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Drinking Water Treatment: An Overview

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Consumers concerned about their water quality must sort through an assortment of information to determine what contaminants are present, which contaminants are of real concern and the appropriate response and treatment that will be most effective for their particular situation. This guide provides an overview of household water problems, causes and potential health effects. The problem then can be matched to appropriate treatment method(s) for further investigation. The treatment methods listed in this guide are for household water problems requiring prolonged treatment.

Using the Overview Tables in This Guide

This guide presents two tables to help identify potential treatment options: the first table is a tool for matching water quality problems with potential treatment solutions and the second table briefly describes practical home drinking water treatment methods. Further discussion includes information on source protection, treatment considerations and drinking water standards. Other useful NebGuides related to drinking water are available online at *http://water.unl.edu/drinkingwater* or can be obtained through your local or state Extension office.

In *Table I, A Summary of Drinking Water Quality Problems and Solutions,* a problem or its symptom can be identified and located in the first two columns of the table. Its source or cause is then listed, followed by possible health effects. The drinking water standard or guideline for that contaminant is then listed (see discussion of drinking water standards later in this guide). Footnotes indicate the type of standard or guideline. The final column lists possible home treatment options effective for the situation; it is possible that other treatments may be effective but may not be as practical from a cost, operation or maintenance standpoint. Also, some treatments for one contaminant may help reduce the amount of another contaminant even though that treatment would not be a primary choice for the secondary contaminant. Less frequently used treatment options listed in *Table I* are not included in *Table II,* but instead are discussed in the appropriate NebGuide concerning specific contaminants (e.g., iron and manganese). Consult a water treatment professional for assistance in situations with multiple contaminants. Since certain contaminants have no visible taste, color, or odor, the last portion of *Table I* lists contaminants for which there are no symptoms of the problem other than possible health effects.

Once practical treatment methods are identified, a brief description of the treatments can be found in *Table II, Summary of Drinking Water Treatment Methods.* Further information on specific alternatives is available in other UNL NebGuides which focus on specific treatments. These are available online at *http://water.unl.edu/drinkingwater.* The NebGuide series on drinking water treatment focuses on contaminants most likely to be encountered in Nebraska drinking water supplies. It is possible that some water supplies may contain contaminants not addressed here, such as cryptosporidium, giardia, hexavalent chromium, and others.

Source Protection

The *best* option for assuring good water quality is protecting the water source from contamination in the first place. Once a supply is contaminated, in addition to treating the water as necessary, it is important to correct the situation causing the contamination. Contaminant removal can be costly and take considerable time. In situations where

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treatment would be extensive or costly such as high nitrate concentration, septic system contamination, or presence of numerous contaminants, improved water quality may be achieved more practically by drilling a new well or connecting to a rural or municipal water system. This guide focuses on treatment options. Other management options for dealing with specific contaminants may be viable alternatives to treatment; further information on managing specific contaminants can be obtained from the appropriate NebGuide in the contaminant series.

Treatment System Considerations

When considering water treatment, it is important to realize that *there is no one piece of treatment equipment that manages all contaminants.* All treatment methods have limitations. The treatment system that is best for any particular household depends on the contaminant(s) present, concentration(s), the size of the household, the age and health of its occupants and maintenance and operational requirements of the system. There also may be situations in which a combination of treatment methods is most effective. An example of this is the use of a sediment filter as pre-treatment before activated carbon treatment. Also, treatment systems can be classified as either Point-of-Use (POU) or Point-of-Entry (POE). POU devices treat water at the point it is used, such as the faucet. This allows treatment of water used only for drinking and cooking. POE devices treat water as it enters the household; so all water used within the house is treated. This is important if a contaminant can be absorbed through the skin or by inhalation during bathing, showering or other times of water contact. It is also important when managing substances that may cause staining, mineral deposits or other problems in the water distribution system.

Consumer Reports and Drinking Water Standards

People who use water from a public or municipal supply can be assured that their water meets federal and state guidelines to protect public health and that their water is tested regularly. This does not mean the water is free of regulated contaminants, but that they are below the level established for the standard. Consumer Confidence Reports (CCRs), available from local water utilities, inform consumers on the source of the water, contaminants that are present, potential health effects of those contaminants and methods of treatment used by the utility.

