



STATE HYGIENIC LABORATORY
AT THE UNIVERSITY OF IOWA

Well Water Quality and Home Treatment Systems





A HISTORY OF WATER TREATMENT

Water is necessary for life. It is not surprising, then, that concerns about safe water and treatment methods have existed since the dawn of civilization. Because early man was not aware of the many naturally occurring contaminants that modern instrumentation and methods can now detect, they assumed good tasting water was safe for human consumption with no need for further treatment.

The first known records referring to water treatment methods were found in early Sanskrit writings (4000 B.C.). These water treatment methods included filtering water through sand or charcoal filters and storing water in copper containers. Other suggestions were to boil the water, either heating by the sun or immersing a hot metal instrument in the water prior to consumption.

Even Hippocrates (circa 460-377 B.C.), the Father of Medicine, realized the importance of good tasting water, and recommended that boiling water be filtered through a cloth prior to drinking. As early as 1500 B.C., the Egyptians discovered that filtration could be enhanced by the addition of alum. Filtration, especially sand filtration, became more widespread, resulting in the first application of the technology in the early 1800s in the city of Paisley, Scotland. Filtration in American cities was first introduced in the 1890's.

Dr. John Snow's work with the cholera epidemic in England in the mid-to-late 1850s led to the use of chlorination as a treatment option to disinfect drinking water in addition to filtration. The effectiveness of chlorine to control waterborne diseases led to the first use of chlorine as the primary disinfectant of drinking water in Jersey City, New Jersey, in 1908.

Today, the detection of naturally occurring and manmade organic and inorganic chemicals and various microbial pathogens in drinking water has become quicker and more accurate to an ever lower detection limit due to continued improvements in instrumentation and methods.

And, treatment technologies have also become better, more reliable and more efficient in removing those contaminants.



"The noblest of the elements is water"

—Pindar, 476 B.C.

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For added information relevant to the drinking water industry, visit AWWA's website or call 800-926-7337.

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Additional copies of this booklet can be ordered by completing and mailing the tear-out postcard in the back of this booklet or by contacting the State Hygienic Laboratory.

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April 2013

INTRODUCTION

This publication is an overview of systems commonly used to treat water quality problems. It is preferable to provide a safe source of water rather than depend upon treatment devices to remove aesthetic and/or health related contaminants because treatment units may unknowingly fail completely or malfunction. The best approach is to determine how and where contaminants are entering the system and eliminate the entry pathway. Some contaminants are naturally occurring in ground water and treatment may be the only option.

If water treatment appears to be the only option, the treatment system(s) must match the specific contaminant(s) that must be removed. Selecting the wrong treatment unit may actually increase the concentration of the contaminant you want to remove. No system treats all water quality problems, all have limitations. Before buying a treatment system, an accurate analysis of the water is necessary to determine what contaminants are present and at what concentration.

Before purchasing any unit, know the unit's limitations, removal efficiencies of various contaminants, life expectancy and especially routine maintenance procedure requirements. Remember, the claims of manufacturers and dealers may not accurately describe how the treatment unit will perform when applied to your water. Renting a unit may be an alternative to determine if the unit performs as advertised and expected.

Once the appropriate unit is installed and operating normally for a short period of time, it is highly recommended that the product water be tested to make sure the contaminant(s) is being removed completely or reduced to safe levels. Product water testing is recommended annually and at any time the water changes in taste, odor or appearance, and after routine maintenance.

Call the State Hygienic Laboratory at The University of Iowa (800-421-IOWA) if you have any questions as to what analysis may be needed and what types of units are appropriate for your intended purpose.



State Hygienic Laboratory building on the University of Iowa Research Park Campus, Coralville, Iowa

Coliform Action Response

If your water tests **POSITIVE** for Coliforms, determine mode of entry and/or source of Coliforms.

Possible Sampling Procedure Problems:

1. Poor choice of sampling tap (Avoid the following)
 - swivel
 - outside
 - basement
 - leaking
 - flexible hose
 - corroded
2. Aerator not removed
3. Tap not flushed before sampling
4. Touched/dropped sterile bottle or cap
5. Treatment device attached to faucet not removed

Possible Distribution System Problems:

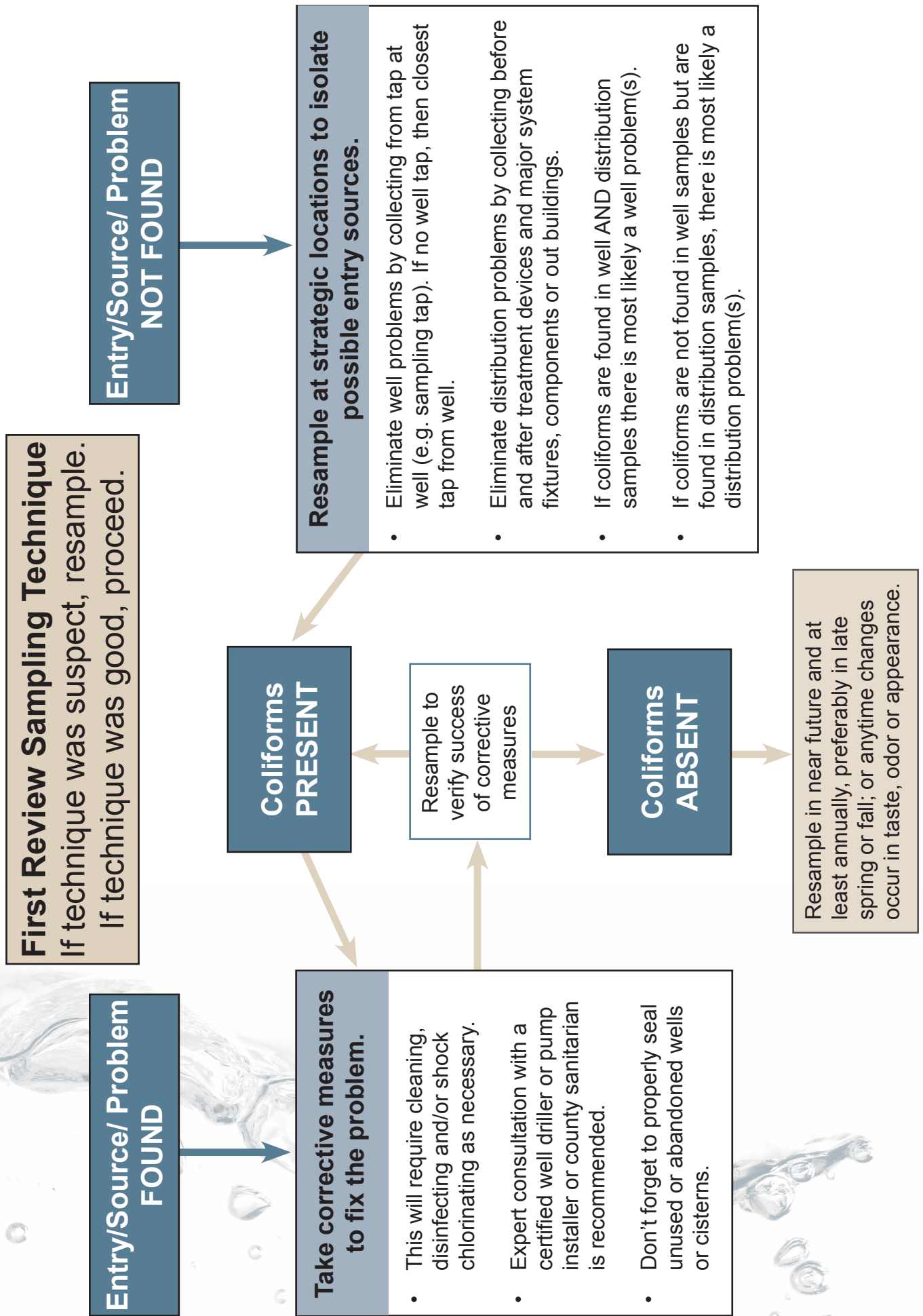
1. Contaminated or biofouled water treatment devices
 - softeners
 - particulate filters
 - carbon filters
 - reverse osmosis units
2. Plumbing renovations
3. Leaky fixtures, distribution lines or cisterns
4. Malfunctioning pressure tank
5. Cross connections

