

Drinking Water Problems: Nitrates

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Nitrogen is present in the environment in many forms. The earth's atmosphere consists of 70 percent nitrogen.

When nitrogen interacts with another element in the environment, it changes form and becomes a compound. Two kinds of nitrogen compounds found in nature are nitrates (NO_3) and nitrites (NO_2). Nitrates and nitrites are chemicals that are made up of nitrogen and oxygen and that combine with various organic (related to or derived from living organisms) and inorganic compounds. Once taken into the body, nitrates are converted into nitrites.

Nitrates occur naturally in drinking water. However, if there are high levels of nitrates in the water, it is probably caused by human activities such as the overuse of chemical fertilizers and improper disposal of human and animal wastes. These fertilizers and wastes contain nitrogen compounds that are converted to nitrates in the soil.

Nitrates dissolve easily in water and can move readily through soil into the drinking water supply. As nitrate accumulates in water, high levels can build up over time. For most adults, nitrates are unlikely to be harmful, even at elevated levels. But ingesting too much nitrate can be harmful for very young infants and susceptible adults.

Who regulates drinking water safety?

In 1974, the United States Congress passed the Safe Drinking Water Act. This law requires the U.S. Environmental Protection Agency (EPA) to determine

the safe levels of chemicals for U.S. drinking water.

The EPA conducts research to determine the level of a contaminant in drinking water that is safe for a person to consume over a lifetime and that water systems can reasonably be required to remove from drinking water, given present technology and resources. This safe level is called the maximum contaminant level (MCL). The MCL for nitrate-nitrogen is 10 milligrams per liter (mg/L), which is commonly referred to as parts per million (ppm). For nitrite-nitrogen, the MCL is 1 ppm.

The EPA's drinking water standards—and the regulations for ensuring that these standards are met—are called the National Primary Drinking Water Regulations. All public water supplies must abide by these regulations.

Although private water wells are not required to meet the national drinking standards, private well owners can use these standards to monitor the quality of their water. Just as public water suppliers may not deliver water containing contaminants over the MCL to the public, private well owners should not use water above MCL levels for human consumption.

How are people exposed to nitrate?

Because nitrate is a natural substance found in both water and plants, people are exposed to it primarily through the diet. In the United States, the average person consumes about 75 to 100 milligrams (mg) of nitrate per day.

About 80 to 90 percent of this amount comes from vegetables. Vegetables naturally containing high levels of nitrates include beets, celery, lettuce and spinach. Some vegetarians have nitrate intakes of up to 250 mg per day.

Drinking water generally accounts for 5 to 10 percent of the nitrates that people consume. However, in areas where the drinking water is contaminated to a level of 50 ppm—five times the MCL for nitrate-nitrogen—drinking water may supply as much as half of a person's total daily intake.

Nitrate intake depends on a variety of factors, including diet and the amount and quality of water that a person consumes. If there are high levels of nitrite in the body, it is generally because of high levels of nitrates in the drinking water.

Some adults who eat many vegetables and drink water containing high levels of nitrate (up to 10 mg nitrate-nitrogen/L) could take in as much as 1.6 mg of nitrate-nitrogen per kilogram of material consumed per day. This is the estimated highest dose of nitrates that a person can take in every day without harm.

What are the health effects of nitrates/nitrites?

Nitrate becomes toxic primarily when bacteria in our digestive system convert it to nitrite. The nitrite oxidizes iron in the hemoglobin of our red cells to form methemoglobin.

Hemoglobin transports oxygen through the body. However, methemoglobin cannot bind oxygen and, therefore, cannot supply oxygen to the body. When hemoglobin is converted into methemoglobin, the body cannot get the oxygen it needs to function well. This results in a medical condition known as methemoglobinemia.

Low levels of methemoglobin occur normally in people, with typical values usually ranging from 0.5 to 2.0 percent. Because the blood has extra capacity to carry oxygen, a person can have methemoglobin levels of approximately 10 percent with no significant symptoms of illness.

If methemoglobin levels rise above 10 percent, a person's skin and lips may turn bluish. Levels above 25 percent can lead to weakness, rapid pulse and rapid breathing. Levels over 50 to 60 percent can cause death.

