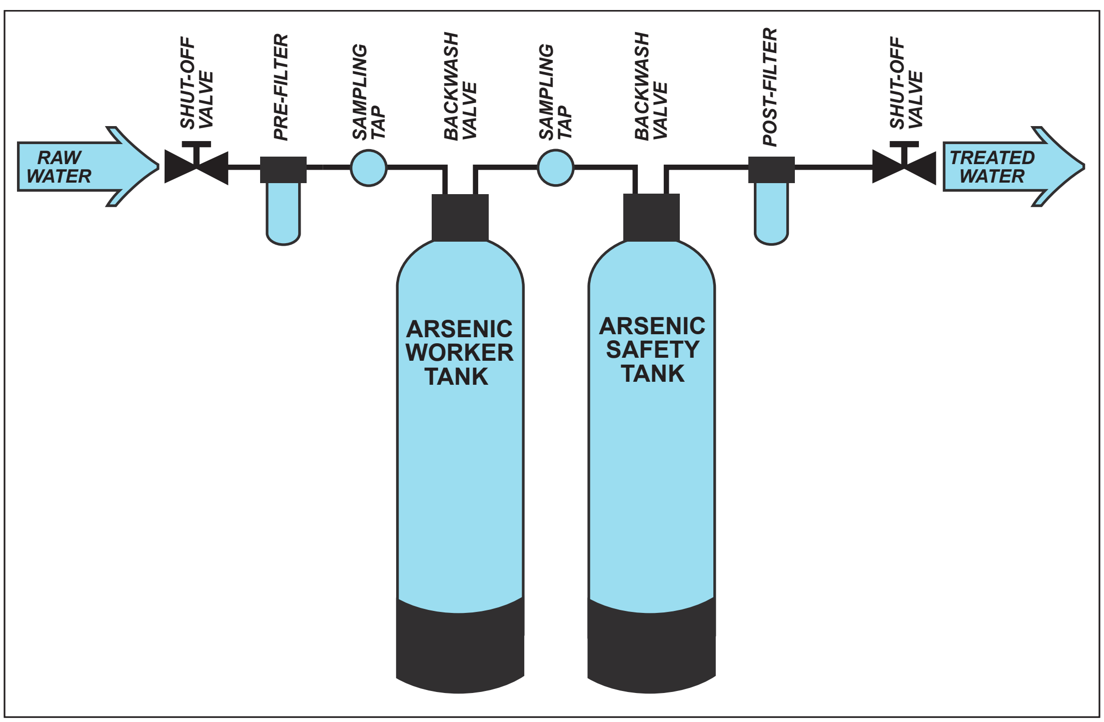

Figure 2. Arsenic water treatment system schematic.

one cubic foot of adsorption media (if arsenic concentrations are greater than 50 µg/L or high flow rates are required (based on number of bathrooms), larger tanks and a greater volume of media should be considered in consultation with your water treatment professional),
- automatic backwash control valves on each tank,a sample tap between the tanks,
- a 5-micron post-treatment sediment filter,
- a shut-off valve after the system,
- and a water meter (optional).

The system should be thoroughly backwashed before being placed into service. The backwash valves should be set to backwash the media at least once per month, each tank on a separate day. The backwash line should be piped to a suitable disposal location, maintaining a proper air gap according to local plumbing codes.

Pre-treatment of the water may be needed on some New Jersey wells. Water that has pH greater than 8.5, iron at greater than 0.5 milligrams per liter (mg/L), manganese at greater than 0.05 mg/L, sulfate at greater than 100 mg/L, high concentrations of iron bacteria, and/or a hardness greater than 300 mg/L (17.5 grains per gallon) may shorten the useful life of the arsenic treatment system and greatly increase maintenance costs. A water treatment professional should be able to recommend pre-treatment methods based on the water test results.

Untreated water from the well, called "raw water", flows through the first tank and then through the second tank. The first tank is called the “worker tank” because it performs most of the work removing arsenic. When the worker tank is new it will remove all the arsenic, but after about one year (depending on the arsenic level and how much water is used), the worker tank’s arsenic removal efficiency will start to decline and some arsenic will start to break through the worker tank. When this occurs, the second tank will remove the arsenic, and this is why the second tank is called the “safety tank”. Without the safety tank, users would be exposed to the arsenic breaking through the worker tank.