Possible Well/Casing/Grouting/Platform Problems:

1. New well construction or well repairs not followed with adequate disinfection
2. Structural integrity compromised
 - hole in casing
 - platform cracked
 - sanitary cap, seal or screen compromised
3. Poorly constructed or obsolete well/casing
 - brick-lined well
 - water in well pit
 - no or inadequate grout
4. Shallow or susceptible well too close to coliform source(s)
 - septic system/laterals
 - feedlot, backyard, confinement runoff
 - abandoned well/cistern
5. Flood water intrusion

If entry and/or source of coliforms are not found, follow remedial schematic on page 6.

Coliform Action Response: Remedial Schematic



DRINKING WATER QUALITY PROBLEMS IN IOWA

I. Problems That May Threaten Health

Contaminant	Possible Suggested Health Effects*	Possible Source	Suggested Treatment
A. Coliform Bacteria	Indicates sanitary defect in well or system if collected properly	Surface or shallow subsurface water, waste water or topsoil	Refer to flowchart on pages 5-6
B. <i>E. coli</i>	Indicates disease-producing microorganisms may be present; diarrhea	Human waste, animal manure or wastewater; flood water	Refer to flowchart on pages 5-6
C. Nitrate	Methemoglobinemia (blue baby disease)	Fertilizer, manure, septic system, etc.	Eliminate source if possible: correct defects of well or supply; anion exchange; reverse osmosis; distillation
D. Pesticide	Acute: vomiting, weakness, etc. Chronic: cancer, genetic or birth defect risks	Improper use, disposal, spills, or back-siphoning accident	Eliminate source if possible: purge system; depending on type of pesticide, treatment units may be available (consult manufacturer)
E. Lead	Chronic: adverse effects on blood, nervous and kidney systems	Improper use, disposal, spills, or back-siphoning accident	Reduce corrosion (see below), lead pipe/solder replacement, reverse osmosis, distillation
F. Gasoline/Organic Solvents (BTEX)	Chronic: cancer risks; taste or odor	Leaking storage tanks, spills, improper use or disposal	Eliminate source if possible: purge system; activated carbon filter in series; vented distillation
G. Arsenic	Acute: gastrointestinal problems Chronic: cancer risks	Most common is natural mineral deposits	Distillation, reverse osmosis, activate alumina, anionic resin

*Varies with exposure, contaminant, and susceptibility

II. Problems That Usually Do Not Threaten Health

Contaminant	Complaint	Possible Source	Suggested Treatment
A. Iron and Manganese	Rusty water, rust stains on sink or clothes, deposits inside pipes	Corrosion or naturally present in aquifer	Water softeners for soluble (ferrous) iron; iron removal units (green sand); reverse osmosis; distillation
B. Hardness	Scale, soap scums, deposition inside pipes	Dissolved calcium and magnesium from soil and/or aquifer	Water softener (ion exchange; reverse osmosis; distillation)
C. Iron Bacteria	Oily film on water, slime growth in water tanks or toilets	Present in iron-rich aquifer; contaminated drilling equipment	Shock chlorination; continuous chlorination to retard growth
D. Corrosion	Metallic taste, greenish stains on faucets, sinks, leaking pipes	Corrosive water present in aquifer; "softened" water; incompatible metals in plumbing; aggressive water	Add corrosion control chemicals or sacrificial metal
E. Hydrogen Sulfide	Rotten egg odor	Hydrogen sulfide gives water this odor; possibly caused by corrosion or naturally occurring sulfur bacteria. NOTE: make sure odor is not due to coliform bacteria problem (see I. A. above)	Shock chlorination; green sand iron filter; activated charcoal filters

CAUTION

- No one treatment system corrects ALL water quality problems
- ALL systems have limitations and life expectancies
- ALL systems require routine maintenance and/or monitoring
- Match the treatment system to the specific contaminant to be removed — laboratory testing may be necessary to determine the problem(s)

ARSENIC

What is Arsenic?

Arsenic is a naturally occurring element that is widely distributed in the Earth's crust and occurs naturally in rocks and soil, water, air, and plants and animals. Arsenic is usually found in the environment combined with other elements such as oxygen, chlorine, and sulfur. Most inorganic and organic arsenic compounds are white or colorless powders that do not evaporate. They have no smell, and most have no special taste. Thus, you usually cannot tell if arsenic is present in your food, water, or air.

Arsenic can be further released into the environment through natural activities such as volcanic action, erosion of rocks, and forest fires, or through human actions. Approximately 90 percent of industrial arsenic in the U.S. is currently used as a wood preservative, but arsenic is also used in paints, dyes, metals, drugs, soaps, and semi-conductors. Agricultural applications, mining, and smelting also contribute to arsenic releases in the environment.

Higher levels of arsenic tend to be found more in ground water sources than in surface water sources (i.e., lakes and rivers) of drinking water. Parts of the Midwest have some systems whose current arsenic levels are greater than the drinking water standard of 0.010 mg/L (10 ppb), but more systems with arsenic levels that range from 2-10 ppb. While many systems may not have detected arsenic in their drinking water above 10 ppb, there may be geographic "hot spots" with systems that may have higher levels of arsenic than the predicted occurrence for that area.

What are the Health Effects of Arsenic Exposure?