The most significant health effect associated with nitrate ingestion is methemoglobinemia in infants under 6 months old. Methemoglobinemia is often called "blue baby syndrome" because the affected infant's fingers, toes, arms and legs begin to turn

blue. This condition results from high nitrite levels in the blood.

Untreated, severe methemoglobinemia can result in brain damage and even death. Infants in the first 6 months of life are particularly susceptible to nitrite-induced methemoglobinemia. Because infants live on a mainly liquid diet, they drink more water for their weight than do adults and, consequently, they ingest a much higher level of nitrate.

Some adults may also be susceptible to nitrite-induced methemoglobinemia. These include pregnant women with a particular enzyme deficiency, adults with reduced stomach acidity and those with a deficiency in the enzyme needed to change methemoglobin back to normal hemoglobin, a condition that can be hereditary.

Fortunately, methemoglobinemia is easily recognized by the medical and public health communities, and it can be readily diagnosed and treated. Symptoms include shortness of breath and blueness of the skin.

Research suggests that methemoglobinemia does not occur in infants when drinking water levels are 10 mg nitrate-nitrogen/L (or ppm) or less. This is supported by many research studies in humans.

Another concern regarding nitrate ingestion is that nitrites in the stomach and intestines may contribute to the development of some cancers. Also, lifetime exposures to nitrates and nitrites can cause an excessive discharge of urine, increased starchy deposits and hemorrhaging of the spleen.

Nitrate in groundwater is of concern not only because of its toxic potential, but also because it may indicate that the groundwater is contaminated with other substances. The source of the nitrate may be a clue as to other contaminants that may be present. If the water is contaminated by animal waste or effluent from septic tanks, it may also contain disease-causing bacteria, viruses and protozoa. If the water is contaminated by fertilizers, it may also contain other agricultural chemicals besides nitrates, such as pesticides.

What happens to nitrates/nitrites in the environment?

In natural waters, most nitrogenous materials tend to be converted to nitrate. So you should consider all sources of combined nitrogen, particularly organic nitrogen and ammonia, as potential sources of nitrate.

The most common sources of nitrate are municipal and industrial wastewaters, refuse dumps, animal feed lots and septic systems. Commercial fertilizers in rural and urban areas can also be a source of nitrates in the environment.

Once nitrate is formed, its movement in soil and potential to contaminate groundwater depends on several factors, including the soil characteristics, soil texture, the depth and characteristics of the underground water formations (aquifers), and climatic rainfall conditions. The potential for nitrate contamination of drinking water also depends on the depth and construction of wells.

Many factors can make it difficult to identify the source of nitrates for an individual well. Because nitrates move with the flow of groundwater, the source may be far from the well. The amount of time it takes for nitrate to pass through the soil into groundwater is affected by many variables, including the chemical's application rate, the soil type and the depth of the soil to the water table. The water table is the top of the groundwater formation, or the point where the saturated zone on the soil surface begins.

Where in Texas have wells with high levels of nitrate been found?

In Texas, groundwater quality is monitored by several agencies, including the Texas Water Development Board (TWDB), which collects groundwater samples through its Groundwater Quality Sampling Program. From 1988 to 2004, TWDB staff collected 24,272 samples from 11,501 wells for nitrate (Fig. 1). Of those samples:

- 16 percent contained no detectable amounts of nitrate.
- 20,498 samples contained detectable amounts of nitrate, averaging 4.0 milligrams/liter (mg/l).
- 1,141 samples, or 5 percent of the total sample population, contained levels of nitrate above the primary MCL of 44.3 mg/l. Note: The MCL for nitrates alone is 44.3 mg/L or ppm. The MCL for nitrate-nitrogen is 10 mg/L or ppm.

High levels of nitrate (over the MCL) were found in 24 of the 31 major and minor aquifers (Figs. 2 and 3). One household well in the Yegua aquifer and one industrial well in the Marathon aquifer contained nitrate detected at 63 mg/l and 64 mg/l respectively.

The two aquifers having the most wells with excess nitrate were the Ogallala, with 278 wells (401 samples), and the Seymour, with 138 wells (185 samples). The highest nitrate values were found in two aquifers: the Seymour, where a

sample from an unused well contained 1,484 mg/l, and the Dockum, where a sample from a stock well contained 244 mg/l.