A properly installed and maintained two-tank Whole House POE system will reduce your water arsenic exposure to zero, which is the EPA MCL-goal for arsenic. A one-tank POE system cannot meet this goal. A two-tank POE system is also more economical over the life of the system. If the system has only one tank it must be changed as soon as the concentration gets near 5 µg/L. Otherwise arsenic levels might exceed the state standard. However, with a two-tank Whole House POE system, the home owner can safely conduct annual sampling and not need to replace the worker tank until the concentration after the worker tank exceeds 5 µg/L. Even if the concentration after the worker tank goes up to 10 or 20 µg/L, the safety tank will remove all of the arsenic before it reaches the household taps.

The pre-treatment sediment filter is needed to prevent well water particulates from infiltrating the treatment system. The post-treatment sediment filter is needed to prevent any particles of treatment media from entering the drinking water. Studies conducted by NJGWS in conjunction with Rutgers University have documented that water treatment media particles, mostly smaller than can be seen with the naked eye, often escape the treatment tank and get into the water supply. In a study of 65 New Jersey homes with arsenic water treatment and no post-treatment sediment filter, samples collected from faucet screens and the base of toilet tanks, analyzed under light microscopy, showed media particle breakthrough present in 72% of the homes (Rockafellow-Baldoni, 2016). A 5-micron post-treatment sediment filter should provide protection from these treatment media particles that likely contain high arsenic levels (Rockafellow-Baldoni et. al., 2021 in press).

The advantages of whole house point-of-entry adsorption treatment systems include the removal of both arsenate and arsenite from all the water in the home, arsenic not being returned to the environment via regeneration disposal, and easy operation and maintenance. If new and improved adsorption medias become available in the future, they can likely be used with the same equipment.

A maintenance plan provided by a water treatment professional should be a serious consideration when dealing with arsenic treatment. Because you can’t see, smell, or taste arsenic in your water, it is very important that the system be monitored and maintained as recommended. The results of a 2014 cost survey conducted by NJGWS and Columbia University for domestic/residential well arsenic water treatment installation and maintenance are shown in the Table 1 (Treatment Options).

Treatment Media Performance

With all adsorption systems, the initial testing of treated water should show no detectable levels of arsenic. However, eventually the media will start to reach its arsenic capacity and some arsenic will start to exit the treatment tank above the MCL, which we call breakthrough. There can be large variations in adsorption media performance and system longevity. Breakthrough curves can be used to compare various arsenic treatment media. Figure 3 shows simulated break-through curves for three different arsenic adsorption treatment media at a well with the raw untreated water arsenic concentration at 30 µg/L. For Media 1, the treated water arsenic concentration breaks through the MCL concentration of 5 µg/L after two years. Media 2 performs better and does not break through the 5 µg/L level until three years. Media 3 is the best performer and does not break through the 5 µg/L level until the sixth year. Well owners should ask their water treatment professional how their recommended media’s breakthrough compares to other available media types.

Assume the media costs per cubic foot are: Media 1 - $700 per cubic foot, Media 2 - $800 per cubic foot, and Media 3 - $1,000 per cubic feet. If ordering the system and assuming the performance will be the same for each media, Media 1 has the lowest upfront cost. However, which media will be the best investment over time, like a 12-year period? The 12-year costs for media alone (not including labor) will be: Media 1 - $4,200 (for

