

Drinking Water Problems: Arsenic

Bruce J. Lesikar, Professor and Extension Agricultural Engineer, Texas Cooperative Extension,
Rebecca H. Melton, Extension Assistant, Texas Cooperative Extension,
The Texas A&M University System

Michael F. Hare, Senior Natural Resources Specialist, Pesticide Programs Division,
Texas Department of Agriculture

Janie Hopkins, Manager, Groundwater Monitoring Section,
Texas Water Development Board,

Monty C. Dozier, Assistant Professor and Extension Specialist,
Texas Cooperative Extension,
The Texas A&M University System

The element arsenic occurs naturally in different forms, which may be classified either as organic or inorganic. Arsenic is distributed widely in rocks, soil, water and air—and in living things. Arsenic can be released to the environment as a result of natural events or its release can be caused by human activities. Natural concentrations of arsenic in soil typically range from 0.1 to 40 parts per million (ppm), with an average concentration of 5 to 6 ppm. Through erosion, dissolution and weathering, arsenic can be released from the Earth's crust into groundwater or surface water. Geothermal waters (e.g., "hot springs") also can release arsenic into groundwater, particularly in the Western United States. Other natural sources of arsenic include volcanoes and forest fires.

In nature, arsenic can be found in many forms, both organic and inorganic. Inorganic arsenic is generated when arsenic binds with elements such as oxygen, chlorine and sulfur.

Arsenic is usually found in inorganic forms in water, the most predominant form being arsenate [As(V)], although arsenite [As(III)] may be present under some conditions. When arsenic is found in plants and animals, it bonds with carbon and hydrogen, forming organic arsenic.

Organic arsenic is usually less harmful than inorganic arsenic, although exposure to high levels of some organic arsenic compounds may cause similar effect to those from inorganic arsenic.

In water, arsenic can undergo a series of changes, including oxidation-reduction reactions (an arsenic atom taking electrons from another atom or losing them to another atom), ligand exchanges (electron exchanges involving other atoms which are combined with a central arsenic atom), and biotransformations (chemical changes to arsenic atoms within the body of a living thing). For example, many arsenic compounds can dissolve in water, so fish and shellfish can accumulate arsenic, but most of this arsenic will be bound in a form that is not harmful to other animals.

An arsenic atom's oxidation state (either its combination with oxygen or its loss of electrons, making the atom positive in charge) and its oxidation-reduction potential (its willingness to exchange electrons with other atoms) affect its fate and its transport processes in groundwater. The following characteristics of water also have been identified as affecting the transport and disposition of arsenic:

- the acidity or alkalinity of the water (pH)
- amount of iron in the water
- amount of metal sulfide and sulfide in the water
- water temperature and salinity
- distribution and composition of the living things present in the water

Oxidation state appears to be the most important factor determining arsenic's fate and its transport

through drinking-water treatment systems. Arsenate is removed more easily than arsenite, because of its greater ionic charge. Treatment procedures using activated alumina, ion exchange, and reverse osmosis technologies can achieve relatively high arsenate removal rates. However, these technologies do not achieve comparable removal rates for arsenite, although its oxidization to arsenate (removal of two more electrons from each atom) can improve removal efficiencies. If arsenite is found in the source water, an oxidation step should be added to the treatment system before the arsenic removal unit.

What are the agricultural uses of arsenic?

Most agricultural uses of arsenic have been banned in the United States. The last agricultural use of inorganic arsenic, arsenic acid on cotton, was canceled voluntarily in 1993. Inorganic arsenic compounds (arsenic acid, arsenic trioxide and sodium arsenate) currently are used only in sealed ant baits and in wood preservatives.

Organic arsenic is found in the organic herbicides monosodium methanearsonate (MSMA) and disodium methanearsonate (DSMA), which currently are applied to cotton fields or used for the postemergence control of crabgrass, Dallisgrass and other turf weeds. Organic arsenic also is found in feed additives for poultry and swine and appears to concentrate in the wastes of these animals. Soil bacteria turn organic arsenic compounds in soil into alkylarsines and arsenate; no published data currently are available on the leaching or transport of MSMA or DSMA from soil.

How can arsenic affect health?