Other aquifers in which a significant number of samples (and wells) contained excessive nitrate were the Edwards-Trinity High Plains (62 samples), the Dockum (60 samples) and the Trinity (65 samples). Eleven of the 24 aquifers with high nitrate contained wells from which no more than 10 samples were over the standard.

Of the 1,141 samples from wells with high nitrate:

- About 47 percent came from wells that supplied water to households.
- 20 percent came from irrigation wells.
- 13 percent were from wells supplying livestock.
- 10 percent were from public supply facilities.
- 4 percent from wells with other uses.
- 6 percent were from unused wells.

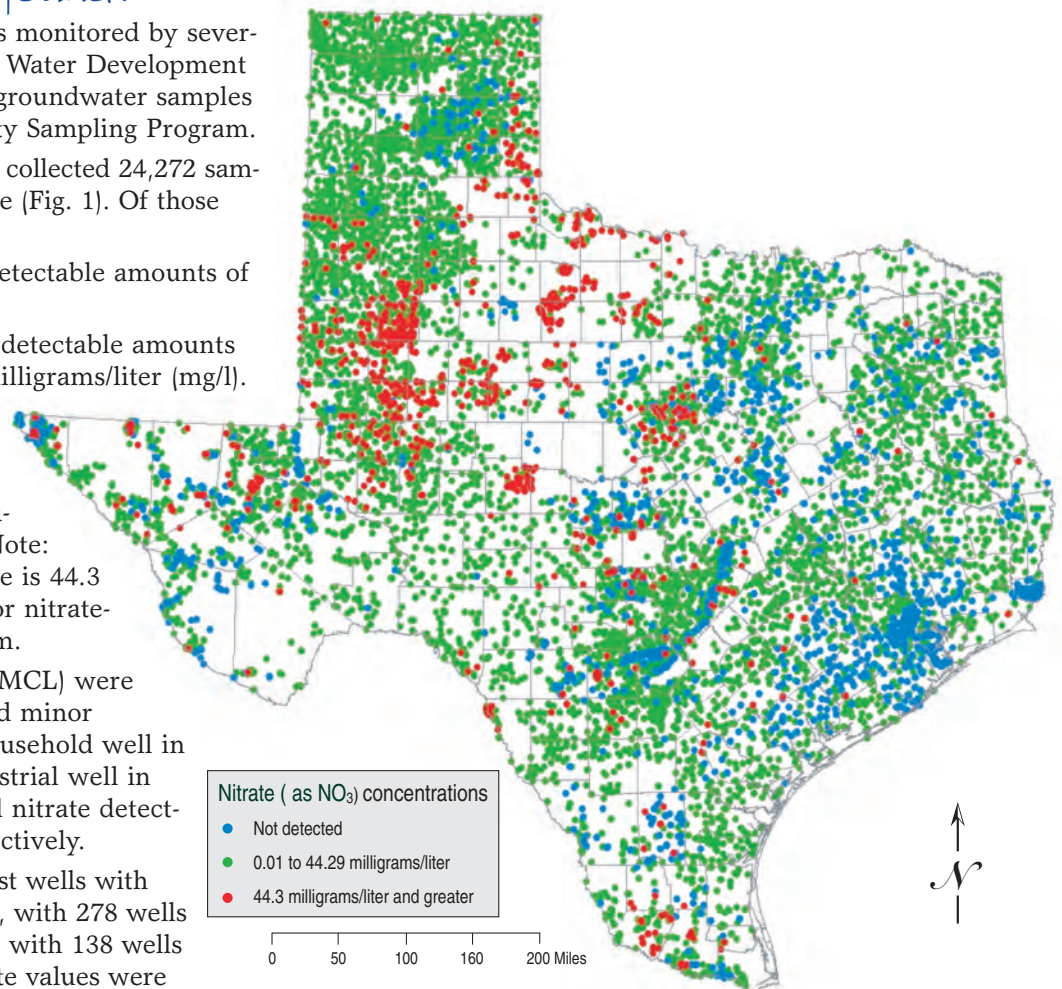


Figure 1. Nitrate concentrations in Texas water wells 1988-2004.