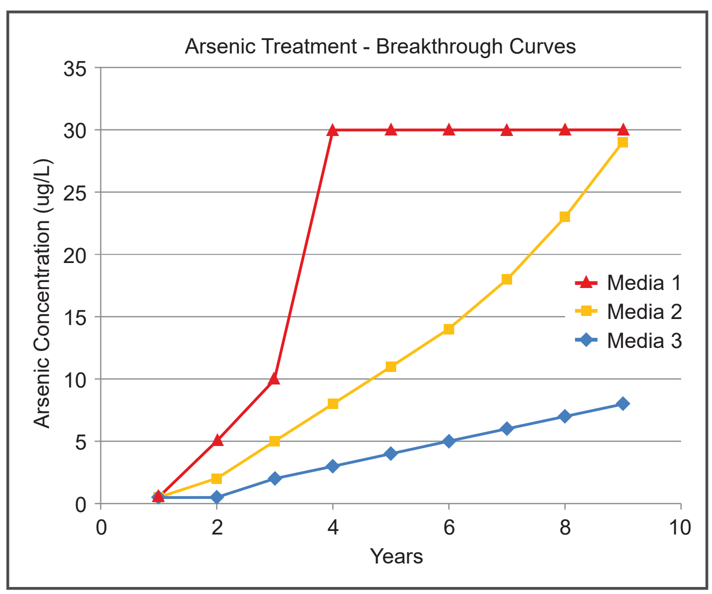

Figure 3. Simulated arsenic breakthrough curve for three different media types and a raw/untreated water arsenic concentration of 30 µg/L.

media replacement every two years - six times), Media 2 - $3,200 (for media replacement every three years - four times), and Media 3 - $2,000 (for media replacement ever six years - only two times). Based on the breakthrough curves, you will likely choose Media 3 as it will be a much better long-term investment and in 12 years can save you over $2,000 in media costs, not to mention savings in labor. Media costs listed here are for demonstration purposes only. Costs also vary with time and market conditions.

Potential Problems With Arsenic Water Treatment

Arsenic Species

As mentioned in the Arsenic Water Testing section, arsenic in New Jersey well water occurs in two species (arsenate and arsenite) and the arsenite species (the reduced species - also referred to as As^{III}) is much more difficult to treat because it has a neutral charge. The adsorption capacity of arsenic adsorption treatment media is much lower for arsenite. When arsenite is present, the breakthrough of arsenic through the media into the drinking water will occur much faster than if arsenate (the oxidized species - also referred to as As^{V}) was the predominant species present. Therefore, if arsenite is present and not pre-treated, the operating cost for the system will be greatly increased due to the need to prematurely change out the relatively expensive arsenic treatment media.

The tests to determine arsenic species are not widely available from commercial labs and speciation is not included in the general arsenic test. Therefore, NJGWS recommends two methods for determining the arsenic species.

The first method for arsenic speciation is a rule-of-thumb developed by NJGWS to determine which arsenic species is predominant. It uses readily available tests to determine if the water is reduced or oxidized. If raw water has any of the following, it is likely reduced and arsenite is the predominant arsenic species:

- dissolved concentration of iron greater than 100 µg/L (0.1mg/L),
- dissolved concentration of manganese greater than 50 µg/L (0.05 mg/L),
- sulfur odor, or
- a measured oxidation reduction potential that is negative.

The likelihood of having a significant portion of arsenite in raw well water increases as the number of the above items present in your water increases.

The second method for arsenic speciation uses commercially available arsenic speciation cartridges. These cartridges remove only arsenate from water. The process involves filling two sample bottles for total arsenic analysis. The first water sample bottle is filled directly with untreated water from the raw water tap. To fill the second water sample bottle, first a sample of the untreated water is drawn into a syringe. Then an arsenic speciation cartridge is installed on the end of the syringe. The water sample is slowly pushed from the syringe, through the speciation cartridge, and into the second water sample bottle (fig. 4). Both water sample bottles are sent to the lab for total arsenic analysis. The first bottle result will indicate the total arsenic concentration in the water. The second bottle has had the arsenate removed so that the total arsenic concentration in this bottle will indicate the arsenite concentration. Subtracting the arsenite concentration from the total arsenic concentration gives you the concentration of arsenate. A speciation cartridge example is shown in Table 2.

Figure 4. Use of arsenic speciation cartridge. *Photo by Z. Allen-Lafayette*

Table 2. Arsenic speciation cartridge example.

Bottle 1	Total Arsenic in Raw Water	27 µg/L
Bottle 2	Arsenite Only	21 µg/L
Calculation	Bottle1 - Bottle 2 = Arsenate	6 µg/L
This well water has a high amount of arsenite and needs arsenite pre-treatment.		

Pre-Treatment to Convert Arsenite to Arsenate

If your water has arsenite, pre-treatment of the water to oxidize arsenite to arsenate will improve removal and should provide long-term cost savings. This can be accomplished by several different methods.