Rats require tiny amounts of arsenic for normal development of their fetuses, and there is limited evidence that trace amounts of arsenic may be beneficial for humans and animals. In most cases, infrequent ingestion of water containing relatively low levels of arsenic can be converted by the body to organic forms and passed through the body without an adverse impact.

However, exposure to elevated levels of inorganic arsenic can be harmful to the body. Although the new Maximum Contaminant Level (MCL) for arsenic is 10 micrograms /liter, the United States Environmental Protection Agency (EPA) estimates that about 350,000 people in the United States may drink water containing more than 50 micrograms/liter of arsenic, and nearly 25 million people may drink water containing more the 25 micrograms/liter.

The resulting effects of arsenic exposure may depend on a person's sex, ethnicity, age, health and nutritional status and especially the concentration in the water and duration of exposure. When high levels of arsenic (concentrations above 60 milligrams/liter) are ingested over a short period, acute poisoning occurs. Acute poisoning can kill.

Nonlethal symptoms of acute poisoning include:

- Gastrointestinal effects such as nausea, vomiting, abdominal pain and severe diarrhea
- Swelling of tissue around the eye
- Decreased production of red and white blood cells
- Abnormal heart rhythms
- Damage to blood vessels
- Tingling in hand an feet ("pins and needles")

Arsenic levels are rarely high enough in drinking water supplies to result in acute poisoning.

Chronic ingestion of low levels of inorganic arsenic can cause skin to darken and small "corns" or "water" to form on palms, soles and torso. Long-term exposure can also lead to gastrointestinal symptoms, diabetes, anemia, cardiovascular, pulmonary, neurological effects and liver disease.

Manifestations of these effects can include noncirrhotic portal hypertension (high blood presser in the blood vessels of the liver in the absence of the live diseases known as cirrhosis), bleeding esophageal varices (bulging veins in the esophagus), splenomegaly (enlarged spleen), hypersplenism (spleen destroying more blood cells than usual), metallic taste in mouth, Mee's lines in nail beds, bone marrow depression (less production of blood cells) and peripheral neuropathy. Contact with inorganic arsenic may cause skin to turn red and swell.

Workplace exposure or chronic ingestion of arsenic-contaminated water or medications containing arsenic also is associated with development of skin, lung and other cancers. Several studies have shown that inorganic arsenic can increase risk of lung cancer, skin cancer, bladder cancer, liver cancer, kidney cancer and prostate cancer. The World Health Organization (WHO), the United States Department of Health and Human Services (DHHS), and the EPA have determined inorganic arsenic to be a human carcinogen.

It is not known if arsenic exposure causes birth defects or other developmental effect in people, although birth defects have been observed in animals exposed to high amounts of inorganic arsenic. It seems likely that health effects seen in children exposed to high amounts of arsenic will resemble effects seen in adults exposed to high amounts.

Tests can measure arsenic levels in blood, urine, hair or fingernails, with urine tests the most reliable indicator of arsenic exposure within the last few days. Tests on hair and fingernails can measure exposure to high levels of arsenic over the past 6 to 12 months. These tests can determine exposure to above-average levels of arsenic but cannot predict how such arsenic levels will affect health.

What is the standard for arsenic levels in drinking water?

On January 22, 2001, the EPA lowered the amount of allowable arsenic in public drinking water from 50 micrograms/liter to 10 micrograms/liter. U.S. public water systems must comply with this new standard beginning January 23, 2006. With this decrease in the Maximum Contaminant Level (MCL), the likelihood of exceeding the new standard increases. Public systems with arsenic levels exceeding the new MCL will be required either to treat their water or to find alternative sources of supply. Compliance with this 80 percent decrease in MCL presents a challenge to water treatment systems because of its toxicological, economic and infrastructure implications. While compliance will decrease consumers' exposure to arsenic, it will increase their water costs.

MCLs apply only to public water supplies. Homeowners' private wells are not regulated, which means that such homeowners may be consuming water with arsenic concentrations exceeding official standards. Private well owners must decide whether to test their well water, then treat it if necessary. Testing well water for arsenic typically costs about \$25.

Wells with high arsenic levels sometimes are grouped in a particular area, so the Texas Water Development Board (TWDB) recommends that you inform your neighbors if tests of your water reveal high levels of arsenic and that all residents in the area with private water supplies send samples of their water to state-certified laboratories to be tested for arsenic contamination. A list of labs certified by the Texas Commission on Environmental Quality (TCEQ) for testing public drinking-water supplies can be found at <http://www.tnrc.state.tx.us/permitting/waterperm/pdw/chemlabs.pdf>.