How is nitrate removed from drinking water?

Homeowners using public or private water supplies may choose to treat their water to remove the nitrate before use. The EPA has approved three treatment methods for removing nitrates/nitrites: ion exchange, reverse osmosis and electro dialysis.

Reverse osmosis

The most common treatment method for nitrate in a water supply is reverse osmosis (RO). This method is cost effective for a home that uses only a few gallons of water for human consumption per day. The more drinking water a household uses, the more expensive the treatment.

Most RO units have five components:

- A prefilter to remove solids and extend membrane's life
- An activated carbon filter to remove odors, flavors and chlorine

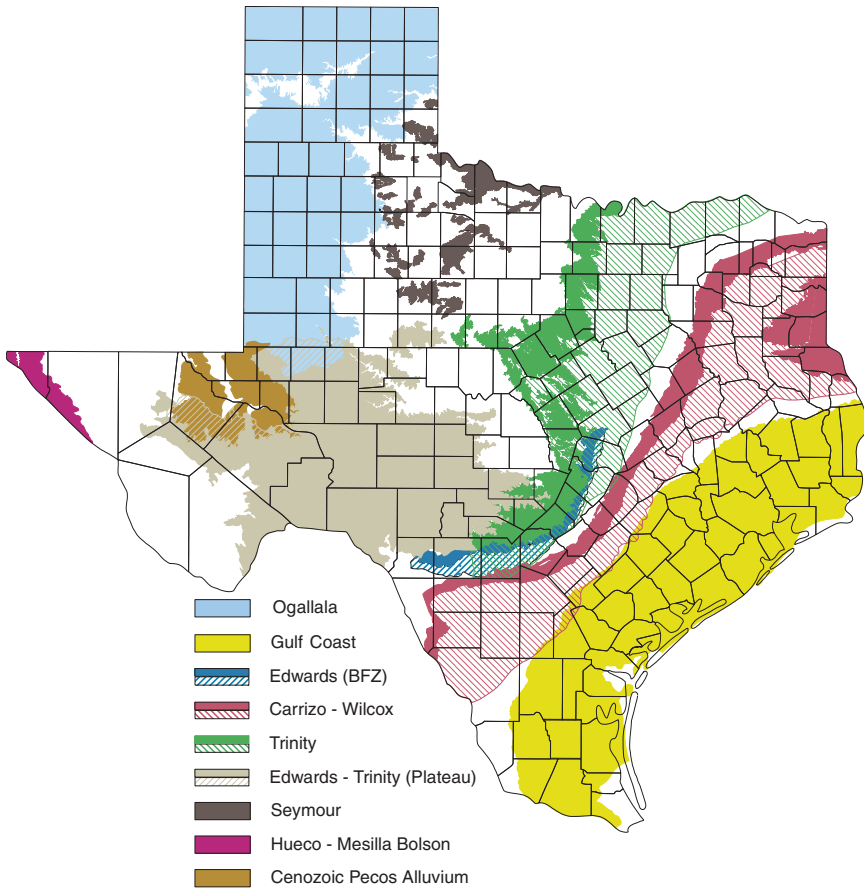


Figure 2. Major Aquifers of Texas.

How are nitrates/nitrites detected in drinking water?

The regulation for nitrates/nitrites became effective in 1992. Between 1993 and 1995, the EPA required water suppliers to collect water samples at least once a year and analyze them to find out if nitrates/nitrites are present above 50 percent of their MCLs. If nitrates/nitrites are found above this level, the system must continue to monitor this contaminant every 3 months.

If contaminant levels are found to be consistently above the MCLs (10 ml/L or ppm for nitrate-nitrogen and 1 mg/L or ppm for nitrite-nitrogen), water suppliers must take steps to reduce the amount of nitrates/nitrites to bring them consistently below that level. The suppliers must also notify the public about the problem via newspapers, radio, TV and other means. They may be required to take additional actions, such as providing alternative drinking water supplies, to prevent serious risks to public health.