Chlorine Injection

- This method is very effective at converting arsenite to arsenate.
- Chlorine has the added benefit of killing any bacteria in the water including iron bacteria, which are harmless to health but can cause early breakthrough of adsorption media due to sliming of the media.
- Chlorine is also effective at oxidizing dissolved iron and manganese, which if present will precipitate as very small particles and simultaneously capture a portion of the arsenic. This extends the life of the arsenic treatment system.
- This method requires you to add a calculated mixture of household bleach (or sodium hypochlorite) and water to a roughly 30-gallon chlorine injection tank monthly. The chlorine mixture is automatically injected in small doses to the water supply based on water use. Chlorine injection systems are very effective but require regular maintenance and several extra components, including an injection pump, flow switch to activate the pump, chlorine contact tank, a backwashing sediment capture tank, and a tank of granular activated carbon at the end of the treatment system to remove any residual chlorine. This system has a significantly larger foot print due to the number of additional tanks.

Ozone or Hydrogen Peroxide Injection

- These methods are very similar to chlorine injection. NJGWS has very limited experience with these systems and suggests you ask your water treatment professional about the pros and cons of each.

Aeration with a Manganese Oxide Catalyst Media

- These systems are desiged to oxidize and remove dissolved iron. They consist of a single tank that contains a manganese oxide or manganese dioxide catalyst.
- The tank will be regenerated with air on a regular basis (usually every three days). The air provides oxygen to keep the media activated.
- During the regeneration proccess the media is backwashed and any precipitated iron or manganese will be flushed out of the system.
- Typically, most of the arsenite is converted to arsenate in these systems.
- Like the chlorine injection system, some arsenic will be adsorbed to the precipitated iron particles. The more dissolved iron in the water, the more arsenic will be adsorbed during this step in the treatment system.
- These systems do not kill bacteria.
- Potential problems with these systems include:
    - There is potential for contaminated air to be drawn into the system and contaminate the water, and
    - Manganese oxide media has a strong tendency to adsorb radium and should not be used with water containing radium. If the water contains radium, the manganese oxide media in the tank can accumulate enough radium to turn it into technologically enhanced naturally occurring radioactive material (TENORM) that will emit gamma rays into the vicinity of the tank. TENORM is very expensive to dispose. Before using this type of system, a water test for gross alpha and radium should be conducted. Installing a water softener before the aeration system with a manganese oxide catalyst media will safely remove the radium and will also remove the iron and manganese.

Elevated pH

If the pH of the raw well water is above 8.0, arsenate adsorption will be reduced, and if the pH of the water is greater than 8.5, arsenite and arsenate adsorption will be greatly reduced. The high pH will cause arsenic breakthrough into the drinking water much faster than if the pH was lower. Without pre-treatment to lower the pH below 8.5, premature change out of the media will greatly increase your long-term costs.

The pH can be effectively reduced using an anion exchange system. If the pH is in the 8-10 range, an anion system will typically reduce the pH by two units into the 6-8 range. Anion exchange has the added benefit of removing arsenate because arsenate is an anion, and if used as pre-treatment to a whole-house adsorption system, it will greatly extend the life of the adsorption media. Anion exchange also removes uranium, nitrate, phosphate, and sulfate from water.

Like a water softener, anion exchange uses salt. The salt tank needs to be monitored and maintained to avoid arsenic dumping into the drinking water system. Dumping is the release of very high arsenic concentrations into the water over a short period of time. This can happen if the salt supply runs out or the resin has not been regenerated on the appropriate schedule for the anions in the water supply. Therefore, it is very important to have a water treatment professional set up the regeneration schedule and to always maintain salt in the salt tank. The regeneration and backwash water from an anion exchange system will likely contain high levels of arsenic and should go to the septic or sewer system.

Other pH lowering methods like injection of acetic or citric acid may be available from your water treatment professional.