Where have high levels of arsenic been found in Texas?

The TWDB collects groundwater samples through its Groundwater Quality Sampling Program. Between 1983 and 2004, the agency analyzed nearly 15,000 samples from more than 10,000 wells for arsenic contamination (some wells were sampled more than

once); 69 percent of the 15,000 samples had undetectable levels of arsenic.

For the 4,642 water samples with detectable arsenic concentrations, the median arsenic level was 5 micrograms/liter, meaning that half the samples had concentrations greater than 5 micrograms/liter and half the samples had concentrations less than 5 micrograms/liter. Twenty-seven percent of these samples contained arsenic in excess of 10 micrograms/liter, the new EPA standard. Of the nearly 900 water wells with concentrations exceeding the new primary standard of 10 micrograms/liter, approximately 30 percent provided water to households, 24 percent to public supply facilities, 18 percent to irrigation wells, 16 percent to stock wells, and 5 percent to other uses, including industrial and commercial facilities; 7 percent of these wells were unused. High arsenic concentrations that are believed to be naturally occurring have been found in the southern High Plains (Ogallala aquifer), in several West Texas counties (various aquifers) and in south Texas (Gulf Coast aquifer) (Fig. 1).

Some data reported to the TCEQ about public drinking-water systems (not shown in Fig. 1) also indicate high arsenic concentrations, mainly in the Ogallala and the Gulf Coast aquifers. For example, Harris-Brazoria-Galveston-area public water systems using significant proportions of groundwater report arsenic levels in excess of 10 micrograms/liter (Regner et al., 2004).

What can water well owners do about arsenic contamination?

Well owners need to consider the following options if their well water is found to contain excessive levels of arsenic:

- **Purchase bottled water for drinking and cooking.** Unless their water source has arsenic levels greater than 500 micrograms/liter, they may safely use their well water for non-consumption activities such as showering, bathing, and washing clothes.
- **Connect to a public water system.** All community water-supply systems are tested regularly for arsenic and other contaminants, and such systems should be in compliance with EPA regulations in 2006.
- **Extend the existing well's casing or drill a new well into different water-bearing formations, possibly reducing arsenic levels.** Well designs may lower arsenic concentrations if they access a different aquifer or allow mixing of water from different levels in an aquifer.

- Purchase treatment systems.** Well owners choosing this option should test their water again to determine if other constituents dissolved in their water also exceed drinking-water standards. Even if levels of other constituents are found to comply with drinking water standards, these constituents may interfere with proposed arsenic remediation systems. Iron and manganese, for example, hinder effective arsenic treatment and should be removed before arsenic treatment begins. Well owners also must consider whether treatment should occur at each tap (point-of-use) or before entry to the residence (point-of-entry), given the different treatment systems available for each option.

What treatment methods are commonly used by private well owners?

(Adapted from USEPA, 2003)

Common treatment methods used to remove arsenic from well water include adsorption columns, reverse osmosis, distillation and ion exchange. Before installing a particular treatment system, well owners should be certain that it will meet their needs. They should work with reputable dealers familiar with the areas where their wells are located and find out the amount of arsenic a treatment system will remove, its maintenance requirements and its costs. Treatment systems certified by an independent agency such as the National Sanitation Foundation (NSF) usually effectively live up to manufacturer's claims. After well owners install a treatment system, they should test their water periodically to ensure that arsenic is being removed.

Adsorption Column

Modified activated alumina and iron-based sorbents are among the adsorptive materials that can be used to remove arsenic from water. The advantages of using an adsorption column operation

include simple operation, low maintenance, low relative cost depending upon cartridge replacement frequency, small under-the-counter footprint, high treatment capacity and slow breakthrough kinetics. Arsenic that has passed untreated through an adsorption column unit is detected more readily by routine monitoring than in systems with rapid breakthrough. To prevent untreated arsenic from leaking into drinking water, well owners can use metered cartridges that will shut off the system outlet once a designated volume of water has passed through the treatment unit.