Studies have linked long-term exposure to arsenic in drinking water to cancer of the bladder, lungs, skin, kidney, nasal passages, liver, and prostate. Non-cancer effects of ingesting arsenic include cardiovascular, pulmonary, immunological, neurological, and endocrine (e.g., diabetes) effects. Short-term exposure to high doses of arsenic can cause other adverse health effects, but such effects are unlikely to occur from U.S. public water supplies that are in compliance with the arsenic drinking water standard of 0.010 mg/L.

Breathing high levels of inorganic arsenic can give you a sore throat or irritated lungs. Ingesting very high levels of arsenic can result in death. Exposure to lower levels can cause nausea and vomiting, decreased production of red and white blood cells, abnormal heart rhythm, damage to blood vessels, and a sensation of "pins and needles" in hands and feet.

Ingesting or breathing low levels of inorganic arsenic for a long time can cause a darkening of the skin and the appearance of small "corns" or "warts" on the palms, soles, and torso. Skin contact with inorganic arsenic may cause redness and swelling.

The severity of the reaction to arsenic exposure depends on the concentration, route of exposure, duration, frequency of exposure and the general health, age and lifestyle of the individual.

Arsenic is rather quickly removed from the body. Most arsenic will be eliminated in several days after discontinuing consumption of water containing arsenic.

Bathing in water containing arsenic is unlikely to result in absorption of significant amounts of arsenic through the skin. Boiling water will not remove arsenic but only concentrates the level of arsenic in the water.

References:

Centers for Disease Control and Prevention (CDC), Agency for Toxic Substances and Disease Registry (ATSDR), Public Health Statement, <http://www.atsdr.cdc.gov/ToxProfiles/tp2-c1-b.pdf>

United States environmental Protection Agency, Fact Sheet: Drinking Water Standard for Arsenic, http://water.epa.gov/lawsregs/rulesregs/sdwa/arsenic/regulations_factsheet.cfm



What is BTEX?

BTEX is not a single chemical but is an acronym of four organic chemicals found in petroleum products. The chemicals are Benzene, Toluene, Ethylbenzene and Xylene.

The presence of these chemicals allow gasoline to meet octane and vapor pressure standards.

These compounds can also be found in many other commonly used products. Benzene can be found in detergents, cosmetics, nylon, insecticides, paints, plastics, synthetic rubber, dyes, resins and glues. Benzene is also found in cigarette smoke. Nationally, about 50% of exposure to benzene comes from smoking or secondhand exposure to tobacco smoke.

Toluene can be found in coatings, gums, resins, oils and as a paint solvent.

Ethylbenzene is primarily an automotive and aviation gasoline additive and can also be found in pesticides, plastics, paints and inks.

Xylene is used in the rubber, printing and leather industries.

How are we exposed to BTEX?

Exposure to these chemicals can be through ingestion of contaminated water and the inhalation of fumes from pumping gas, showering or laundering. Exposure can also be from direct contact with the skin from spills or other accidental contact.

The primary source of BTEX groundwater contamination is leakage of gasoline from underground storage tanks. Surface spills and pipeline leaks can also lead to inadvertent contact with the chemicals.

What are the Health Effects of BTEX?

Acute, short term, contact with these chemicals can result in skin and sensory irritation and in central nervous system (CNS) effects such as tiredness, dizziness, headache and loss of coordination. Exposure can also result in eye and nose irritation. Prolonged exposure can affect the kidneys, liver and blood.

The high levels of exposure resulting in severe reactions are not likely to be found in drinking water but are most likely from occupational exposures.

The severity of the reaction to BTEX depends on the dose, duration and frequency of the exposure and the general health, age and lifestyle of the individual.

Does BTEX cause cancer?

Benzene has been determined to be a human carcinogen. Exposure to high levels of benzene in occupational settings was found to increase the occurrence of leukemia. Ethylbenzene has been classified as a possible human carcinogen based on laboratory animal studies. At this time, toluene and xylene have been categorized as not classifiable as to human carcinogenicity by the EPA (Environmental Protection Agency) and the IARC (International Agency for Research on Cancer).

How can the exposure to BTEX be reduced?

All products containing volatile chemicals should be stored outside the home in properly labeled containers, preferably in their original containers, with tamper-proof caps out of reach of children. When such products are used, provide ample ventilation to prevent the accumulation of the chemicals in the air.

Do not smoke indoors with windows and doors closed. Also, avoid breathing secondhand smoke.



State Hygienic Laboratory scientists prepare samples for testing.

IOWA REGULATIONS GOVERNING THE SALE & MARKETING OF RESIDENTIAL WATER TREATMENT SYSTEMS

(Iowa Code Chapter 714.16 and Iowa Administrative Code 641--14)

The purpose of the regulations is to protect the consumer from false or deceptive claims by sellers of residential water treatment devices in Iowa regarding the reduction of health-related contaminants in drinking water. The legislation applies to sellers or manufacturers of any residential water treatment device offered for sale, lease or rent for which claims of reducing health-related contaminants are made.

Manufacturer's Performance Data Sheet

Before purchasing a water treatment device, a consumer should read the Manufacturer's Performance Data Sheet. By law, this document *must* be given to the buyer by the seller and signed and dated by both parties *prior* to the consummation of the sale. The Performance Data Sheet must contain, but is not limited to, the following information:

1. The name, address and telephone number of the seller.
2. The name, brand or trademark under which the water treatment device is sold and its model number.
3. Performance and test data including but not limited to:
 - a. The list of contaminants found to be reduced by the device.
 - b. The average test influent concentration of each contaminant.
 - c. The percent reduction effluent concentration of each contaminant.
 - d. The maximum contaminant level (MCL) specified in the U.S. EPA's National Primary Drinking Water Regulations for each contaminant.
 - e. The approximate capacity in gallons or the period of time during which the treatment device is effective in reducing the contaminants based on the contaminant influent concentration used for the performance test. The gallon capacity of the device need only be based on the claimed contaminant most likely to break through into the effluent during the performance test period.
 - f. If applicable, the flow rate, pressure and temperature of the water during the performance tests.

The following information must also be on the Performance Data Sheet or be referenced in the owner's manual.

1. Installation instructions.
2. Procedure and requirements necessary for proper operation of the treatment device including but not limited to electrical requirements, maximum and minimum pressure, flow rate, temperature limitations, maintenance requirements and expected replacement frequencies.
3. The seller's warranty limitations.
4. Non-health-related substances may be listed on the Performance Data Sheet but may not be referred to as contaminants.

Consumer Information Pamphlet

In addition to the Performance Data Sheet, a Consumer Information Pamphlet prepared by the Iowa Department of Public Health (IDPH) *must* also be given to the buyer by the seller *prior* to the consummation of the sale.

Registration

All treatment devices covered by this legislation *must* be registered by the seller with the IDPH. Before registration is approved, the device must be performance tested in accordance with approved protocols by a third-party testing agency. This registration will certify that the system has been thoroughly tested for structural integrity and will assure effective performance.

