RECLAMATION

Managing Water in the West

Desalination Series Report No. 68

Water Treatment Primer for Communities in Need

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2010

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Water Treatment Primer for Communities in Need

prepared by

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September 2010

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Acknowledgments

The Water Treatment Primer was first printed in 2001 and has since been continuously updated. We would like to thank contributors past and present for their contributions including: Vanessa Aguayo, Katie Benko, Saied Delagah, Steve Dundorf, Erik Jorgenson, Bob Jurenka, Susan Martella, and Bob Rodriguez.

Funding for this primer has come from a number of Reclamation desalting research programs:

- Reclamation Desalination & Water Purification Research & Development Program (DWPR)
- Reclamation Manual and Standards Program

Acronyms & Abbreviations

AA	activated alumina
AWTR	Advanced Water Treatment Research Program
BAC	biologically activated carbon
BAT	best available technology
^{o}C	degrees Celsius
CFU	colony forming units
CT	contact time
cu	color unit
DBPs	disinfection byproducts
DBPR	Disinfection Byproducts Rule
DE	diatomaceous earth
DF	direct filtration
DOC	dissolved organic carbon
DWPR	Desalination and Water Purification Research and Development Program
^{o}F	degrees Fahrenheit
ED	electrodialysis
EDR	electrodialysis reversal
FDA	Food and Drug Administration
ft	foot
g	gram
G	velocity gradient - feet per second per foot
GAC	granular activated carbon
gal	gallon
HAAs	haloacetic acids
HDPE	high density polyethylene
hr	hour
IX	ion exchange
lbs	pounds
L	liter
m	meter
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MF/L	million fibers per liter
MGD	million gallons per day
mg/L	milligrams per liter (ppm)
min	minute
mL	milliliter
MSDS	material safety data sheets
MW	molecular weight
NF	nanofiltration

NOM	natural organic matter
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity unit
O&M	operation and maintenance
PAC	powdered activated carbon
pCi/L	pico Curie per liter
PCBs	polychlorinated byphenols
POE	point-of-entry
POU	point-of-use
ppb	parts per billion (µg/L)
PPE	personal protective equipment
ppm	parts per million (mg/L)
psi	pounds per square inch
RO	reverse osmosis
RT	retention time
SCC	solids contact clarifier
SDWA	Safe Drinking Water Act
sec	second
SLR	surface loading rate
SMCL	secondary maximum contaminant level
SOC	synthetic organic chemicals
TDH	total dynamic head
TDS	total dissolved solids
THM	trihalomethane
ton	threshold odor number
TSS	total suspended solids
TT	treatment technique
TTHMs	total trihalomethanes
µg/L	microgram per liter (ppb)
µm	micrometer
USEPA	United States Environmental Protection Agency
UST	underground storage tank
UV	ultraviolet
VOC	volatile organic chemical
w	watt

Glossary of Terms

Advanced Water Treatment Research (AWTR) Program – A past Reclamation internal research program funded which specifically supported engineering and research with a direct impact on Reclamation's mission. The primary goal of the program is to provide engineering assistance and research support for Reclamation's Regional and Area Offices.

Agglomeration - The coming together or clumping of small scattered particles into larger particles which settle.

Alkalinity - The capacity of water to neutralize acids. A measure of how much acid can be added to a liquid without causing a great change in pH.

Anion - A negatively charged ion resulting from the dissociation of salts, minerals, or acids in water.

Antiscalant - A chemical agent added to water that raises the solubility limit and inhibits chemical precipitation.

Bacteria - Microscopic living organisms usually consisting of a single cell which live either by absorbing food from the environment (photosynthesizing) or by using some chemical reactions to provide energy and multiply by simple division.

Best Available Technology - A USEPA term for the water treatment process(es) that provide optimum treatment for a specified contaminant.

Biofouling - Blockage or obstruction on a membrane surface due to living or dead animal or plant matter.

Blending - Mixing desalted water with undesalted water to obtain the following advantages: the addition of hardness and alkalinity from undesalted water reduces the corrosivity of the product water; and the amount of posttreatment chemical and the water treatment plant size are reduced, thereby lowering capital and operating costs.

Cation - A positively charged ion resulting from the dissociation of salts, minerals, or acids in water.

Cellulose Acetate - A acetic acid ester of cellulose which when compounded with suitable plasticizer forms a tough thermoplastic material which may be manufactured as semipermeable membrane.

Coagulation – The destabilization of colloids and initial aggregation of colloidal and finely divided suspended solids.

Concentrate - The waste stream (concentrated ions) produced as a byproduct of membrane treatment. Also called brine or reject.

Contaminant - Any undesirable physical, chemical, or microbiological substance or matter in a given water source or supply. Anything in water which is not chemically water may be considered a contaminant.

Demineralization - Any process that removes mineral substances from water. Usually synonymous with deionization.

Desalination and Water Purification Research and Development Program (DWPR) - A Reclamation external research program funded from 1997 to 2005, with the primary goal of developing more cost-effective, technologically efficient, and implementable means to desalinate water.

Direct Filtration - A method of filtration where the feed stream is fed directly to the filtration media. In conventional terms, the conventional treatment train less sedimentation or clarification.

Distillation - The process of heating water to evaporation and its subsequent condensation to purify the water.