Those who obtain water from a private source are not bound by such regulations and are responsible for the quality of their supply, including protection, testing, maintenance and treatment. It is essential to know what contaminants are present, their quantities and reasons for their removal (i.e., to reduce contaminants posing health risks, to remove tastes or odors, etc.) prior to selecting treatment methods or equipment. Some contaminants of concern have no taste, color or odor. Information should be obtained through water analysis by an approved laboratory.

The Safe Drinking Water Act (SDWA) established two classifications of water quality standards. Primary Standards are established for substances considered to be a threat to human health if present in excess amounts. Maximum Contaminant Levels (MCLs) set by these standards indicate the highest level of the contaminant considered to be safe. Secondary Standards are not established to protect public health, but rather as guides to manage taste, odor, color and corrosive effects. Suppliers are not required by federal law to meet secondary standards.

The U.S. Environmental Protection Agency (EPA) also has established Health Advisory Levels (HAL) for various contaminants. These are not legally enforceable, but are guidelines. They contain a margin of safety that is typically 100-1,000 times lower than the highest concentration thought to cause no adverse health effects. This safety margin accounts for differences in body types and individual sensitivity to a contaminant. HAL contaminants are categorized as probable carcinogens (cancer causing agents), possible carcinogens or non-carcinogens. If the contaminant level is at or below the non-carcinogen level, EPA states an individual can consume that water every day for a lifetime without increasing health risks. If the contaminant level is equal to the probable carcinogen level, that water consumed over an entire lifetime increases the risk of cancer by one in a million. HAL summaries can be obtained from the EPA's Safe Drinking Water Hotline (Phone: (800) 426-4791).

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Table I. A Summary of Home Water Quality Problems and Solutions

Problem	*Symptom*	*Source or Cause*	*Possible Health Effects*	*Standard/Guideline**	*Treatment Options*
Appearance, Odor, or Taste					
	White scaly deposits in pipes or appliances, on glassware; soap scum in sinks and bathtubs	Naturally occurring deposits of calcium and magnesium	Generally contributes a small amount to total calcium and magnesium dietary needs	G) Hardness mineral concentration, mg/L: 0-17 = soft; 17-60 = slightly hard; 60-120 = moderately hard; 120-180 = hard; over 180 = very hard	Ion exchange water softener
	Green stains on fixtures; blue-green tint to water	Acidic water; Water high in carbon dioxide or dissolved oxygen with pH below 6.8; reaction with brass and copper plumbing	Stains may indicate copper or lead; see section for specific metals under *Contaminants with no visible color, odor or taste.*	SS) pH of 6.5-8.5	Calcite filter; soda ash chemical feed followed by sediment filtration
	Grittiness, abrasive texture to water when washing, residues in sink	Naturally occurring fine sand particles or silt in water that passes through well screen	May be harmful contaminants attached to soil/clay particles		Sediment filtration; distillation
	Salty or brackish water; Blackening and pitting of stainless steel sinks and kitchen utensils	Naturally occurring high sodium content	Excess sodium for those on low sodium diets due to blood pressure		Reverse osmosis; distillation
	Soda taste, slippery feel	High total dissolved solids that are alkaline	No direct health effects; can interfere with disinfection	SS) 500 mg/L total dissolved solids; SS) pH of 6.5-8.5	Reverse osmosis; distillation
	Sharp chemical odor in water; may also be odorless (refer to section on odorless contaminants)	Leaching of pesticides into groundwater	Anemia or other blood disorders, nervous system or reproductive disorders; increased risk of cancer, stomach, liver, kidney problems, etc., especially if consumed over long term	EPA has specific standards for many pesticides	Activated carbon filtration; reverse osmosis, distillation
	Musty, earthy, or woody smell	Usually harmless organic matter	None	SS) odor	Activated carbon filtration
	Chlorine smell	Excessive chlorination	Chlorine in water is not poisonous to humans or animals although high concentrations can cause eye or nose irritation and stomach discomfort.	PS) mg/L chlorine residue	Activated carbon filtration

*PS = Safe Drinking Water Act (SDWA) Primary Standard; SS = SDWA Seconday Standard; HAL = EPA Health Advisory Level; G = Guideline.