Initial capital cost of an adsorption unit ranges from \$100 to \$300. Operation and maintenance costs will include water

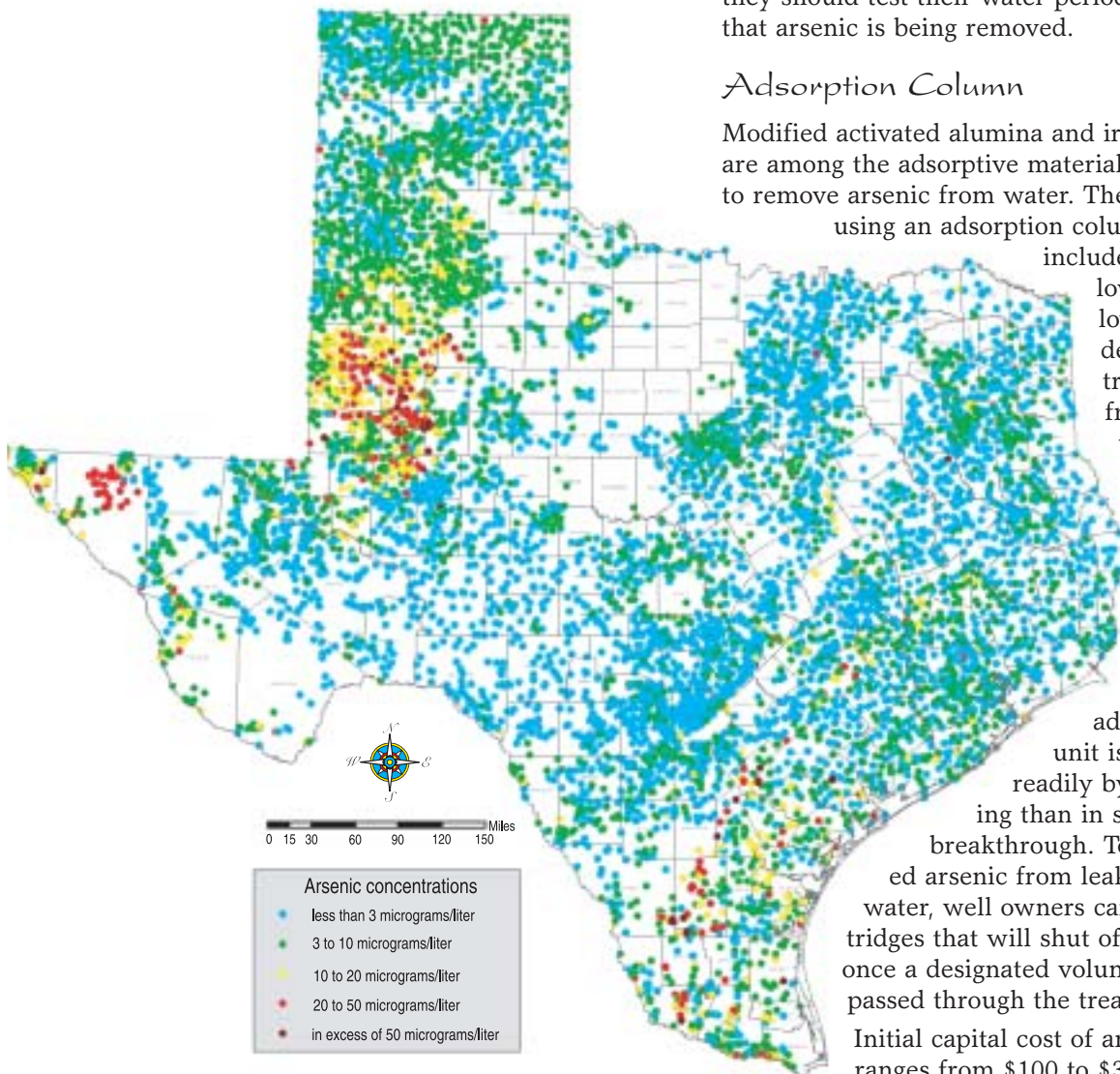


Figure 1. Arsenic content in groundwater sampled from 1983 to 2004 by the TWDB.

sampling and laboratory analysis and replacement of pre-filters and membrane cartridges, as well as other regular maintenance.