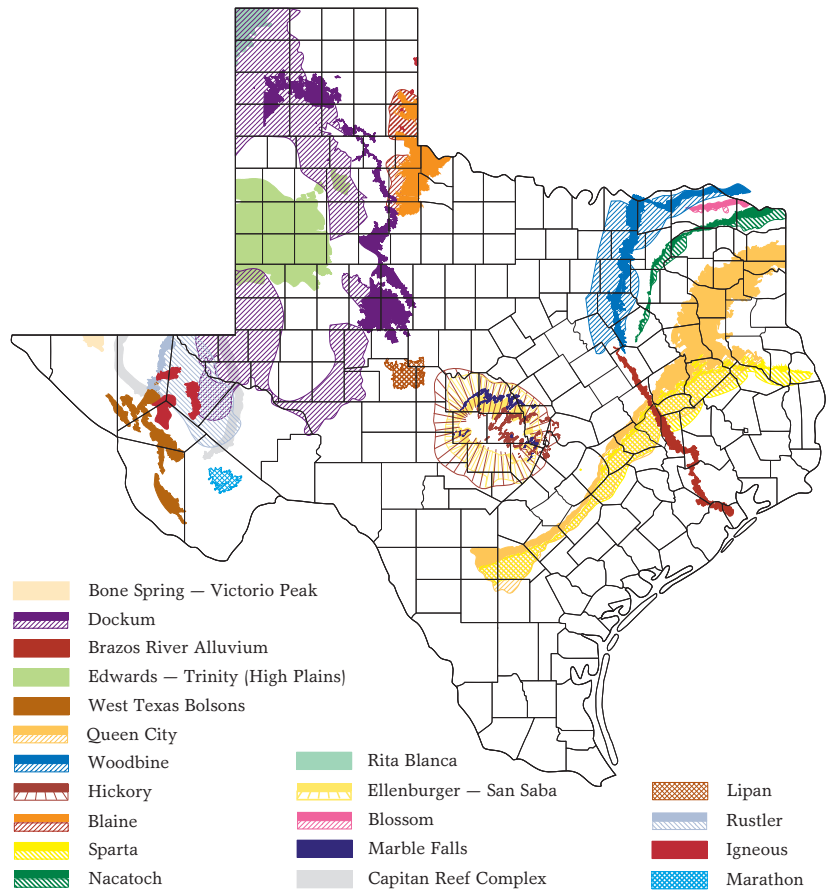


Figure 3. Minor Aquifers of Texas.

- A semipermeable membrane through which water flows under pressure; the most effective treatment to remove nitrate using an RO system is a thin film composite membrane
- A tank to hold the treated water
- A drain connection for discharging the wastewater produced by the treatment process

The RO unit operates by passing water under pressure through a semi-permeable membrane (Fig. 4). The membrane allows water to pass through but blocks the nitrate. You can improve the nitrate removal in this system by increasing the water pressure with a booster pump.

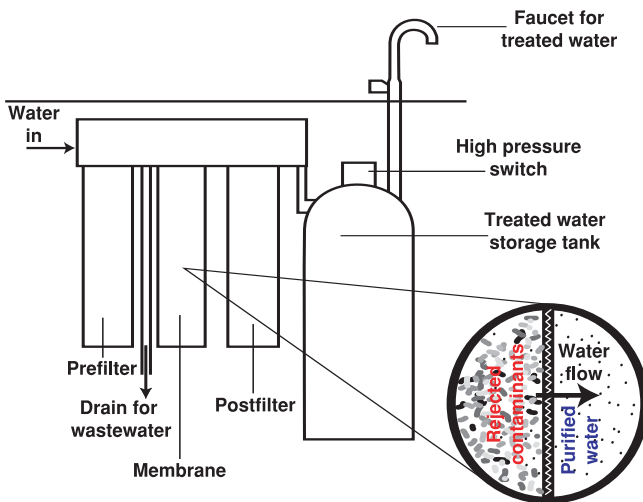


Figure 4. Reverse osmosis treatment unit (Adapted from Kneen et al., 1995 and USEPA, 2003).

The disadvantage of an RO unit is the small amount of consumable water produced. Most units achieve only 20 to 30 percent water recovery, meaning that of 100 gallons treated, only 20 to 30 gallons will be usable. The rest of the water is sent to the wastewater treatment system. Homeowners using on-site wastewater treatment systems should consider the effect that the additional loading may have on their septic systems.