Table I. A Summary of Home Water Quality Problems and Solutions (continued)

Problem	*Symptom*	*Source or Cause*	*Possible Health Effects*	*Standard/Guideline**	*Treatment Options*
Appearance, Odor, or Taste (continued)					
	Gasoline or oil smell	Potential leak in fuel tank or underground storage tank leaking into water supply; discharge from factories or landfills; runoff from agriculture or other nearby source	Varies depending on the contaminant; possibly anemia, increased risk of cancer, liver and kidney problems especially if consumed over long term	PS) Benzene = 0.005 mg/L; PS) Ethyl benzene = 0.7 mg/L; PS) Toluene = 1.0 mg/L; PS) Xylenes = 10 mg/L; G) MTBE = 0.20 mg/L	Activated carbon filtration in some cases
	Rotten egg odor	Dissolved hydrogen sulfide gas; naturally occurring	Not usually a health risk at concentrations present in household water; however, hydrogen sulfide gas is flammable and poisonous if released at high concentrations	SS) 250 mg/L sulfate	Oxidizing filter; continuous chlorination followed by activated carbon filtration; de-aeration may reduce to acceptable levels; activated carbon filtration
	Rotten egg odor	Presence of sulfate-reducing bacteria in water supply	No known health risk	SS) 250 mg/L sulfate	Continuous chlorination followed by activated carbon filtration
	Rotten egg odor	Action of magnesium rod in hot water heater in presence of soft water	No known health risk		Replace magnesium rod from heater with acceptable alternative such as an aluminum rod
	Detergent odor or foaming water	Septic tank leakage into water supply which may indicate associated bacterial or viral contamination	Gastrointestinal illnesses (diarrhea, vomiting, cramps)		Eliminate source and shock chlorinate well
	Phenol (chemical) odor	Industrial waste seepage into groundwater	Varies depending on the contaminant	Varies depending on the contaminant	Activated carbon filtration for a short time; filter capacity is reached quickly
	Cloudy water or suspended particles that settle out in water	Clay, silt or sand from well	May be harmful contaminants attached to soil/clay particles		Sand trap; new well screen; sediment filtration
	Brownish-blackish stains on fixtures and laundry; affects the flavor and color of food and water Black cast to water	Natural deposits of manganese in soil which interact with organics; Above 0.05 mg/L manganese causes staining and is usually found combined with iron	No known health risk	SS) 0.05 mg/L Manganese	Ion exchange water softener; oxidizing filter; continuous chlorination followed by sediment filtration; ozonation followed by sediment filtration; aeration followed by sediment filtration

*PS = Safe Drinking Water Act (SDWA) Primary Standard; SS = SDWA Seconday Standard; HAL = EPA Health Advisory Level; G = Guideline.

Table I. A Summary of Home Water Quality Problems and Solutions (continued)

Problem	*Symptom*	*Source or Cause*	*Possible Health Effects*	*Standard/Guideline**	*Treatment Options*
Appearance, Odor, or Taste (continued)					
	Water appears clear when first drawn from tap; water turns reddish-brown during cooking/ heating; reddish-brown stains on sinks and other porcelain fixtures; stains on laundry	Dissolved iron; natural deposits; Indicates more than 0.3 mg/L dissolved iron	No known health risk	SS) 0.3 mg/L Iron	Ion exchange water softener; oxidizing filter; continuous chlorination followed by sediment filtration; ozonation followed by sediment filtration; aeration followed by sediment filtration
	Water is reddish or discolored when drawn	Precipitated iron	No known health risk		Oxidizing filter
	Brownish cast that does not precipitate and drop out of water	Organic (bacterial) iron	No known health risk		Shock chlorinate well, followed by continuous chlorination and activated carbon filtration
	Reddish color in water sample after standing 24 hrs.	Colloidal iron	No known health risk		Continuous chlorination followed by activated carbon filtration
	Yellowish tint to water after softening and/or filtering	Tannins (humic acids) present from water passing through peaty soil, decaying vegetation, or from influence of nearby surface water	No known health risk	SS) 15 color units	Anion exchange; continuous chlorination followed by activated carbon filtration

*PS = Safe Drinking Water Act (SDWA) Primary Standard; SS = SDWA Seconday Standard; HAL = EPA Health Advisory Level; G = Guideline.