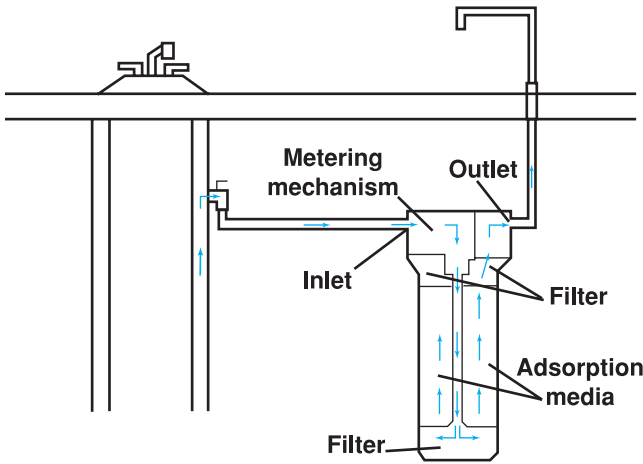


Figure 2. Adsorption Treatment (Adapted from USEPA, 2003).

Reverse Osmosis (RO)

RO treatment units are recommended for use with arsenic-rich water containing high levels of sulfates, phosphates or dissolved solids. When operated at typical tap pressures, some RO devices remove more than 95 percent of the arsenate present (90 percent of arsenite). An RO unit passes water under pressure through a semi-permeable membrane. This membrane allows water to pass through but prevents arsenic from doing so. Most units will have

- A pre-filter to remove solids and extend membrane life.
- An activated carbon filter to remove odors, taste and chlorine.
- A semi-permeable membrane.
- A tank to hold the treated water.
- A drain connection for discharging wastewater generated.

However, RO units achieve relatively poor water recovery. Most units are designed to recover 20 to 30 percent of the water treated. For example, if 100 gallons are treated, only 20 to 30 gallons will be useable; the rest of the water will be sent to the wastewater treatment system. Homeowners using on-site wastewater treatment systems should consider the impact additional loading from an RO unit may have on their septic systems. Because of RO systems' inefficiency, such units typically are used to treat only drinking and cooking water, so system size should be based on the number of gallons used for these pur-

poses each day. Typical treatment-unit production rates range from 5 to 15 gallons of water per day.

The typical cost range of RO devices is from \$300 to \$1,000. The RO unit's membrane should 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, based on a 10-year average, cost of water production ranges from 5 to 10 cents/gallon, not including the cost of water wasted or the cost, if any, of treating wastewater from the RO unit.

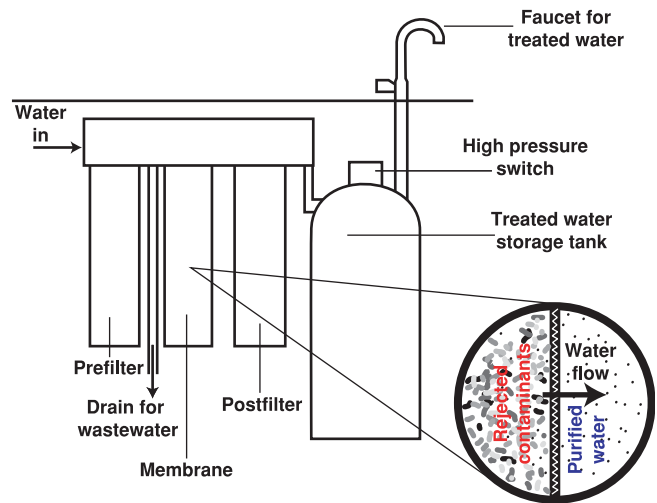


Figure 3. Reverse Osmosis Treatment Unit (Adapted from Kneen et al., 1995 and USEPA, 2003).

Distillation

Distillation reduces arsenic levels from a water source. In the distillation process, water is heated to boiling in an enclosed container, with impurities left behind as the water evaporates. The resulting steam then cools and condenses back into a liquid. Thus, dissolved gases and compounds that volatilize near the boiling point of water will be carried with the steam and end up in the treated water. Such contaminants can be removed by passing the distilled water through a post-filter. Most distillation units can treat 5 to 11 gallons of water a day.