For more information please contact:

Bureau of Environmental Health Services
Division of Environmental Health
Iowa Department of Public Health
Lucas State Office Building, 321 E. 12th Street
Des Moines, IA 50319-0075
Telephone: 515-281-7726

HOW TO SUBMIT A SAMPLE TO THE STATE HYGIENIC LABORATORY

After determining what contaminant(s) are present in the raw water and selecting and installing an appropriate treatment unit, the treated water should be tested to make sure the unit is working properly and to verify that the contaminant(s) have indeed been removed. The sample can not be collected in just any clean container. Contact the laboratory for the appropriate type of container for the specific contaminant(s).

Different contaminants require different containers (glass or plastic), sample volumes, preservatives, in transit temperatures and times in order to obtain the most reliable and accurate results possible. The containers are carefully prepared and quality controlled by the laboratory to ensure they are sterile (if necessary), free of interfering substances, and free of the contaminant the sample is being tested for.

The various contaminants will also require different sampling techniques. The faucet may need to be flushed for a few minutes before collecting some samples. For other contaminants, the first draw sample may be required. For still others, the flow rate may need to be very slow to reduce the effect of aeration. Disinfecting the faucet may be necessary prior to collecting samples for bacteria. It is therefore critical that the directions supplied by the laboratory with the container for collecting the samples, are followed carefully.

The directions accompanying the sample should also provide information how to properly send the sample to the laboratory. Some samples will require shipment with ice packs, which should be frozen one or two days prior to collecting the sample. Other samples have a short holding time and therefore should be shipped on the same day the samples are collected.

Please contact the laboratory if you have any questions as to what tests are necessary, what sampling containers are required, and the correct sampling and shipping procedures.



Private well collection kit from the State Hygienic Laboratory

ACTIVATED CARBON FILTERS

Activated carbon is created by the destructive distillation of wood, nutshells, animal bones or other carbonaceous material; and “activated” by heating to 800-900 degrees C with steam or carbon dioxide. In the activated state, carbon has a high absorbability for many gases, vapors and colloidal solids. As water passes through these filters, particles are trapped and some types of contaminants adsorb onto the carbon, thus removing them from the water. This characteristic of carbon filters can vary widely due to the variety of materials from which the carbon can be made.

Strengths

Removes many organic compounds, especially volatile organics, such as petroleum hydrocarbons, including BTEX (benzene, toluene, ethylbenzene and xylene); trihalomethanes, some organic solvents and pesticides.

Removes humic substances.

Removes taste- and odor-causing agents such as hydrogen sulfide (“rotten eggs smell”).

Removes chlorine and ozone if used in disinfecting drinking water.

Removes radon.

Limitations

Activated carbon has a finite life span, and needs to be replaced frequently.

There is no reliable way to determine if the carbon is saturated with contaminants and needs to be replaced.

Activated carbon will NOT effectively remove bacteria, viruses, nitrates or most metals.

Carbon filters provide an excellent medium for bacterial growth, resulting in potential health problems. Therefore they should not be used on waters where bacterial quality is unknown or not continuously disinfected.



Granulated carbon (above)
Carbon filters (right)



ANION EXCHANGE UNITS/RESINS

Anionic exchange is a demineralization process in which negatively charged ions (non-metals) are removed by passing water through an anionic resin bed.

Strengths

Removes negative charged (anions) inorganic ions such as nitrates, nitrites, fluorides, sulfates, bicarbonates, chromates (VI), cyanide, perchlorates, arsenic and uranium.

Removes some ionized organics such as naturally occurring humic substances like humic acid, fulvic acid and humin.

Limitations

A pH adjustment of the raw water may have to be made to facilitate the efficiency of the exchange process.

Since the chloride concentration will increase during the process, the water may taste salty.

Removal of bicarbonates may result in more corrosive water.

Positively charged ions (cations) such as metals and some radionuclides will not be removed.

High TDS (total dissolved solids) greater than about 500mg/L may adversely affect treatment performance.

Pretreatment may be necessary if the turbidity of the raw water is greater than 0.3NTU's.

Arsenic III, if present, will need to be pre-oxidized to arsenic IV to facilitate arsenic removal.

The resin may be fouled by suspended solids, oil and grease, oxidants, non-ionic organics and formation of a bacterial biofilm.

High concentrations of chlorine over extended contact time, such as after a shock chlorination of the well and system, can cause the resin to deteriorate.

Some ions such as sulfates and nitrates compete for adsorption sites. Therefore if the intended use is to remove nitrates from the water and the sulfate concentration is high, the nitrate removal efficiency may be very low.



Resin beads (above)

Anion exchange units (right)



CHLORINATORS

Chlorination is a procedure of adding (or injecting) a chlorine-releasing chemical into drinking water as a method of disinfection to control microorganisms (bacteria, viruses or parasites). The chlorine can come from various sources such as calcium hypochlorite (a solid), sodium hypochlorite (liquid bleach), chlorine gas, chloramines or chlorine dioxide. Each form has slightly different disinfection and oxidation characteristics and capabilities.

Strengths

Kills or inactivates microorganisms such as bacteria, viruses and protozoans.

Breaks down bacterial biofilms.

Facilitates the removal of iron via oxidation of soluble ferrous iron into insoluble ferric iron.

Helps control algae.

Helps control iron bacteria and sulfur bacteria

Facilitates the conversion of hydrogen sulfide ("rotten egg") into a non-odiferous form of sulfur.

Limitations

Trihalomethanes (THM's), carcinogenic chlorination by-products, may be formed under certain conditions.

Nitrates, fluoride, sodium, heavy metals, pesticides, radionuclides, chlorates, BTEX and arsenic are not removed.

A threshold level of free residual chlorine must be reached and maintained for an adequate contact time to achieve the desired disinfection or oxidation results.

Improper shock chlorination of wells may result in corrosion of metal structures in the well such as the submersible pump, well screen, metal casing or electrical conduits.



DISTILLERS

Distillation is a separation process by which water is vaporized by heating and the resulting steam condensed back into a liquid.

Strengths

Removes inorganics such as arsenic, sodium, calcium, magnesium, iron, manganese, heavy metals, nitrates, sulfates, chlorides and fluorides.

Removes non-volatile organics such as humic substances and some pesticides.

Removes microorganisms such as bacteria, viruses and parasites.

Removes particulates such as sand and iron oxide (rust particles).

Limitations

Most units have slow and small production capacities.

Contaminants with a lower boiling point than water such as some pesticides, volatile organic compounds such as BTEX and solvents, and chlorine will be “distilled over” with the water and NOT be removed.

A mineral buildup, primarily calcium carbonate (hardness or “boiler scale”), will decrease the unit’s efficiency.

Distilled water may have a “bland” taste.

Some bacteria (non-pathogenic) may colonize the holding tank, causing off tastes and odors in the product water.