Table I. A Summary of Home Water Quality Problems and Solutions (continued)

Problem	*Symptom*	*Source or Cause*	*Possible Health Effects*	*Standard/Guideline**	*Treatment Options*
Contaminants with no visible color, odor or taste					
High chloride content in water	No visible color, odor or taste	Excessive salt content	Excess sodium for those on low sodium diets due to blood pressure	SS) 250 mg/L Chloride	Distillation; reverse osmosis
Fluoride		Natural deposits; fertilizer; aluminum industries; water additive	Optimal fluoride level is 0.07 mg/L for good dental health; excess leads to dental fluorosis; yellowish or mottled teeth in children may occur at concentrations over 2 mg/L; excess levels can contribute to bone disease if consumed over long term	PS) 4.0 mg/L; SS) 2.0 mg/L	Reverse osmosis; distillation
Nitrate		Nearby human or animal waste leaching into groundwater; heavy use of fertilizers with nitrogen entering groundwater; natural deposits	Inadequate oxygen-carrying capacity in the blood of a fetus or infant less than 6 months (Blue baby syndrome or methemoglobinemia)	PS) 10 mg/L Nitrate as Nitrogen	Reverse osmosis; distillation
Radon		Radon gas is given off by naturally occurring decaying radium dissolved in water	Increased risk of lung cancer if inhaled over long term	5 pCi/L for Radium 226 and Radium 228 combined	De-aeration; activated carbon filtration
Lead		Corrosion of lead pipes or solder in home; erosion of natural deposits	Serious damage to brain/ nervous system, kidneys and red blood cells	PS) 0.015 mg/L	Reverse osmosis; distillation; activated carbon filtration equipped with special media; replace lead pipes and solder in home
Copper		Corrosion of copper plumbing in home; natural deposits; wood preservatives	Short-term exposure — nausea/ vomiting, diarrhea, stomach cramps; liver and kidney damage if consumed over long term	PS) 1.3 mg/L; SS) 1.0 mg/L	Activated carbon filtration equipped with special media; reverse osmosis; distillation
Other heavy metals (zinc, cadmium, etc.)		Industrial waste pollution; corrosion from plumbing caused by low pH water (Possible metallic taste)	Kidney and nervous system disorders; blood disorders; gastrointestinal disorders if consumed over long term	EPA has maximum contaminant levels (MCL's) for each metal	Reverse osmosis; distillation; activated carbon filtration in some cases; ion exchange water softener will remove cadmium, copper and zinc if operated properly
Arsenic		Natural Deposits, smelters, glass, electronics wastes	Increased risk of cancer, skin, nervous system, and circulatory disorders if consumed over long term	PS) 0.010 mg/L	Reverse osmosis; distillation; iron- or manganese-doped adsorbent media

*PS = Safe Drinking Water Act (SDWA) Primary Standard; SS = SDWA Seconday Standard; HAL = EPA Health Advisory Level; G = Guideline.

Table I. A Summary of Home Water Quality Problems and Solutions (continued)

Problem	*Symptom*	*Source or Cause*	*Possible Health Effects*	*Standard/Guideline**	*Treatment Options*
Contaminants with no visible color, odor or taste (continued)					
Uranium	No visible color, odor or taste	Erosion of natural deposits	Increased risk of cancer; kidney toxicity if consumed over long term	0.030 mg/L	Reverse osmosis, distillation, special adsorbent media (such as titanium dioxide) and anion exchange)
Chloramines		Water additive used to control microbes	Eye and nose irritation; stomach discomfort; anemia	PS) 4.0 mg/L as Cl_2 maximum residual	Activated carbon filtration
Disinfection Byproducts (Trihalomethanes)		By-product of chlorination of drinking water; Water additive used to control microbes	Increased risk of cancer; liver, kidney or central nervous system problems if consumed over long term	PS) 0.08 mg/L	Activated carbon filtration
Bacteria-(coliform) (*E. coli*)		Bacteria commonly tested for include coliform and *E. coli* bacteria. Coliform bacteria are commonly found in the environment and are generally not harmful. *E. coli* bacteria is an indication of contamination from human or animal waste, which indicates pathogens could be present in the water supply.	Gastrointestinal disorders (diarrhea, vomiting, cramps) if pathogenic bacteria are present	PS) If coliform bacteria are detected, pathogens may or may not be present. Steps must be taken to identify the source and fix problems. The MCL for *E. coli* bacteria is zero. If *E. coli* bacteria are detected, pathogens are more likely to be present. Immediate action must be taken to ensure pathogen-free water.	Ultraviolet radiation; continuous chlorination; distillation; ozonation
Cryptosporidium		Unlikely in groundwater unless well is extremely close to surface water; Human or animal wastes leaching into water	Gastrointestinal disorders (diarrhea, vomiting, cramps)	PS) 99% killed/inactivated	Fine micron filters with molded activated carbon blocks; ozonation; reverse osmosis
Giardia		Unlikely in groundwater unless well is extremely close to surface water; Human or animal wastes leaching into water	Gastrointestinal disorders (diarrhea, vomiting, cramps)	PS) 99.9% killed/inactivated	Ultraviolet disinfection; continuous chlorination; ozonation; fine micron filters with molded activated carbon blocks
Viruses		Unlikely in groundwater unless well is extremely close to surface water; Human or animal wastes leaching into water	Gastrointestinal disorders (diarrhea, vomiting, cramps)	PS) 99.99% killed/inactivated	Ultraviolet disinfection; continuous chlorination; ozonation; ultra filters; reverse osmosis