Electrodialysis - A process in which ions are transferred through membranes from a less concentrated to a more concentrated solution as a result of the passage of direct current electrical potential.

Electrodialysis Reversal - An automatic operating feature of some ED units that reverses the electrical potential applied to the two electrodes about every 15 minutes to promote cleaning of the unit.

Feed Water - The input solution to any water treatment process.

Flocculation -The gathering of particles, by slow stirring, in water to bind them into larger aggregates to form a rapidly settling floc.

Fouling - The act of depositing suspended solids on a membrane surface or in the feed channel which impedes the proper operation of the membrane unit.

Greensand - A naturally occurring mineral that consists largely of dark greenish grains of glauconite, and is a natural ion exchange mineral capable of softening water and removing iron and manganese.

Indicator organism – does not typically cause disease, but is a good indicator that disease-causing organisms may also be present.

Inorganic - Substances which are of mineral origin, such as sand, salt, iron, and calcium salts.

Ion - An electrically charged atom, radical, or molecule formed by the loss or gain of one or more electrons.

Ion Exchange - A chemical process where certain unwanted ions of a given electrical charge are absorbed on to resin, removed from solution, and replaced by wanted ions of a like charge.

Maximum Contaminant Level (MCL) - The maximum concentration of a contaminant allowed under the USEPA National Primary Drinking Water Standards. Primary contaminants threaten human health.

Maximum Contaminant Level Goal (MCLG) - The recommended maximum concentration of a contaminant allowed under the USEPA National Primary Drinking Water Standards. MCLGs are not enforceable, and are health goals based entirely on health effects.

Membrane - A thin sheet of natural or synthetic material that is permeable to substances in solution.

Microfiltration - The low pressure membrane filtration through a coherent medium with a nominal pore size range from slightly below 0.1 μm to slightly above 1.5 μm.

Microorganisms - A plant or animal of microscopic size.

Nanofiltration - A membrane process capable of filtering down to 0.001 micron. NF has a lower rejection rate for monovalent ions than multivalent ions and can operate at significantly lower operating pressures than RO membranes.

Natural Organic Matter (NOM) - Substances that come from animal or plant sources, and always contain carbon.

Oxidation - The addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound.

Pathogens - Disease causing organisms.

Permeate - The product water from a desalting process. Also called product.

pH - Measurement of acidity (<7) or alkalinity (>7). The logarithm of the reciprocal of hydrogen ion concentration in an aqueous solution.

Phytoplankton - Small, usually microscopic plants (such as algae) found in lakes, reservoirs, or other bodies of water.

Pretreatment - Treatment units located upstream of the main treatment process which are necessary to remove compounds that are detrimental to the main treatment process.

Product - See permeate.

Protozoa - Single-celled, parasitic animals.

Raw Water - Water in its natural state, prior to any treatment. Usually the water entering the first treatment process of a treatment plant.

Recovery - The amount of permeate water attainable, expressed as a percent of the feed flow.

Rejection - The process where certain ions are not allowed to pass through a semipermeable membrane.

Reject - See concentrate.

Resins - A class of chemicals, many of which have ionic replacing properties to absorb specific ions (and releasing others) such as ammonia, nitrate, metals, etc. An anion resin adsorbs anions in the water while a cation resin removes cations in the water. Both require careful selection of a regenerant type and concentration (i.e. caustic or acid base).

Reverse Osmosis - The reverse of the natural osmosis process. The application of pressure to a concentrated solution which causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane.

Secondary Maximum Contaminant Level (SMCL) - The maximum concentration of a contaminant allowed under the USEPA National Secondary Drinking Water Standards. Secondary contaminants do not threaten human health, but cause aesthetic problems.

Sedimentation - A process in which solid particles settle out of the water being treated in a clarifier or sedimentation basin.

Sediments - A general description of any number of materials or large waterborne particles that settle.

Scaling - A process where precipitation or crystallation of salt compounds or solids form a coating on working surfaces of a system.

Semipermeable - The ability to allow some molecules from a mixture to pass through but not all.

Sodium Bisulfite - An acid salt ($NaHSO_3$) usually prepared by passing sulfur dioxide through a solution of sodium carbonate.

Total Dissolved Solids (TDS) - All of the dissolved solids in the water. The residue after filtering of suspended solids and evaporation.

Total Plant Cost - The cost of treated water expressed in $/1000 gal. TPC includes the annualized capital equipment costs for all the unit processes, annual O&M costs, and various project related special costs.

Total Suspended Solids (TSS) - The quantity of material removed by filtering, usually with either a Gooch crucible or a 0.45 μm filter

Toxicant - A substance which is poisonous to an organism.

Treatment Technique - A USEPA term for a procedure that a water system must follow, in lieu of meeting an MCL, that assures the water delivered to the system's customers prevents known or anticipated adverse health effects. The procedures include such things as installation of a treatment technology to achieve specified goals, self-certification of adhering to certain standard operating procedures, public education, replacement of pipe, etc.

Turbidity - The cloudy appearance of water caused by the presence of suspended particles and colloidal matter, which interferes with the passage of light through the water.

Viruses - Viruses are a major class of microorganisms but lack many of the attributes of cells. Only when a virus infects a cell does it acquire the ability to reproduce.