Because of the RO system's inefficiency, it is typically used to treat only drinking and cooking water. When choosing the size of the system to buy, base your decision on the number of gallons to be used for these purposes each day. The typical unit produces from 5 to 15 gallons per day.

Cost

Typical RO devices cost from \$200 to \$1,000. The device takes about 30 to 60 minutes to install, assuming no significant plumbing modifications are needed.

The RO membrane must be replaced according to the manufacturer's recommended schedule. New membranes cost about \$150, and a carbon-based pre-filter typically costs between \$15 and \$50.

Depending on the system and based on a 10-year life of the system, the cost of treating the water ranges from 5 to 10 cents per gallon produced. This estimate does not include the cost of the wasted water or the cost, if any, of treating the wastewater.

Remember to always check and replace all filters as needed. If used filters are not changed when needed, they can reintroduce previously filtered nitrates back into the water system and actually increase the concentrations of nitrates in the water.

Distillation

Distillation removes nitrate from water without wasting water. In the distillation process, water is heated to boiling in an enclosed container (Fig. 5). As the water evaporates, the impurities in the water are left behind. The steam then cools and condenses back into a liquid.

Some of the dissolved gases and compounds from the water will also be carried up with the steam and therefore end up in the treated water. These contaminants can be removed by passing the distilled water through a post filter. Most units will treat 5 to 11 gallons of water a day.

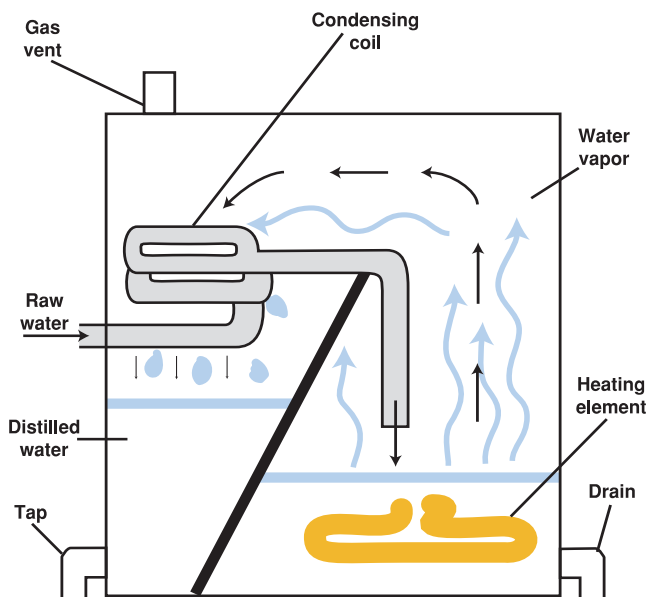


Figure 5. Distillation process (Adapted from Kocher et al., 2003).

Cost

The operating costs for distillation may be higher than other treatment methods because of the amount of electricity needed to operate the distiller. Use this formula to estimate the cost of energy:

$$\text{Cost/gal} = 0.024 \times \frac{\text{Wattage of unit}}{\text{Production (gal/day)}} \times \text{cost of electricity (\$/kWh)}$$

Distillation units can be purchased for \$300 to \$1,200.

Ion exchange

A good option for treating large amounts of water is ion exchange. Ion exchange removes nitrates from water by passing it under pressure through one or more columns packed with a compound called an exchange resin (Fig. 6).

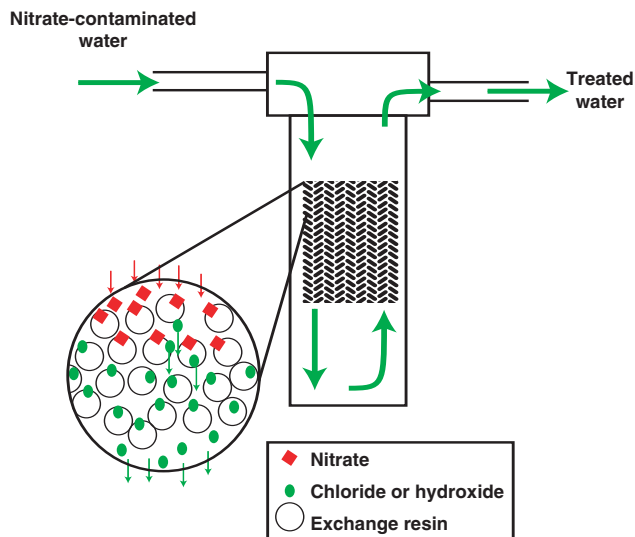


Figure 6. Ion Exchange Process (Adapted from Robillard et al., 2001).