Distiller

OZONATORS

Ozonation is a process by which ozone (O_3) is injected into the water. Ozone acts as a bactericidal and oxidation agent. The ozone is generated by corona discharge, the most common method, or by vacuum-ultraviolet (VUV) light.

Strengths

Kills or inactivates microorganisms such as bacteria, viruses, parasites and algae.

Controls taste and odor causing chemicals.

Breaks down organically bound iron and manganese to facilitate their removal.

Removes color by breaking down humic substances.

Controls hydrogen sulfide ("rotten eggs") by oxidation of the odiferous sulfide into a non-odiferous form of sulfur.

Breaks up some pesticides.

Reduces colloidal turbidity, facilitating filtration.

Will oxidize ferrous and manganous ions, forming a precipitate to facilitate their removal by subsequent filtration.

Will detoxify cyanides by oxidation to cyanates, which are a thousand times less toxic.

Limitations

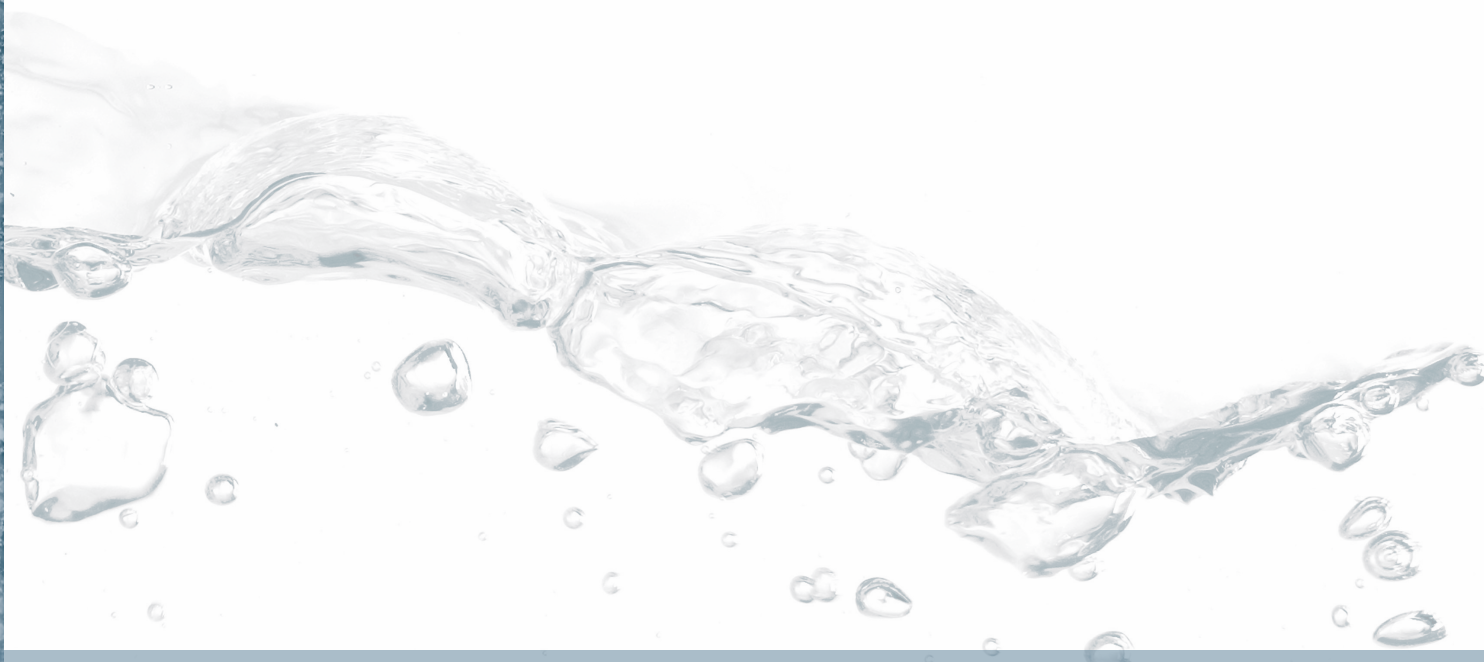
Ozone does not provide a disinfecting residual; therefore, bacterial regrowth is possible.

Some pesticides may be broken down into more toxic components.

Ozone must be generated on site with comparatively elaborate and expensive equipment.

A certain threshold concentration of ozone must be reached and maintained to achieve the desired treatment results.

Ventilation may be necessary to eliminate or prevent accumulation of ozone in the air.



REVERSE OSMOSIS UNITS

Reverse osmosis (RO) is a purifying process by which water is forced under pressure through a membrane, effectively “screening” soluble and insoluble material from water. The efficiency of the process can reach 100% depending on temperature, pressure and chemical characteristics of the impurities present and their concentrations.

Strengths

Removes inorganics (cations and anions) such as arsenic, sodium, calcium, iron manganese, magnesium, heavy metals (copper, lead), nitrates, sulfates, fluorides, chlorides, radium, uranium,

Removes organics such as pesticides, petroleum hydrocarbons (BTEX) and humic substances with various degrees of efficiency.

Removes particulates such as rust flakes, sand, grit and clay particles.

Removes colloidal suspensions causing turbidity.

Removes some radionuclides such as radium and uranium but NOT radon to a significant degree.

Limitations

Large amounts of water are needed to produce usable amounts. Only about 10-30% of the water is recovered as treated water, the rest goes to waste.

Volatile organics are not removed with high enough efficiency to warrant using RO for that purpose.

RO units are usually more expensive than other treatment units.

Not intended to remove microbial contaminants, especially bacteria and viruses.

RO membranes can be plugged by bacterial growth, particulates and hard water (calcium and magnesium).

Some RO membranes are susceptible to degradation by chlorine, chloramines and iron. Other membrane types are susceptible to bacterial decomposition.



Reverse osmosis membranes

WATER SOFTENERS

Water softening is a demineralization process by which positively charged ions (cations) such as metals are removed by passing water through a cationic resin.

Strengths

Removes hardness chemicals such as calcium and magnesium.

Removes other inorganics such as soluble iron and manganese, nickel, copper chromate III, cadmium and lead.

Removes some radionuclides such as radium and uranium.

Limitations

Water may become more corrosive.

Sodium concentrations will increase.

Resin bed must be periodically recharged.

The resin can be fouled by oil and grease, oxidants, particulates, iron bacteria, insoluble iron (ferric iron), naturally occurring non-ionic organics, bacterial biofilms.

Continuous high concentrations of chlorine, such as after numerous shock chlorinations of well AND inside plumbing system, can cause the resin to deteriorate.



Water softener

IRON AND MANGANESE REMOVAL

Iron is present in many minerals in the underlying geology and is a major constituent of clay soils. Because of its prevalence and chemical characteristics, iron is responsible for many aesthetic problems in domestic water systems, thus making its removal desirable. Iron is commonly present in two forms, soluble ferrous iron and insoluble ferric iron. A less common form of iron is 'heme' iron or organically-bound iron.