Introduction

This primer contains the following major sections:

- Rule Summary Sheets
- Treatment Technology Descriptions
- Contaminant Fact Sheets

These primer fact sheets are resources offered by the Bureau of Reclamation (Reclamation) as a means of sharing technical information. The purpose is to provide timely and accurate summations of water treatment principles, techniques and regulations for various water quality contaminants of concern. The fact sheets are intended as a first source of information for small communities or communities of low economic status which typically do not have the resources to hire water treatment consultants. Cooperation with other federal, state, and local agencies and water treatment entities in solving the water treatment issue of concern is recommended and encouraged. As research reveals new water treatment techniques, the fact sheets will be revised and updated to reflect state of the art methods for water treatment. All fact sheets are available on the Reclamation website (www.usbr.gov/pmts/water/publications/primer.html).

Treatment Technologies

Each of the USEPA Best Available Technologies (BATs) and other commonly used technologies are listed with the following sections:

- Applicable Contaminants
- Description of Technology
- Example Treatment Train Schematic
- Safety and Health Concerns
- References

Contaminant Fact Sheets

Each of the USEPA Best Available Technologies (BATs) and other commonly used technologies are listed with the following sections:

- Contaminant Data
    - Chemical Data: including name, symbol, molecular weight, cation/anion, metal/nonmetal, reactivity, etc.
    - Source in Nature: including sources of contamination in surface and groundwater.
    - SDWA Limits: including MCL, MCLG, and SMCL limits.
    - Health Effects of Contamination.
- Removal Techniques
    - USEPA BAT: including brief description.
    - Alternative Methods of Treatment: including all other commonly used technologies.
- Process Description – Used for either how a particular process relates to the specific contaminant or a full process description when not included in the "Treatment Technologies Description"
- Example Treatment Train Schematic
- Safety and Health Concerns

- References

Rule Summary Sheets

The Rule Summary Sheets summarize all the major drinking water rules. There is a quick overview that covers all the rules and individual rule sheets that provide a more in depth summary. These are similar to the USEPA quick reference sheets, but sometimes go into greater depth.

Revisions

- New Treatment Technology Descriptions: All technologies
- New Treatment Technology Fact Sheets: Ozone, Chlorine Dioxide
- New Contaminants Fact Sheets for: Natural Organic Matter, Organic Chemicals, and Sulfate
- New Rule Summary Sheets for: Arsenic Rule, Disinfection By-Products Rules, Filter Backwash Rule, and Long Term 2 Surface Water Treatment Rule
- References added for all contaminant fact sheets

Planned Revisions (2011)

- New contaminant fact sheets for secondary MCLs
- New treatment technology sheet for Permanganate

Contact Information

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Revision Date: 09/20/10

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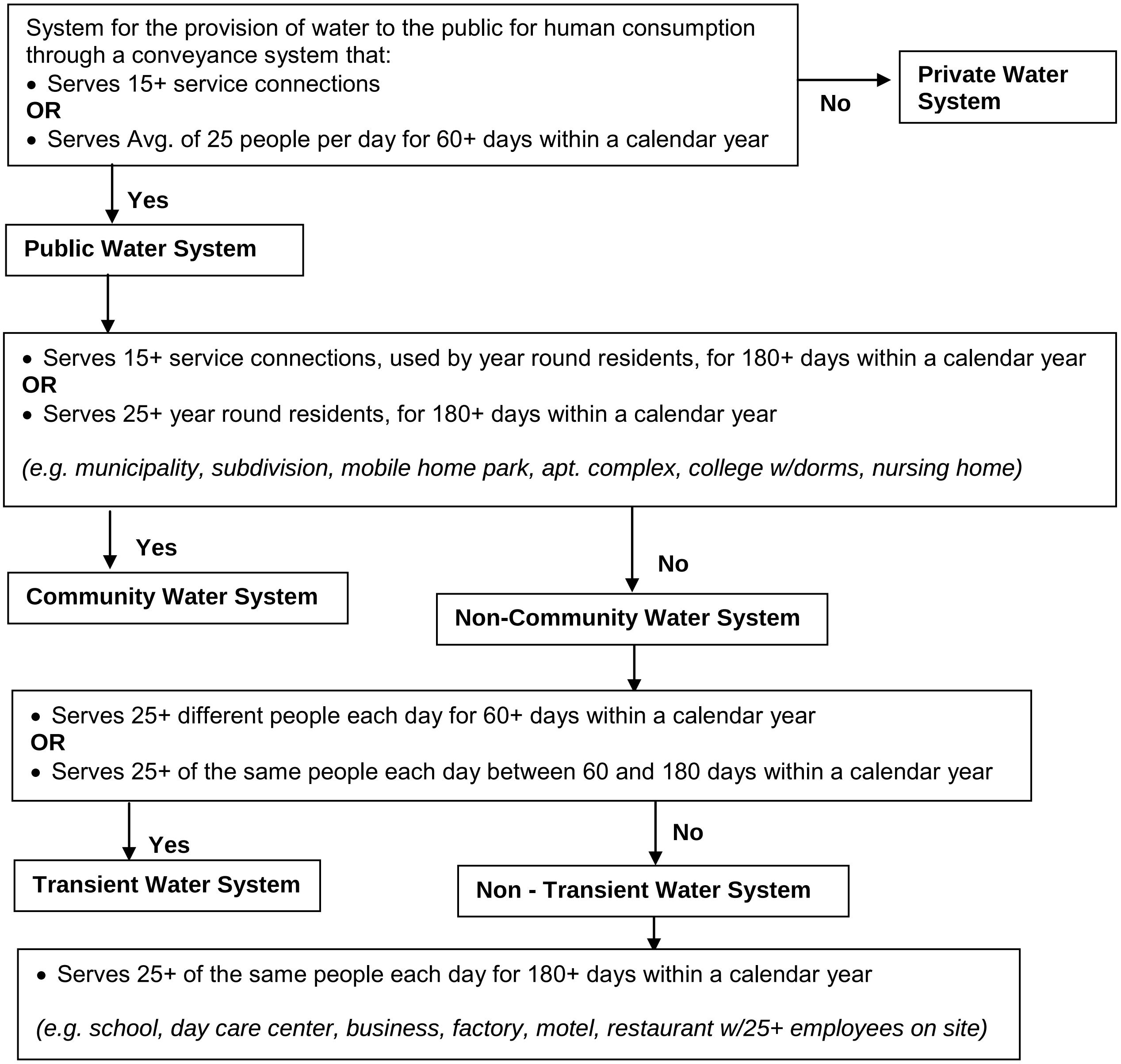
USEPA Drinking Water Systems Definitions