*PS = Safe Drinking Water Act (SDWA) Primary Standard; SS = SDWA Seconday Standard; HAL = EPA Health Advisory Level; G = Guideline.

Table II. Summary of Drinking Water Treatment Methods

Treatment Method	*How It Works*	*What It Removes*	*Operation and Maintenance Issues*	*For Further Information*
Activated carbon filtration	As water flows through the filter contaminants adsorb, or stick to, the surface of activated carbon particles.	Pesticides; organic compounds such as benzene and carbon tetrachloride; many odors (check *Table I* for specific odors); bacterial or colloidal iron or tannins when combined with continuous chlorination; radon; lead or copper if equipped with special media; some other heavy metals in certain cases; chlorine; chloramines; trihalomethanes. Filters with molded activated carbon blocks will treat Cryptosporidium and Giardia.	System must be monitored and carbon cartridges must be replaced at regular intervals. Failure to replace filter regularly can result in "breakthrough" with elevated levels of contaminants in water.	G1489 *Drinking Water Treatment: Activated Carbon Filtration (Ion Exchange)*
Reverse osmosis (RO)	Contaminants are removed by forcing water through a membrane which has microscopic holes. Water molecules pass through the membrane but larger particles cannot. The membrane is flushed to remove trapped contaminants.	Certain tastes (See *Table I* for specific tastes); some pesticides; high chloride content; fluoride; nitrate; lead, copper, and other heavy metals; arsenic; Cryptosporidium; viruses.	Activated carbon or sediment filtration is often used to pre-filter water before reverse osmosis. Activated carbon post-filters are also common. Pre-filters and post-filters require regular replacement. RO membrane must be regularly monitored and disinfected. RO systems can waste a large amount of water.	G1490 *Drinking Water Treatment: Reverse Osmosis*
Ion exchange water softening	As water passes through a resin bed in the softener, calcium and magnesium in the water are exchanged for sodium or potassium which do not create the nuisance problems associated with hard water.	Hard water (calcium and magnesium); dissolved iron; manganese; will treat cadmium, copper and zinc if operated properly.	When the resin is filled to capacity, it must be recharged. Depending upon the type of softener, some degree of monitoring of the regeneration cycle is necessary. People on restricted sodium diets should consult their doctor about drinking softened water since it contributes sodium to the diet.	G1491 *Drinking Water Treatment: Water Softening (Ion Exchange)*
Sediment filtration	As water passes through a filter made of sand, filter paper, compressed glass wool or other straining material suspended particles such as sand, soil or other particles are trapped on the filter.	Sediment; acidic water when preceded by soda ash feed; dissolved iron or manganese when preceded by continuous chlorination, ozonation or aeration; turbidity.	Depending on the type of filter, cartridge replacement or backwashing must be done on a regular basis in order to maintain effectiveness.	G1492 *Drinking Water Treatment: Sediment Filtration*

Table II. Summary of Drinking Water Treatment Methods (continued)