Do not assume that the orange color in water is due to iron. Naturally occurring organics, specifically tannins, can give an iron-like color to the water. Testing the water for total iron will determine if the color is due to iron or some other compound.

Manganese is an element similar to iron but considerably less prevalent, causes similar problems at even lower concentrations, making its removal also desirable.

Suggested Maximum Levels for Iron and Manganese

IRON 0.3 mg/L

MANGANESE 0.05 mg/L

These limits are Secondary Safe Drinking Water Act standards and as such are not enforceable. These limits are intended only as guidelines since iron and manganese are related to the aesthetic quality of drinking water and have no direct health effects.

Problems Associated with Iron and Manganese

Iron concentrations above 0.3 mg/L and manganese concentrations above 0.05 mg/L may result in any of the following:

- Plumbing fixtures, porcelain, dishes and laundry may become stained.
- The buildup of these minerals may decrease the efficiency and life expectancy of hot water heaters.
- Water may taste bitter or metallic.
- Teas and certain alcoholic beverages may darken in color.
- Pipes may need to be replaced due to mineral buildup and subsequent constriction and impeding of water flow.
- The build up (fouling) of these minerals may reduce the efficiency of other water treatment units.

IRON AND MANGANESE REMOVAL OPTIONS

Zeolite Ion Exchange (Water Softening)

- For adequate removal, the iron and manganese must be in the soluble ferrous and manganous state, respectively.
- Iron and manganese removal is most efficient if the levels are no greater than 0.5 mg/L
- Care must be taken to avoid aeration prior to softening, otherwise iron and manganese will precipitate, clogging the softener.

Oxidation followed by Filtration

- Possible oxidants: Chlorine, chlorine dioxide, potassium permanganate, atmospheric oxygen, hydrogen peroxide or ozone.
- The rates of oxidation are pH dependent:
 - Iron oxidation can be accomplished within 10 minutes at pH 7.2 but may require 1 hour at pH 6.9
 - Manganese oxidation is slower, requiring less than one hour only at a pH of 9.5 or above.
- A detention tank may be necessary to provide adequate contact time for iron and manganese precipitation.
- Oxidizing Media:
 - Oxidizing media may be referred to as birm, manganese greensand, copper-zinc medium, manganese dioxide medium; or pyrolox, a natural mineral ore form of manganese dioxide.
 - Useful if water softening is not desired.
 - Effective for high iron and manganese concentrations of 3 to 10 mg/L
 - Results in rapid and almost complete oxidation and removal.
 - Optimum operating pH of 7.5-9.0.

Distillation

- Very efficient in removing iron and manganese since pH and ion concentrations are not limiting factors in this process.
- Proper maintenance of the unit is required to maintain efficiency.
- Stills will not produce sufficient water to meet whole-house needs.

Reverse Osmosis (RO)

- Removes soluble as well as particulate iron and manganese.
- Membrane plugging may make RO unsuitable for most applications.
- Usually more expensive than other treatment methods.
- May not provide an adequate amount of water for whole-house needs.

'HEME' IRON REMOVAL

Heme iron is organically bound iron, making its removal more difficult. Heme iron may be removed by the following:

- Distillation
- Carbon filtration
- RO which will remove heme iron but not recommended for that purpose because the organic may foul the membrane
- Any strong oxidizing process or UV at about 185 nm will destroy the organic portion of heme iron, freeing the iron, which can then be removed by a conventional treatment process.



ULTRAVIOLET (UV) DISINFECTION

UV disinfection is a process by which water is exposed to UV radiation. The bactericidal UV wavelength is approximately 258 nm (UV-C) and disrupts bacterial activity at the molecular level, attacking DNA and proteins specifically.

Strengths

Disinfects without using chemicals.

Does not introduce objectionable tastes or odors into the water.

Low power consumption.

Low capital and operating accosts.

Compatible with other treatments such as activated carbon, softeners or reverse osmosis.

Minimal space requirement.

Limitations

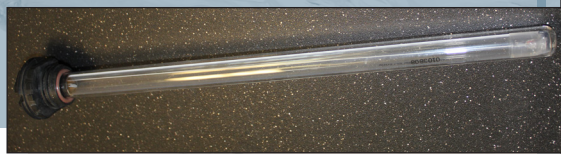
Particles in the water greater than about 5 microns in size may reduce the UV's disinfection ability by shielding bacteria from the UV light.

Large numbers of bacteria (greater than about 1,000 coliforms per 100mL) may reduce the UV's disinfection ability by shielding some bacteria from the UV light.

Some naturally occurring compounds in water such as humic acids, tannins, hardness, iron and manganese may reduce UV's disinfection ability by either absorbing UV light or by coating the inside sleeve of the UV chamber.

"Cyst forming" microorganisms such as the parasites *Giardia* sp. and *Cryptosporidium* sp. require a larger UV dose than produced by most home treatment units. In waters where "cysts" are likely to be present, boiling the water or an absolute 1 micron particulate filter (tested and rated by NSF for this purpose) may also be required for "cyst" inactivation or removal, respectively.

The UV output will gradually decrease through use with a corresponding decrease in disinfection ability. Most units do NOT have a mechanism to alert the consumer when the UV light is not providing an adequate dosage.



UV light (above)
Ultraviolet disinfection unit (right)



ROTTEN EGG ODOR IN DRINKING WATER

Sulfur and its many compounds are present in gaseous, liquid and solid states. The sulfur form that is responsible for the rotten egg odor in water is hydrogen sulfide, most commonly produced by sulfate reducing bacteria (SRBs). SRBs normally reside in some aquifers. Hydrogen sulfide can also be produced in hot water heaters. Hydrogen sulfide is not a health hazard in the concentrations found in drinking water.

Treatment Methods

Aeration

- Effective for reducing up to 2 mg/L of hydrogen sulfide. For higher concentrations, choose another treatment method (see below).
- A detention or storage tank may be required to provide adequate contact time to convert the odiferous hydrogen sulfide to a non-odiferous form of sulfur.
- Filtration with a sand and gravel filter may be necessary to remove the resulting elemental sulfur precipitate.

Chemical Oxidation (from least to most effective: $\text{Cl}_2 > \text{KMnO}_4 > \text{H}_2\text{O}_2 > \text{O}_3$)

Chlorine (Cl_2):

- About 8.7 mg/L of free chlorine is needed to oxidize 1 mg/L of hydrogen sulfide.
- Filtration may be needed to remove the resulting elemental sulfur precipitate.
- Continuous chlorination of 0.5-1.0 mg/L
- Activated carbon may be needed to remove residual chlorine or sulfide odor.

Potassium Permanganate (KMnO_4):

- After treatment, filtration may be necessary to remove the resulting manganese dioxide (MnO_2) and elemental sulfur precipitate.
- A better oxidant for sulfide removal than chlorine.