System for the provision of water to the public for human consumption through a conveyance system that:
- Serves 15+ service connections

OR
- Serves Avg. of 25 people per day for 60+ days within a calendar year

Public Water System

- Serves 15+ service connections, used by year round residents, for 180+ days within a calendar year

OR
- Serves 25+ year round residents, for 180+ days within a calendar year

(e.g. municipality, subdivision, mobile home park, apt. complex, college w/dorms, nursing home)

Non-Community Water System

- Serves 25+ different people each day for 60+ days within a calendar year

OR
- Serves 25+ of the same people each day between 60 and 180 days within a calendar year

Non - Transient Water System

- Serves 25+ of the same people each day for 180+ days within a calendar year

(e.g. school, day care center, business, factory, motel, restaurant w/25+ employees on site)

Definitions:

Service Connection = connection to public water system providing water to:
-single family residence
-residential population
-nonresidential population
*must have a meter for billing (e.g. not hotel rooms)

Resident = person that claims location as residence (e.g. not hotel workers)

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USEPA Drinking Water Regulation Summary

The following provides a brief description of EPA's major drinking water rules. More information, including the official language of the rules can be found on the following website: http://water.epa.gov/lawsregs/rulesregs/sdwa/currentregulations.cfm .

Refer to "USEPA Drinking Water Systems Definitions' sheet for further explanation of terms used in this sheet.

Biological and Disinfection Byproducts

Total Coliform Rule (54 FR 27544-27568, June 29, 1989, Vol. 54, No. 124)

The Total Coliform (TC) rule applies to all public water systems. The purpose of this rule is to improve public health protection by reducing fecal pathogens to minimal levels through control of coliform bacteria. Total coliforms include fecal coliforms and *Escherichia coli* (*E. coli*). The following is a list of major provisions of the TC Rule:

- Representative TC samples must be collected at regular time intervals throughout the month, number of samples per month depends on the population size that the system services (see Rule for exception)
- Reduced monitoring frequency may be available for systems serving 1,000 persons or fewer and using only ground water if a sanitary survey within the past five years shows the system is free of sanitary defects
- Each TC-positive sample must be repeated and also tested for the presence of fecal coliforms or *E. coli*

2010 Proposed Revisions to the Total Coliform Rule

The EPA is proposing revisions to the 1989 Total Coliform Rule. The proposed revisions will require public water systems that are vulnerable to microbial contamination to identify and mitigate sources of contamination. The revisions will also establish criteria for reduced monitoring which will provide incentives for maintaining improved water systems (EPA Fact Sheet: Announcement of Proposed Revisions to Total Coliform Rule, http://edocket.access.gpo.gov/2010/pdf/2010-21697.pdf).

Surface Water Treatment Rule (40 CFR 141.70-141.75)

This rule applies to systems of all sizes. The purpose of the Surface Water Treatment Rule (SWTR) and the subsequent Interim Enhanced Surface Water Treatment Rule (IESWTR), Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) and Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), is to improve public health protection through control of microbial contaminants. The SWTR regulates the following pathogens:

- Viruses : 99.99% (4-log) removal/inactivation
- *Giardia lamblia*: 99.9% (3-log) removal/inactivation

Residual disinfectant requirements are as follows: ≥0.2 mg/L at the entrance to the distribution system and must be detectable in the distribution system. The SWTR rule also enforces turbidity monitoring standards (monitoring/recording at least every 4 hours) in the combined filter effluent for systems using any type of filtration and requires readings to be less than 0.5 NTU in the combined filter effluent or a max value of 5 NTU (as of 1993). The filtration avoidance criteria must be met for systems not using filtration.