This system works like a water softening system. As nitrate moves across the resin, an ion is released from the resin. The nitrate leaves the water and takes the place of the ion in the column. After all the original ions have been replaced, the column is saturated with nitrate and must be regenerated or replaced.

A disadvantage of ion exchange systems is the cost of recharging the resins. To treat water for nitrates, the resins can be recharged only at special facilities, which makes treatment by ion exchange expensive.

If the column is not regenerated or replaced, nitrate will be dissolved back into the water system. This can actually increase the nitrate concentration of the water.

Another major concern when using ion exchange treatment is a phenomenon called chromatographic peaking. When chromatographic peaking occurs, the water leaving the column will have higher concentrations of nitrate than will the water entering the column.

Peaking should not occur if a nitrate-selective resin is used. Peaking is most often seen when the water source contains sulfate and the column is being operated past saturation.

Chromatographic peaking and other problems can erupt quickly in ion exchange units. Because of this, you should check the water supply often to make sure the unit is working properly if your unit uses a resin that is not nitrate-selective.

Another factor that significantly affects nitrate removal is flow rate. A good flow rate for an ion exchange system is 2.5 gallons/cubic foot/minute.

When buying a system, be sure to select one that is appropriate for residential use. Take care to not mix the nitrate resin with water softener resin.

Cost

In addition to the cost of monitoring and resin replacement, the initial cost for an ion exchange unit ranges from \$400 and \$1,500.

Electrodialysis

Electrodialysis removes nitrates by feeding water through several stacked membranes that alternate in selecting anions (negatively charged ions) and cations (positively charged ions) (Fig. 7). Nitrate ions are drawn through the membrane pores with electrical currents. The nitrate is pulled from the water into a brine waste stream.

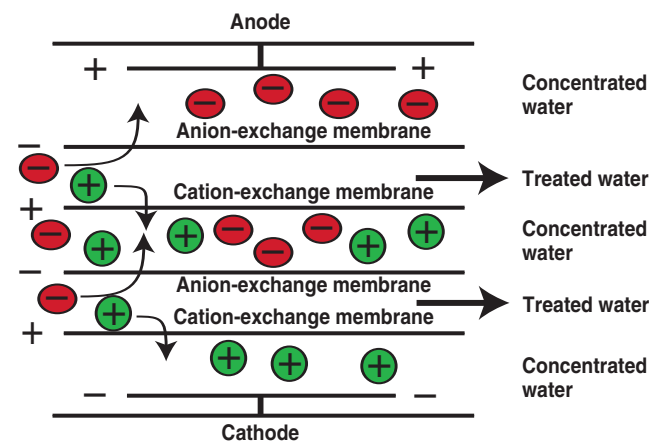


Figure 7. Electrodialysis Process (Adapted from GE, 2005).

The drawbacks to using electro dialysis for home water treatment are that the process is complicated and costly, and sometimes local codes prohibit it for nitrate removal.

How to select a treatment unit

Because no single technology can treat all water contaminants, you should have your water tested by a qualified laboratory before selecting a treatment option. For a list of labs certified by the Texas Commission on Environmental Quality (TCEQ) to test drinking water, visit <http://www.tnrcc.state.tx.us/permitting/waterperm/pdw/chemlabs.pdf>.

Once you have established what is in the water, research the different products on the market and find one suitable for treating the constituents in your water supply. Compare the initial, operation and maintenance costs and requirements, contaminant removal efficiency, warranties, life expectancy of the system and the reputation of the company. Also consider the wastewater or solid waste that the system will generate in your final decision.

For more information on the types of in-home water treatment options for specific contaminants, refer to the Drinking Water Problems series of publications by the Texas AgriLife Extension Service. They are available at <http://AgriLifebookstore.org>.