Distillation units can be purchased for between \$300 and \$1200. However, operating costs for distillation systems may be higher than for other treatment methods due to the large amounts of electricity required to operate the distiller. Energy costs can be estimated using the following formula:

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

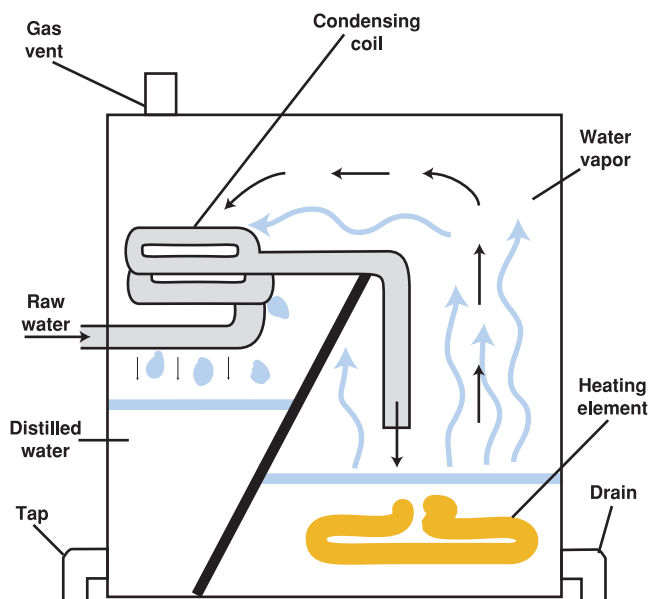


Figure 4. Distillation Process (Adapted from Kocher et al., 2003).

Ion Exchange (IE)

Ions are charged particles. Because arsenate forms an anion (negatively charged ion), it can be removed from water through an ion exchange process (IE). This process removes arsenic from a water source by passing the water under pressure through one or more columns packed with an exchange resin. The resin typically used for arsenic treatment is a strong-base ion exchange resin in either a chloride or a hydroxide form. As an arsenic ion (arsenate) moves across the resin, a chloride or a hydroxide ion is released from the resin and the arsenate takes its place, because the resin exchange site attracts the arsenic ion more strongly than the ion it replaced. Replacement of all the original ions saturates the resin column, and it must be regenerated or replaced. For treatment of arsenic, resin recharging can be done only at special facilities, making IE treatment expensive.

If the water source contains iron, more than 500 mg/L of total dissolved solids (TDS), more than 50 mg/L of sulfate (SO_4^{2-}) or high levels of nitrate, ion exchange most likely is not the best treatment option. Arsenic combined with iron may pass through the column untreated. Arsenic breakthrough also can occur when nitrate and sulfate ions compete with arsenate for places on the resin. If nitrate and sulfate ions displace arsenic ions, arsenate will pass untreated through the IE unit. As the resin column becomes saturated with ions, sulfate-rich water fed through the system may cause chromatographic peaking, making concentrations of arsenic and nitrate in the effluent from the column higher than they were in the water entering the column. Because chromatographic peaking and

other breakthrough events can occur very quickly, effluent from an IE treatment unit should be monitored frequently to ensure the unit is operating properly.

In addition to ongoing costs of monitoring and for resin replacement, an ion exchange unit initially costs somewhere between \$400 and \$1500.

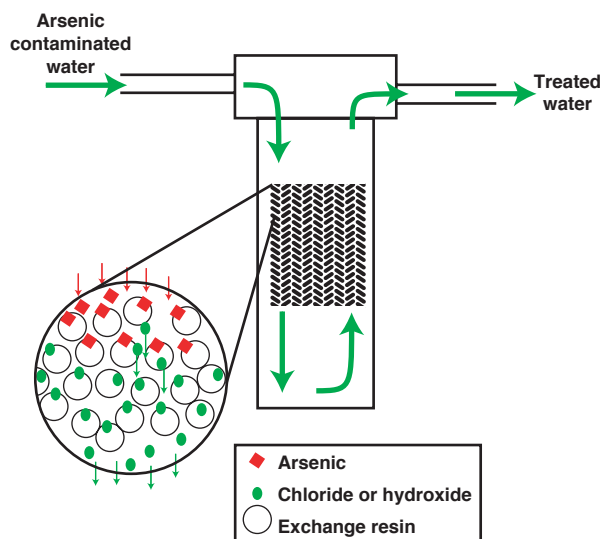


Figure 5. Ion Exchange Process (Adapted from Robillard et al., 2001).

How should a well owner select a treatment unit?