Long Term 1 Enhanced Surface Water Treatment Rule (67 FR 1812, January 14, 2002, Vol. 67, No. 9)

This rule applies to public systems that use surface water or GWUDI of surface water and serve fewer than 10,000 people. This rule builds upon the requirements of the 1989 SWTR and is the smaller systems counterpart of the Interim Enhanced Surface Water Treatment Rule (IESWTR). The major provisions of this rule for the control of *Cryptosporidium* are as follows:

- MCLG of zero
- Filtered systems must physically remove 99% (2-log)
- Unfiltered systems must update their watershed control programs to minimize the potential for contamination by *Cryptosporidium* oocysts

With the implementation of this rule, the turbidity requirement for combined filter effluent was reduced to ≤ 0.3 NTU for 95% of the samples and 1 NTU for the maximum combined filter effluent value. Additionally, individual filter effluent monitoring must be performed continuously (every 15 minutes) since the combined filter effluent may meet regulatory requirements even if one filter is producing high turbidity water.

Interim Enhanced Water Treatment Rule (63 FR 69478-69521, December 16, 1998, Vol. 63, No. 241)

This rule builds upon the 1989 SWTR and relies on existing technologies currently in use at water treatment plants. The sanitary survey part of this rule applies to all public water systems using surface water or GWUDI of surface water, regardless of size. All other requirements apply to public water systems that use surface water or GWUDI of surface water and serve 10,000 or more people. The *Cryptosporidium* and turbidity provisions of this rule are the same as the LT1ESWTR. Additional requirements include:

- Disinfection profiling and benchmarking
- Construction of new uncovered finished water storage facilities is prohibited
- Sanitary surveys conducted by the state, for all surface water and ground water under the direct influence of surface water systems regardless of size (every 3 years for community water systems and every 5 years for non-community water systems).

Long Term 2 Enhanced Surface Water Treatment Rule (71 FR 654, January 5, 2006, Vol. 71, No. 3)

This rule aims to improve public health protection through the control of microbial contaminants by focusing on systems with elevated *Cryptosporidium* risk. The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) requires systems to monitor their source water, calculate an average *Cryptosporidium* concentration, and use those results to determine if their source is vulnerable to contamination and may require additional treatment. Filtered and unfiltered systems must conduct 24 months of source water monitoring for *Cryptosporidium*. Filtered systems must also record source water *E. coli* and turbidity levels. Filtered systems will be classified into one of four bins based on the results of their source water monitoring. Unfiltered systems will calculate a mean *Cryptosporidium* level to determine treatment requirements. Installation of additional treatment may be required for both filtered and unfiltered systems.

Stage 1 Disinfectants and Disinfection Byproducts Rule (63 FR 69390-69476, December 16, 1998, Vol. 63, No. 241)

The purpose of this rule is to improve public health protection by reducing exposure to disinfection byproducts. Some disinfectants and disinfection byproducts (DBPs) are suspected to cause bladder cancer and reproductive effects in humans. This is the first of a staged set of rules that will reduce the allowable levels of DBPs in drinking water. The rule establishes MCLs and MCLGs for total trihalomethanes, five haloacetic acids, bromate, chlorite, chlorine, chloramines, and chlorine dioxide. Enhanced coagulation or enhanced softening to improve removal of DBP precursors for systems using conventional filtration treatment is also established. The rule is designed to limit capital investments and avoid major shifts in disinfection technologies until additional information is available on the occurrence and health effects of DBPs.

Stage 2 Disinfectants and Disinfection Byproducts Rule (71 FR388, January 4, 2006, Vol. 71, No. 2)

This rule builds on the Stage 1 Disinfectants and Disinfection Byproducts Rule (DBPR) by focusing on monitoring for and reducing concentrations of two classes of DBPs (TTHM and HAA5) in drinking water. This rule applies to all community water systems and non-transient non-community water systems that either add a primary or residual disinfectant other than ultraviolet light, or deliver water that has been treated with a primary or residual disinfectant other than ultraviolet light. Stage 2 DBPR requires some systems to complete an initial distribution system evaluation to characterize DBP levels in their distribution systems and identify locations to monitor DBPs for Stage 2 DBPR compliance. This rule bases TTHM and HAA5 compliance on a locational running annual average calculated at each monitoring location.

Regulated Contaminants

Lead and Copper Rule (56 FR 26460-26564, June 7, 1991 – latest revision complete in January 2000)

This rule applies to all community water systems and non-transient, non-community water systems and is intended to minimize public health risk from lead and copper exposure from drinking water by reducing water corrosivity. Lead and copper enter drinking water mainly from corrosion of plumbing materials. This rule establishes an action level (AL) of 0.015 mg/L for lead and 1.3 mg/L for copper based on the 90th percentile level of tap water samples. A water system exceeding the AL is not necessarily in violation, however, other requirements may be required, including water quality parameter monitoring, corrosion control treatment, source water monitoring/treatment, public education, and lead serve line replacement.

Radionuclides Rule (66 FR 76708, December 7, 2000, Vol. 65, No. 236)

This rule applies to all community water systems. The purpose of this rule is to reduce the exposure to radionuclides in drinking water to reduce the risk of cancer and exposure to all radionuclides. The rule retains the existing MCLs for combined radium-226 and radium-228, gross alpha particle radioactivity, and beta particle and photon activity and regulates uranium for the first time.