Treatment Method	*How It Works*	*What It Removes*	*Operation and Maintenance Issues*	*For Further Information*
Distillation	Water is heated to create steam which is then condensed to be collected as treated water. Contaminants removed remain in the heating chamber or boil off into the atmosphere.	Sediment; high salt content; high total dissolved solids; pesticides if properly equipped with gas vent; fluoride; nitrate; lead, copper and other heavy metals; arsenic; bacteria.	Energy costs for distillation can be significant. Scale buildup and sediment must be periodically removed from the distiller. Contaminants with a boiling point lower than water, such as some pesticides and solvents, can vaporize with the water and condense with treated water instead of being removed. Some units have a gas vent to release these contaminants to the air. Distilled water may have a flat or bland taste.	G1493 *Drinking Water Treatment: Distillation*
Aeration	Oxygen is introduced into the water by an aerator. This oxidizes contaminants such as iron and manganese, causing them to form solids which can then be filtered out of the water.	Dissolved iron or manganese when followed by sediment filtration; may help reduce rotten egg odor from dissolved hydrogen sulfide gas; radon.	Regular backwashing of the filter following aeration is required. Aeration is not recommended for water containing bacteria which may clog the system.	
De-Aeration	Mix air with water to remove dissolved gases from the water. Aeration and De-aeration equipment sometimes are very similar, but are designed for different treatment goals.	Dissolved hydrogen sulfide gas; radon.	If water has high hardness (e.g., calcium, magnesium, iron, manganese), system should be designed to manage precipitates and scale build-up.	
Continuous Chlorination	Chlorine is fed or injected into the water to kill bacteria and other microbial contaminants, as well as to oxidize iron and manganese causing them to form solids which can then be filtered out.	Dissolved iron or manganese when followed by sediment filtration; rotten egg odor from dissolved hydrogen sulfide gas or sulfate-reducing bacteria (followed by activated carbon filtration); bacterial or colloidal iron or tannins when combined with activated carbon filtration; bacteria; Giardia; viruses.	Chlorine must have adequate contact time with water to disinfect it. Therefore the chlorine dose must be carefully synchronized with the water flow so water does not move too quickly through the system. Chlorine feed pumps must be carefully calibrated and maintained. Careful handling of chlorine is required since it is toxic. Depending on the organic content of the water, byproducts of the chlorination process may include trihalomethanes (THM's) which may increase the risk of cancer. Activated carbon filtration may be used after chlorination to remove excess chlorine and its byproducts; filters should be changed regularly.	G1496 *Drinking Water Treatment: Continuous Chlorination*

Table II. Summary of Drinking Water Treatment Methods (continued)

Treatment Method	*How It Works*	*What It Removes*	*Operation and Maintenance Issues*	*For Further Information*
Ultraviolet (UV) radiation	As water passes through the system, a special lamp produces ultraviolet light that kills bacteria and other microbial contaminants.	Bacteria; Giardia; viruses.	Sediment buildup and algae growth may cause problems within the system and must be periodically removed. The lamp must be kept clean to maintain effectiveness. In turbid, or cloudy, water the UV light may not reach some of the organisms. Water may need to be treated for turbidity prior to entering the UV system. Also, UV radiation does not have a residual effect so water that leaves the system can be recontaminated.	
Ozonation	Water enters a system where ozone, a chemical form of pure oxygen, is produced and mixed with the water. Ozonation destroys bacteria and other microbial pathogens and oxidizes compounds such as iron and manganese causing them to form solids which can then be filtered out.	Bacteria; Giardia; Cryptosporidium; viruses; dissolved iron or manganese when combined with sediment filtration.	Equipment that tests for ozone in treated water must be purchased or bacterial tests performed, as this is the only way to determine if the system is operating properly. Dehumidification of surrounding air is frequently required. Careful monitoring is required as ozone is a toxic gas. Ozonation does not have a lasting (residual) effect so recontamination of water can occur. Ozonation equipment is costly.	
Ultra, micro, and nano filtration	As water passes through a filter, suspended particles are trapped on the filter. Particles removed depends upon the size of the pores in the filter. Pore sizes from smallest to largest are nanofiltration, ultra filtration and microfiltration.	Cryptosporidium; Giardia; viruses.	Depending on the type of filter, cartridge replacement or backwashing must be done on a regular basis in order to maintain effectiveness.	

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Portions of *Table I: A Summary of Drinking Water Quality Problems and Solutions* were adapted from:

"Matching Drinking Water Quality Problems to Treatment Methods," University of Nevada-Reno, Cooperative Extension, 2000.

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