Hydrogen Peroxide (H_2O_2):

- About 1 mg/L of hydrogen peroxide is needed to oxidize 1 mg/L hydrogen sulfide.
- Filtration may be needed to remove the resulting elemental sulfur precipitate.

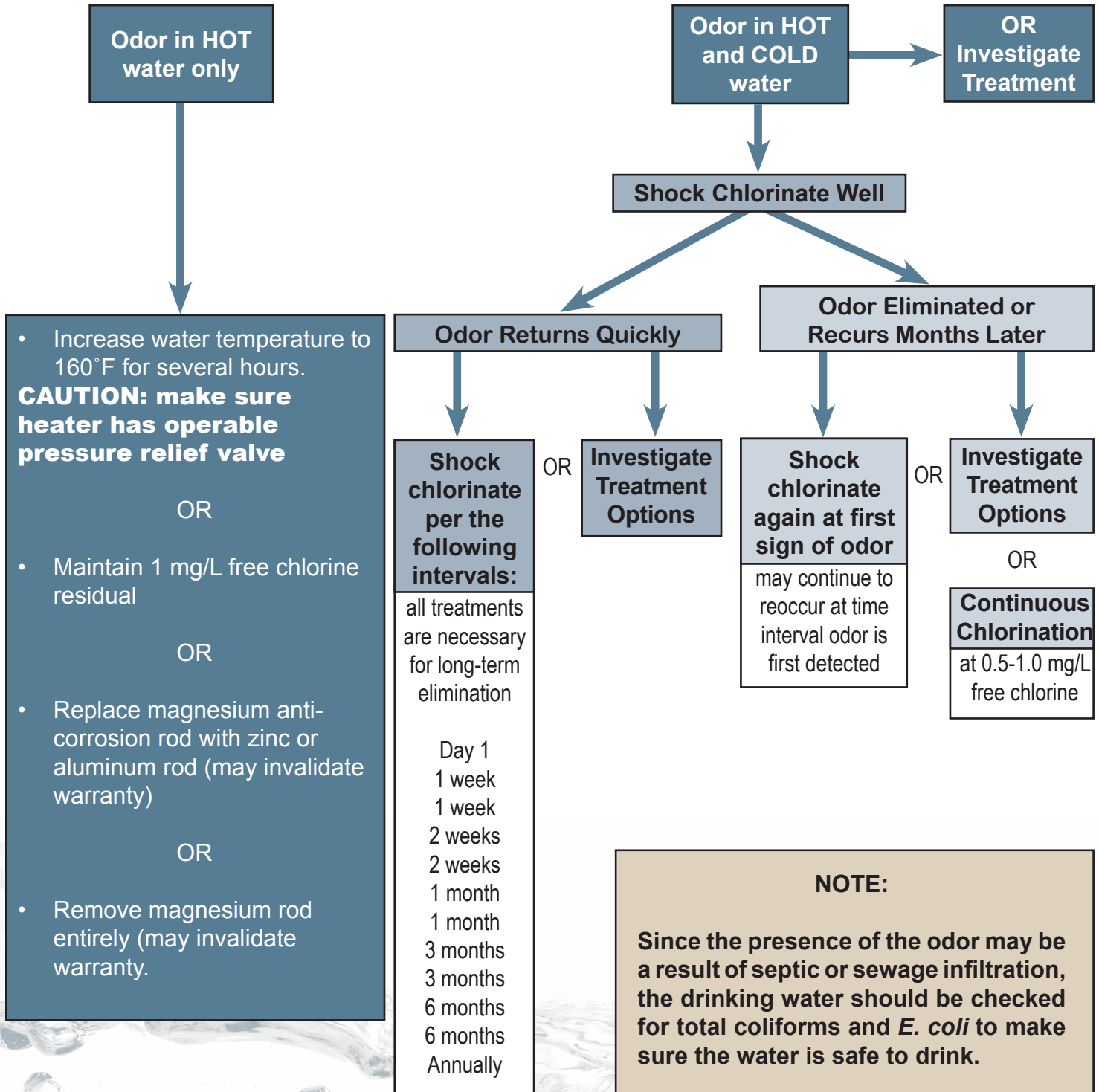
Ozone (O_3):

- The best oxidant for sulfide removal.
- Requires expensive and sophisticated equipment.

Oxidizing Medium (generically referred to as manganese green sand)

- Used primarily for iron removal but will also oxidize up to 6 mg/L of hydrogen sulfide.
- Most require regeneration with potassium permanganate.
- Adequate backwashing of the filter is required to remove the elemental sulfur precipitate which may eventually clog the filter medium. A supplemental pressure tank may be necessary if the existing pressure is inadequate to adequately backwash the filter medium.
- Examples of oxidizing media are:
birm, copper-zinc, granular manganese dioxide, greensand, and pyrolox (a natural mineral ore form of manganese dioxide.)

SCHEMATIC FOR ISOLATION AND ELIMINATION OF SULFIDE ODOR IN DRINKING WATER



IRON BACTERIA

Many microorganisms can manipulate various forms of iron in the environment. The types of iron bacteria that cause the most problems in wells and distribution systems are the filamentous forms, most commonly from the groups *Crenothrix*, *Leptothrix* and *Gallionella*. These organisms are present in many aquifers and are termed iron bacteria because they convert the soluble ferrous iron into the insoluble ferric iron form, the resulting precipitated ferric iron forming an iron sheath around the filamentous bacteria.

Iron bacteria do NOT cause health related problems but only cause aesthetic problems.

Problems Associated with Iron Bacteria

- Create taste, odor, color, staining and turbidity problems.
- Indirectly cause corrosion in distribution systems.
- Restricted well performance can result from the formation of biofilms on well screens, casing, sand packs, pump inlets and discharge components.

Treatment for Iron Bacteria

NOTE: Since iron bacteria are a normal part of the bacterial flora of some aquifers, most treatments are likely to have only a short-term effect. Recurrence of iron bacteria after treatment depends on the remediation process and chemical used, the well characteristics, initial iron bacteria concentration, the type of iron bacteria present and its growth rate.