Arsenic and Clarification to Compliance and New Source Monitoring Rule (66 FR 6976, January 22, 2001)

The purpose of this rule is to improve public health by reducing exposure to arsenic in drinking water. This rule applies to all community water systems and non-transient, non-community water systems. With this rule, the MCL for arsenic was decreased from 50 µg/L to 10 µg/L and the MCLG was set at 0. By December 31, 2006, all surface water systems must complete initial monitoring or have a State approved waiver. By December 31, 2007, all groundwater system must complete initial monitoring or have a State approved waiver. Required monitoring includes one sample after the effective date of the MCL (January 23, 2006). Surface water systems must take annual samples and groundwater systems must take one sample during the 2005-2007 compliance period. If the monitoring result is less than the MCL, ground water systems must collect one sample every 3 years and surface water systems must continue to collect annual samples.

Other

Standardized Monitoring Framework (56 FR 3526, January 30, 1991)

This rule is intended to standardize, simplify, and consolidate monitoring requirements across contaminant groups by reducing the variability within monitoring requirements for chemical and radiological contaminants across system sizes and types.

The Public Notification Rule (65 FR 25981)

The purpose of this rule is to notify the public any time a water system violates national primary drinking water regulations or has other situations posing a risk to public health. This rule applies to all public water systems violating primary drinking water regulations, operating under a variance or exemption or having other situations posing a risk to public health. Notices must be sent within 24 hours, 30 days, or one year depending on the tier to which the violation is assigned (see rule). The clock for notification starts when the public water system learns of the violation. Notices must be provided to persons served (not just billing customers).

Variances and Exemptions Rule (63 FR 43834-43851, August 14, 1998)

The purpose of this rule is to allow eligible systems to provide drinking water that does not comply with a National Primary Drinking Water Regulation (NPDWR) on the condition that the system installs a certain technology and the quality of the drinking water is still protective of public health. Exemption allow eligible systems additional time to build capacity in order to achieve and maintain regulatory compliance of newly promulgated NPDWRs, while continuing to provide acceptable levels of public health protection.

Consumer Confidence Report Rule (40 CFR, Part 141, Subpart O)

The purpose of this rule is to improve public health protection by providing education material to allow consumers to make educated decisions regarding any potential health risks pertaining to the quality, treatment, and management of their drinking water supply. This rule applies to all community water systems. The CCR rule requires all community water systems to prepare and distribute a brief annual water quality report summarizing information regarding source, any detected contaminants, compliance, and educational information. July 1 is the deadline for annual distribution of the CCR to customers and state or local primacy agency for report covering January 1 – December 31 of the previous calendar year.

Filter Backwash Recycling Rule (66 FR 31086, June 8, 2001, Vol. 66, No. 111)

This rule applies to public water systems that use surface water or ground water under the direct influence of surface water, practice conventional or direct filtration, and recycle spent filter backwash, thickener supernatant or liquids from dewatering processes. The purpose of this rule is to improve public health protection by assessing and changing, where necessary, recycle practices for improved contaminant control, particularly microbial contaminants. The filter backwash rule requires systems that recycle to return specific flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state. The deadline for all capital improvements associated with relocating recycle return location (if necessary) was June 8, 2006.

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Arsenic and Clarifications to Compliance and New Source Monitoring Rule

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Arsenic.

1.0 Overview of Rule

The Arsenic and Clarifications to Compliance and New Source Monitoring Rule (66 FR 6976, January 22, 2001) applies to community water systems (serving 15 locations or 25 residents year-round) and non-transient, non-community water systems (serving at least 25 of the same people more than 6 months of the year) [1]. The purpose of the rule is to improve public health by reducing exposure to arsenic in drinking water by lowering the arsenic MCL from 50 µg/L to 10 µg/L and setting the arsenic MCLG to 0 µg/L. The rule also requires monitoring for new systems and new drinking water sources and clarifies the procedure for determining compliance with the MCLs for inorganic contaminants (IOCs), volatile organic contaminants (VOCs) and synthetic organic contaminants (SOCs).

2.0 Rule Requirements

Source Water Monitoring for Total Arsenic The new MCL imposed by this rule, 10 µg/L, is effective as of 2006. All new water systems must conduct initial source water sampling for arsenic to determine compliance with the rule. Samples must be collected at each point of entry to the distribution system, unless otherwise specified by the State. If the monitoring result is less than the MCL, groundwater systems must re-sample every three years and surface water systems must sample annually. A system with a sampling point result above the MCL must collect quarterly samples at that sampling point, until the system is reliably and consistently below the MCL. At a minimum two consecutive groundwater or four consecutive surface water samples will need to be collected to demonstrate that the system is below the MCL.

Compliance Determination for IOCs, VOCs, and SOCs Compliance is based on a running annual average at each sampling point for IOCs, volatile organic contaminants VOCs and synthetic organic contaminants SOCs. Systems will not be in violation until one year of quarterly samples have been collected (unless fewer samples would cause the running annual average to be exceeded). If a system does not collect all required samples, compliance will be based on the running annual average of the samples collected.

Arsenic Treatment For water systems not in compliance with the new MCL, the following BAT technologies are recommended: ion exchange, activated alumina, reverse osmosis, modified coagulation/filtration, modified lime softening, electrodialysis reversal, oxidation/filtration. See the Arsenic Fact Sheet for more information.

Point of use (POU) and point of entry (POE) devises are acceptable compliance strategies for small systems. POU and POE devices must be owned, controlled, and maintained by the public water system or by a person under contract with the public water system to ensure proper installation, maintenance, and compliance with the MCL or treatment technique (see rule for more information).