It is important to note that home water treatment systems are not regulated by federal or state laws. However, some national organizations do certify water-treatment products:

- The Water Quality Association (WQA) offers a validation program and advertising guidelines. Products that receive a Gold Seal Product Validation from the WQA are certified in their mechanical performance but not in their ability to remove harmful contaminants.
- The National Sanitation Foundation (NSF) certifies products that can remove contaminants affecting health. For a list of drinking water treatment units that have NSF certification, visit <http://www.nsf.org/Certified/DWTU>.

If you have questions about whether a particular product is certified, contact the NSF Consumer Hotline at 877-8-NSF-HELP or info@nsf.org or by writing to: NSF International, NSF International, P.O. Box 130140, 789 N. Dixboro Road, Ann Arbor, MI 48113-0140.

Please note: If a product has an EPA registration number, this merely indicates that the unit is registered with the EPA. It does not imply EPA approval or certification.

How to keep it working

No matter what treatment technology is being used, some sort of maintenance will be required to keep the system operating properly. The first step to proper operation and maintenance is proper installation. Qualified installers:

- Carry liability insurance for property damage during installation
- Are accessible for service calls
- Accept responsibility for minor adjustments after installation
- Give a valid estimate of the cost of installation

After your system is installed, it will need to be maintained properly. If you have an RO unit, replace the membranes as necessary. Periodically remove scales and other solids that collect in the still and dispose of them properly.

For ion exchange units, replace or recharge the resin regularly. Maintain and change all filters as needed.

All systems should be operated according to the manufacturers' specifications. If a system treats more water than it is designed for in a certain period, the treatment may be ineffective and quality of the treated water may drop.

Treated water should be tested regularly to ensure that the system is operating properly. The best times of the year to test for nitrate concentration is in the spring and fall because nitrate is typically the highest in raw water sources then.

Although new home-based tests are better than those previously used, the best way to have water tested is by a certified lab. For a lab in your area, consult your local health department, the county office of Texas Cooperative Extension or the TCEQ's list of water testing laboratories mentioned earlier.

For more information

Arsenic Treatment Technology Evaluation Handbook for Small Systems. EPA 816-R-03-014. United States Environmental Protection Agency (USEPA). 2003. Available at http://www.epa.gov/ogwdw000/smallsys/arsenic_treatment_handbook_lo.pdf.

"Choosing home water treatment devices," Water Facts: Number 7. Arizona Cooperative Extension. Available at <http://ag.arizona.edu/pubs/water/az9420.pdf>.

"Drinking Water Treatment: Distillation." Nebraska Cooperative Extension. Available at <http://ianrpubs.unl.edu/water/g1493.htm>.

"Electro dialysis." GE Infrastructure Water & Process Technologies. General Electric. 2005. Available at <http://www.ionics.com/technologies/ed/index.htm>.

"A Guide to Home Water Treatment." Michigan State University Extension. Available at <http://www.gem.msu.edu/pubs/msue/wq21p1.html>.

Harmon, S. 2002. "Nitrate removal: Searching for the ideal in an imperfect world." Water Technology Online. Available at <http://www.watertechonline.com/article.asp?IndexID=6633204>.

"Home Drinking Water Treatment Systems." North Carolina Cooperative Extension Service. Available at <http://dwb.unl.edu/Teacher/NSF/C01/C01Links/www2.ncsu.edu/bae/programs/extension/publicat/wqwm/he419.html>.

Lahlou, M. Z. "Point-of-Use/Point-of-Entry Systems." Morgantown, WV: National Drinking Water Clearinghouse. 2003. Available at http://www.nesc.wvu.edu/ndwc/articles/OT/SP03/TB_Point_of_Use.html.

"Water Quality: Distillation." Kansas State University Cooperative Extension Service. Available at <http://www.oznet.ksu.edu/library/H2OQL2/MF885.PDF>.

"Water Softening." Penn State Cooperative Extension. Available at <http://www.sfr.cas.psu.edu/water/water%20softening.pdf>.

"Water Treatment Notes: Reverse Osmosis Treatment of Drinking Water." Cornell University Cooperative Extension. Available at <http://www.cce.cornell.edu/fact-sheets/wq-fact-sheets/FSpdf/Factsheet4.pdf>.

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