No single technology will treat all water contaminants. Before selecting a treatment option, well owners should test the water source, using a laboratory qualified to determine water quality. A list of labs certified by the Texas Commission on Environmental Quality (TCEQ) for testing drinking water can be found at: <http://www.tnrc.state.tx.us/permitting/waterperm/pdw/chemlabs.pdf>.

Once you have established the constituents present in your water supply, research different products and find one suitable for treating these constituents. Note systems' co-treatment compatibility if more than one contaminant must be treated. For example, although ion exchange can be used to treat both nitrate and perchlorate, a system must be set up specifically to treat both. Compare initial costs, operation and maintenance costs and requirements, contaminant removal efficiency, warranties, life expectancy of the system and company reputation. Before making your final decision, also consider wastewater or solid wastes generated by a system.

Home water-treatment systems are not regulated by federal or state laws, but some national organizations offer product certifications. The Water Quality

Association (WQA) offers a validation program and advertising guidelines. Products that receive the WQA's Gold Seal Product Validations are certified as to mechanical performance but not for ability to remove harmful contaminants. The National Sanitation Foundation (NSF) certifies products' ability to remove contaminants affecting health. A list of drinking-water treatment units with NSF certification can be found on the World Wide Web at: <http://www.nsf.org/Certified/DWTU/>. For questions regarding a particular product's certification, contact the NSF Consumer Hotline at 877-8-NSF-HELP or info@nsf.org or by writing to NSF International, P.O. Box 130140, 789 N. Dixboro Road, Ann Arbor, MI 48113-0140. An EPA registration number on a product indicates merely that the unit is registered with the EPA; this registration number does not imply EPA approval or certification.

How can well owners keep their systems working?

No matter what treatment technology you use, maintenance is required to keep the system operating properly, and 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; and
- give a valid estimate of installation costs.

After system installation, water treatment units must be maintained properly. RO membranes and resin in ion exchange units must be replaced as necessary. All systems should be operated according to manufacturer's specifications. Treating more water in a certain period of time than a system is designed for may lower treatment effectiveness and adversely impact effluent water quality. Water output by treatment units should be tested regularly to ensure proper system operation.

Useful Links

EnviroTools, 2002, *Arsenic*, adapted from ATSDR Factsheet, at: <http://www.envirotools.org/factsheets/contaminants/arsenic.shtm>;

Illinois Department of Public Health, *Arsenic in Groundwater*, at: <http://www.idph.state.il.us/envhealth/factsheets/arsenicwater.htm>

Maine Drinking Water Program, *Arsenic Treatment*, at: <http://www.maine.gov/dhhs/eng/water/ArsenicTreatment.htm> (February 25, 2004)

Minnesota Department of Health, *Arsenic in Well Water*, at: <http://www.health.state.mn.us/divs/eh/wells/arsenic.html> (December 27, 2004)

Massachusetts DEP, *Drinking Water—Arsenic in Private Well Water*, at: <http://www.mass.gov/dep/brp/dws/files/arswell.htm>

Natural Resources Defense Council, *Arsenic in Drinking Water*, at: <http://www.nrdc.org/water/drinking/qarsenic.asp> (March 21, 2001)

Public Health, Seattle and King County Public Health, *Arsenic Facts*, at <http://www.metrokc.gov/health/tsp/arsenic.htm> (July 6, 2004)

Regner, G, Court, M., and Kreig, K, 2004, *Health effects and occurrence of arsenic in Texas' water supplies*, Texas Commission on Environmental Quality, at: http://www.tnrcc.state.tx.us/permitting/waterperm/pdw/tf2004_arsenic.pdf

University of Wisconsin Water Resources Institute, *Arsenic*, at: <http://wri.wisc.edu/Arsenic.pdf> (March, 2004)

U.S. EPA, *Arsenic in Drinking Water*, at <http://www.epa.gov/safewater/arsenic.html> (February 1, 2005)

U.S. EPA, 2001, Fact Sheet: Drinking Water Standard for Arsenic, at: http://www.epa.gov/safewater/ars/ars_rule_factsheet.html

USGS, *Arsenic in Groundwater*, at: <http://water.usgs.gov/nawqa/trace/arsenic/>

USGS, Data map: 31,350 ground-water arsenic samples collected in 1973-2001, at: http://water.usgs.gov/nawqa/trace/pubs/geo_v46n11/fig1.html