3.0 Compliance Deadlines

All compliance deadlines for existing both groundwater and surface water systems have now passed and full compliance with this rule is required, unless a waiver was issued. All new systems are required to comply with this rule.

4.0 References

[1] U.S. Environmental Protection Agency. “National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring.” Federal Register, Volume 66, Number 14, page 6975-7066, Washington DC, 2001.

[2] US EPA Arsenic in Drinkin Water website:
http://water.epa.gov/lawsregs/rulesregs/sdwa/arsenic/index.cfm

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Revision Date: 09/20/10

Disinfectants and Disinfection Byproducts Rules

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; DBP Contaminant Fact Sheet.

1.0 Overview of Rules

Drinking water supplies require disinfection to remove or inactivate microbial pathogens. Disinfectants can react with natural organic matter in the water to form by-products like trihalomethanes, haloacetic acids, chlorite, and bromate. The Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR, 40 CFR Parts 9, 141, and 142, December 16, 1998, Vol 63, No. 241 and Stage 2 DBPR, 71 FR 388, January 4, 2006, Vol 71, No. 2) aims to reduce the potential risk of adverse health effects associated with disinfection byproducts (DBPs) throughout water distribution systems. Stage 1 of the DBPR establishes MCLs for chlorine, chloramine, and chlorine dioxide. It also establishes MCLGs for total trihalomethanes, haloacetic acids, chlorite, and bromate. Stage 2 of the DPBR builds upon Stage 1, by strengthening compliance monitoring requirements. The Stage 2 DBPR requires some systems to complete an Initial Distribution System Evaluation (IDSE) to characterize DBP concentrations in their distribution systems and identify locations to monitor DBPs for Stage 2 compliance. This rule applies to all community water systems (CWSs) and non-transient non-community water systems (NTNCWSs) that either add or deliver a primary or residual disinfectant other than ultraviolet light.

2.0 Rule Requirements

Initial Distribution System Evaluation (IDSE) Requirements Initial distribution system evaluations will be conducted to quantify DBP levels through the distribution system and will be used to determine Stage 2 DBPR monitoring locations. There are four ways to comply with the IDSE requirements: Standard Monitoring, System Specific Study, 40/30 Certification, and Very Small System (VSS) Waiver.

IDSE Option	Description
Standard Monitoring	Requires system to collect one year of TTHM and HAA5 data at a specific frequency and locations to characterize TTHM and HAA5 levels in the distribution system. The system must use available Stage 1 DBPR compliance data to determine the best locations for Stage 2 DBPR compliance monitoring.
System Specific Study (SSS)	Systems that have extensive DBP data (including Stage 1 DBPR compliance data) or technical expertise to prepare a hydraulic model may choose to conduct a system specific study to select Stage 2 compliance monitoring locations.
40/30 Certification	The term "40/30" refers to a system that during a specific time period has all individual Stage 1 DBPR compliance samples less than or equal to 0.040 mg/L for TTHM and 0.030 mg/L for HAA5 and has no monitoring violations during the same time period. These systems have no IDSE monitoring requirements, but will still need to conduct Stage 2 DBPR compliance monitoring.
Very Small System (VSS) Waiver	Systems that serve fewer than 500 people and have DBP data can qualify for a VSS Waiver and would not be required to conduct IDSE monitoring. These systems have no IDSE monitoring requirements, but will still require Stage 2 DBPR compliance.

The IDSE report requirements vary based on the IDSE option followed, consult the DBP Rule for more specific information on how to develop a monitoring plan.

Monitoring Requirements Monitoring requirements under the Stage 2 DBP Rule are population-based and are based on the size of the retail population served by the water system and the source water type. The following table lists the monitoring requirements associated with the Rule.

Source Water Type	Population Size Category	Monitoring Frequency	Total Distribution System Monitoring Locations Per Monitoring Period
Surface water and ground water under the direct influence of surface water	< 500	per year	2
	500-3,300	per quarter	2
	3,301-9,999		2
	10,000-49,999		4
	50,000-249,999		8
	250,000-999,999		12
	1,000,000-4,999,999		16
	≥ 5,000,000		20
Groundwater	< 500	per year	2
	500-9,999		2
	10,000-99,999	per quarter	4
	100,000-499,999		6
	≥ 500,000		8

Regulated Contaminants The following table lists the contaminants that are regulated by the DBPR including the MCLG and MCL for each contaminant:

Regulated Contaminants		MCLG (mg/L)	MCL (mg/L)	Rule
Total Trihalomethanes (TTHM)			0.080 LRAA	Stage 2
	Chloroform	0.07		
	Bromodichloromethane	zero		
	Dibromochloromethane	0.06		
	Bromoform	zero		
Five Haloacetic Acids (HAA5)			0.060 LRAA	
	Monochloroacetic acid	0.07		
	Dichloroacetic acid	zero		
	Trichloroacetic acid	0.02		
	Bromoacetic acid	-		
	Dibromoacetic acid	-		
Chlorite		0.8	1.0	Stage 1
Bromate		zero	0.010	

* LRAA = Locational running annual average

Treatment The following technologies are suggested for compliance and are predicted to meet the MCLs mentioned above:

Surface Water Plants	**Groundwater Plants**
Switching to chloramines as a residual disinfectant	Switching to chloramines as a residual disinfectant
Chlorine dioxide (not for systems serving fewer than 100 people)	UV
UV	Ozone (not for systems serving fewer than 100 people)
Ozone (not for systems serving fewer than 100 people)	Granular activated carbon
Microfiltration/Ultrafiltration	Nanofiltration
Granular activated carbon	
Granular activated carbon + Advanced disinfectants	
Integrated membranes	

3.0 Compliance Deadlines

The compliance requirements for this Rule were established based on four schedules. The following table lists the schedule for compliance with the Stage 2 DPB Rule.