Other Contaminants

There are several other contaminants that can co-occur with arsenic and cause additional problems treating the water:

- Elevated levels of nitrate (> 5 mg/L) and sulfate (> 100 mg/L) can cause dumping of arsenic when using anion exchange.
- Iron bacteria can slime adsorption media and block adsorption sites. If suspected, consult the lab for testing and your water treatment professional for mitigation.
- Radium will accumulate in manganese oxide media, including greensand, and if using this type of media for oxidation of arsenite to arsenate, test for radium and if above 3 pCi/L pre-treat for radium removal with a water softener.
- Elevated levels of phosphate are rare in New Jersey, but if present will compete with arsenate for media adsorption sites. If experiencing early breakthrough of arsenic, test for phosphate and seek assistance from a water treatment professional if it is elevated.
- Elevated levels of silica are also rare in New Jersey but can be found in areas with a pH greater than 9 and can reduce arsenic adsorption. If the silica level is greater than 30 mg/L, seeking assistance from a water treatment professional.

Treatment System Performance

Testing the System While Running the Water

To confirm that the system is working properly, a water sample should be collected from the sample tap between the two adsorption tanks within two weeks of installation. All water samples collected to test the arsenic treatment system should be collected while stressing the system. To stress the system in a typical home, run the water for 10 minutes at 3-5 gallons per minute (simultaneously running the cold water in a bathtub and a sink is usually sufficient) before and during the filling of the sample container at the tap between the tanks.

The initial test should find less than 1 μg/L of arsenic, which will indicate the system is adequate. After the initial test, a water sample should be collected between the two tanks at least once per year to determine when the arsenic is breaking through the worker tank (Tank #1). When the arsenic level at this sample tap reaches 5 μg/L, it is time to schedule maintenance of the system, which involves media replacement for Tank #1.

For a family of three, with typical water use, and adequate pre-treatment, this type of system will likely need to have the Tank #1 media replaced after three to five years, depending on the arsenic concentration and amount of water used. The water treatment professional will remove Tank #1, place Tank #2 into the Tank #1 position, and place a tank with new media into the tank #2 position. The water treatment professional should properly dispose of the used media, which will contain a high level of arsenic. Within two weeks of system maintenance, a water sample should be collected from the sample tap between the two tanks to confirm that the system is working properly. This test should find less than 1 μg/L of arsenic, which will indicate the system is adequate. After the tank changeout, the water test schedule can be based on the initial results to determine when the arsenic will again break through Tank #1. A water use meter with a warning light indicating when

Tank #1 will likely need to be replaced again can be installed and may reduce the need for obtaining water samples.

Other Options

For water treatment at a single tap in the home, an adsorption point-of-use (POU) system can be installed. This system uses under-sink cartridges of arsenic adsorption media to remove both arsenate and arsenite. The cartridges contain the same media types as the whole-house system. These systems should be installed and maintained according to the manufacturer's instructions. They typically produce only two quarts per minute and are used to provide treated water for drinking and cooking only. Cartridges are typically changed once per year. Advantages of this type of system is the installation and maintenance costs are less. The disadvantages of this type of system include the potential for arsenic exposure to continue in the home from other water uses (e.g., drinking from other taps, bathing, showering, and brushing teeth), and it is not uncommon for homeowners to exceed the useful life of these cartridges. Two studies have found continued arsenic exposure among families relying on POU treatment systems or bottled water to mitigate exposure (Smith, et. al., 2016; Spayd, et. al., 2015).

Systems that remove only arsenate from water are not recommended. Anion Exchange and Reverse Osmosis are two systems in this category. They should only be used if arsenate has been determined to be the only species in the water. Anion exchange systems are also problematic due to required maintenance to prevent arsenic dumping into the water, and the disposal of the extracted arsenic to the environment near the home.

In homes with high levels of arsenic (>50 µg/L) in the water, the water heater may have accumulated minerals that contain arsenic. These minerals may release arsenic back into the treated water as it passes through the water heater, resulting in the hot water containing arsenic. Therefore, homeowners with high arsenic levels should consider testing their hot water after installing a whole-house treatment system and replacing the water heater if the levels are elevated.

Frequently Asked Questions

If you have unanswered questions, see the companion document, NJGWS Informational Circular "Arsenic Water Treatment for Private Wells in New Jersey - Frequently Asked Questions" at https://njgeology.org.

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More Information

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