USGS Fact Sheet 063-00, May 2000, *Arsenic in Ground-Water Resources of the United States*, at: <http://water.usgs.gov/nawqa/trace/pubs/fs-063-00/>

Vermont Department of Health, *Arsenic*, at: <http://www.vermont.gov/>

Wilkes University Center for Environmental Quality, *Arsenic in Drinking Water and Groundwater: Residential Water Supply and Homeowner Drinking Water Testing Evaluation Program*, at: <http://www.water-research.net/arsenic.htm>

World Health Organization, May 2001, *Arsenic in drinking water*, at: <http://www.who.int/mediacentre/factsheets/fs210/en/>

References

Hassinger, E., Doerge, T.A., and Baker, P.B. 1994. *Water Facts: Number 7—Choosing Home Water Treatment Devices*. Tucson, AZ: Arizona Cooperative Extension. Available at: <http://ag.arizona.edu/pubs/water/az9420.pdf>.

- Herman, G.M., and Jennings, G.D. 1996. *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>.
- Kamrin, M., Hayden, N., Christian, B., Bennack, D., and D'Itri, F. 1990. *A Guide to Home Water Treatment*. East Lansing, MI: Michigan State University Extension. Available at: <http://www.gem.msu.edu/pubs/msue/wq21p1.html>.
- Kneen, B., Lemley, A., and Wagenet, L. 1995. *Water Treatment Notes: Reverse Osmosis Treatment of Drinking Water*. Ithaca, NY: Cornell University Cooperative Extension. Available at: <http://www.cce.cornell.edu/factsheets/wqfactsheets/home/FSpdf/Factsheet4.pdf>
- Kocher, J., Dvorak, B., and Skipton, S. 2003. *Drinking Water Treatment: Distillation*. Lincoln, NE: Nebraska Cooperative Extension. Available at: <http://ianrpubs.unl.edu/water/g1493.htm>
- Lahlou, M.Z. 2003. *Point-of-Use/Point-of-Entry Systems*. Morgantown, WV: National Drinking Water Clearinghouse. Available at: http://www.nesc.wvu.edu/ndwc/articles/OT/SP03/TB_Point_of_Use.html.
- Powell, G.M., and Black, R.D. 1989. *Water Quality: Distillation*. Manhattan, KS: Kansas State University Cooperative Extension Service. Available at: <http://www.oznet.ksu.edu/library/H2OQL2/MF885.PDF>.
- Robillard, P.D., Sharpe, W.E., and Swistock, B.R. 2001. *Water Softening*. University Park, PA: Penn State Cooperative Extension. Available at: <http://www.sfr.cas.psu.edu/water/water%20softening.pdf>.
- Schwartz, J.J., and Lemley, A.T. 1998. *Reducing Potential Cancer Risks from Drinking Water PART II: Home Water Treatment Options*. Ithaca, NY: Cornell University BCERF. Available at: <http://envirocancer.cornell.edu/FactSheet/Pesticide/fs7b.drnkwrtr.cfm>
- United States Environmental Protection Agency (USEPA). 2003. *Arsenic Treatment Technology Evaluation Handbook for Small Systems*. EPA 816-R-03-014. Washington D.C.: USEPA Office of Water.

Acknowledgments

Guidance and assistance was provided by the Texas Groundwater Protection Committee and the Texas Commission on Environmental Quality. The effort was partially funded by the U. S. Environmental Protection Agency.



This publication was funded by the Rio Grande Basin Initiative administered by the Texas Water Resources Institute of Texas Cooperative Extension, with funds provided through a grant from the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, under Agreement No. 2005-45049-03209.

Produced by AgriLife Communications and Marketing, Texas A&M System
 Extension publications can be found on the Web at: <http://AgriLifebookstore.org>

Visit the Texas AgriLife Extension Service at <http://texasextension.tamu.edu>

Educational programs of the Texas AgriLife Extension Service are open to all people without regard to race, color, sex, disability, religion, age, or national origin.

Issued in furtherance of Cooperative Extension Work in Agriculture and Home Economics, Acts of Congress of May 8, 1914, as amended, and June 30, 1914, in cooperation with the United States Department of Agriculture. Edward G. Smith, Director, Texas AgriLife Extension Service, Texas A&M System.