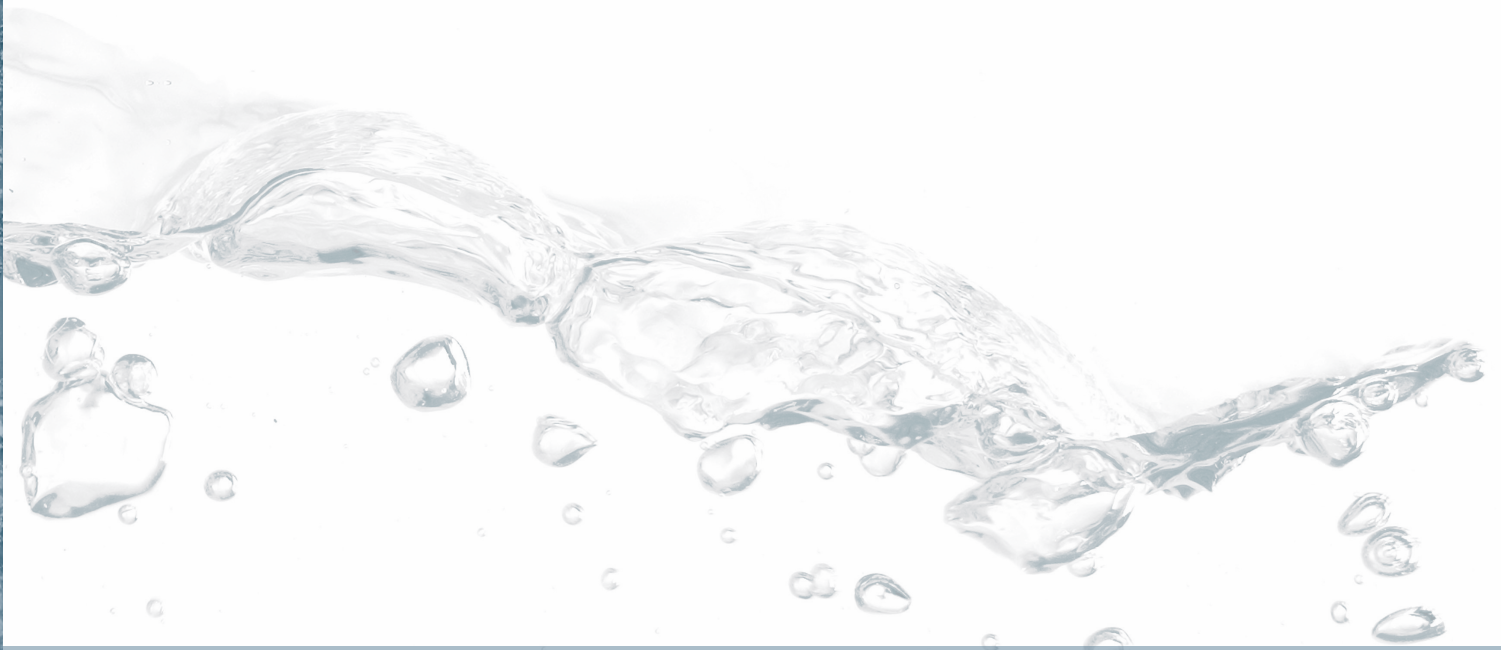
- Periodic shock chlorination.
- Alternatives to chlorine are hydrogen peroxide, organic acids or chelating agents.
- Dispersion of the biofilm by treatment with polyphosphate treatment.
- If the problem is severe, a combination of acid and surfactant treatment may be necessary.
- For a minor problem, sand and gravel or particulate filters may be adequate, assuming the sand and gravel filter can be vigorously backwashed. If not, the filters will need to be replaced as they become clogged.

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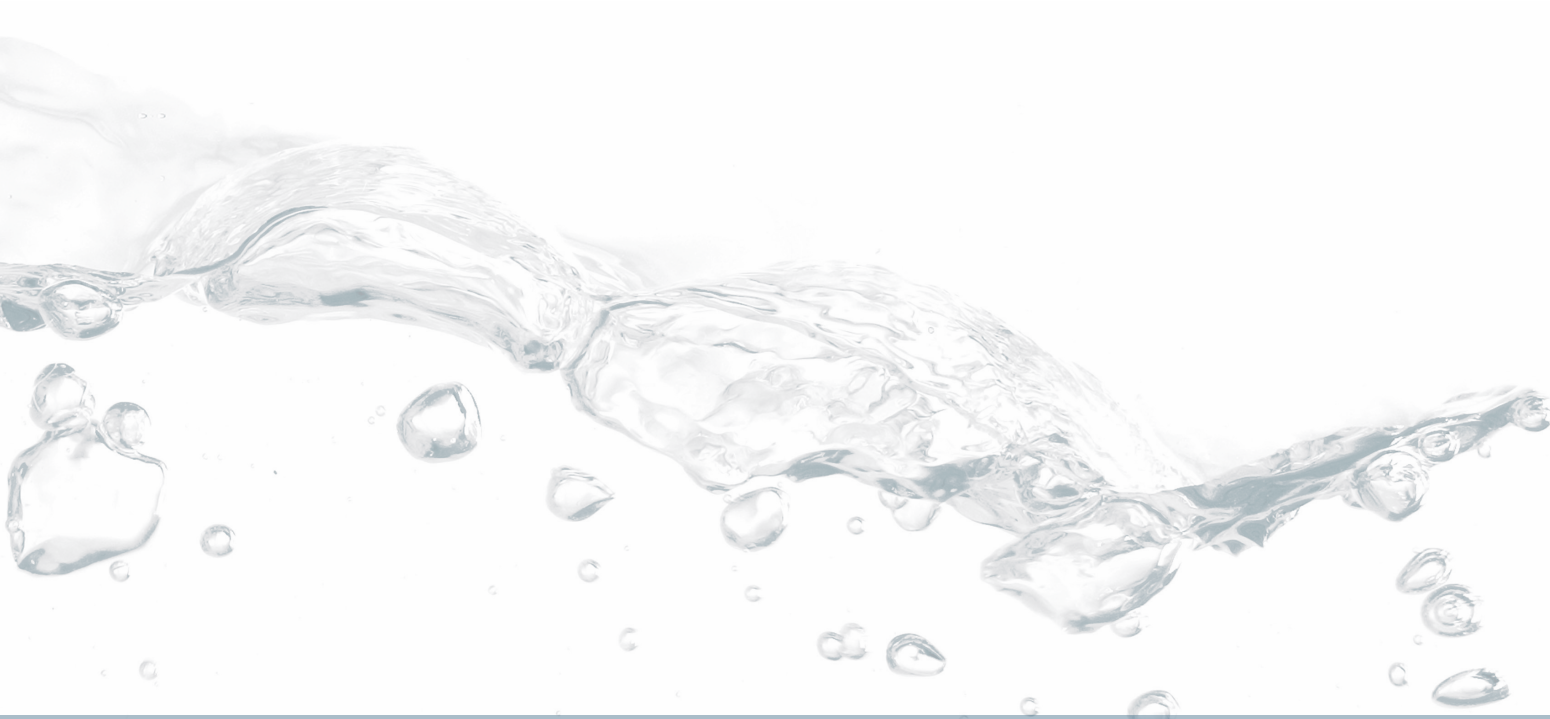
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Mission Statement:

The State Hygienic Laboratory at the University of Iowa protects and improves the quality of life by providing reliable environmental and public health information through the collective knowledge and capabilities of our organization.



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