Public Water Systems	Actions			
	Submit IDSE monitoring plan, system specific plan or 40/30 certification	Complete an initial distribution system evaluation (IDSE)	Submit IDSE report	Begin subpart V (Stage 2) compliance monitoring
CWSs and NTNCWSs serving at least 100,000	October 1, 2006	September 30, 2008	January 1, 2009	April 1, 2012
CWSs and NTNCWs serving 50,000 to 99,999	April 1, 2007	March 31, 2009	July 1, 2009	October 1, 2012
CWSs and NTNCWSs serving 10,000 to 49,999	October 1, 2007	September 30, 2009	January 1, 2010	October 1, 2013
CWSs serving fewer than 10,000	April 1, 2008	March 31, 2010	July 1, 2010	October 1, 2013
NTNCWs serving fewer than 10,000	NA	NA	NA	October 1, 2013

4.0 References

[1] US EPA Safedrinking Water Act, Stage 2 Disinfectants and Disinfection Byproduct Rule, http://www.epa.gov/safewater/disinfection/stage2.

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Revision Date: 09/30/08

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

Filter Backwash Recycling Rule Fact Sheet

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms.

1.0 Overview of Rule

Title: Filter Backwash Recycling Rule, 66 FR 31086 June 8, 2001, Vol. 66 No. 11

Purpose: To improve public health protection, particularly from microbial contaminants such as Cryptosporidium, Giardia, etc., by requiring water treatment plants which choose to recycle filter backwash water, to do so at the head of the process.

Waste streams targeted: The following waste streams are noted in the Rule. Other wastestreams may also be subject to the requirements of the Rule.

- Spent Filter backwash wastewater
- Thickener supernatant
- Liquids from dewatering processes

2.0 Rule Requirements

Systems Affected: Public water systems meeting all of the following are required to meet this Rule:

- The system is a subpart H system (i.e. uses surface or groundwater under the influence of Surface Water)
- The system treats water using conventional (40CFR141.2) or direct (40CFR141.2) filtration.
- The system recycles one or more of the targeted wastestreams noted above.
- suspended or dissolved solids (soluble cyanide), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.
- For community surface and groundwater (under the direct influence of surface water) systems, treatment technique is applied. In this case, the accepted TT is the use of chlorine (Cl_2). Inorganic materials, such as cyanide, are oxidized by Cl_2 and converted to more manageable insoluble forms. Cl_2 reacts with organic matter breaking it down to simpler substances. Benefits: proven; reliable. Limitations: product water has objectionable taste; can react to organic compounds to form THMs.

Definitions of Conventional and Direct Filtration – Conventional filtration: A series of processes including coagulation, flocculation, sedimentation, and filtration. Direct filtration: A series of processes including coagulation, flocculation, and filtration.

Reporting: By December 2003, each system meeting the applicability requirements noted above is to submit to the State Health Department for review and approval

- A schematic showing origin of all flows which are recycled, specifics of transmission piping, frequency, duration and rate;
- Average recycle flow, maximum observed plant flow from most recent year, and design flow for the treatment plant;

- The State approved capacity of the plant if it exists

Failure to submit the above information constitutes a Tier 3 violation. Tier 3 violations require public notification within one year, by either mail, hand delivery, or other method which reaches the public.

Recordkeeping: In addition to the information submitted to the State, the system must collect and maintain the following:

- A list of recycle streams and the frequency with which they are returned
- Average and maximum backwash flowrates and durations
- Typical filter run length and the rationale of how filter run length is determined
- Documentation of treatment of the recycle stream prior to re-admittance to the conventional or direct filtration process
- If treatment is provided, design data of the type and nature of treatment (i.e. equalization specifics, hydraulic loadings, identification of chemicals and dosages, etc)

3.0 Compliance Deadlines

All compliance deadlines have now passed and full compliance with this rule is required, unless a waiver was issued. All new systems are required to comply with this rule.

4.0 References

EPA Publications: Available from EPA from their Safe Drinking Water Hotline, (1-800-426-4791), the National Service Center for Environmental Publications (1-800-490-9198) or the National Technical Information Service (1-800-553-6847) or www.ntis.gov.

- EPA 816-F-01-019, A Quick Reference Guide, June 2001
- Filter Backwash Recycling Rule A Rule Summary for Systems
- Technical Guidance Manual
- Implementation Guidance for the Filter Backwash Recycling Rule

Website: http://water.epa.gov/lawsregs/rulesregs/sdwa/filterbackwash.cfm

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Revision Date: 09/20/10

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

Long Term II Enhanced Surface Water Treatment Rule (LT2ESWTR)

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Giardia and Cryptosporidium.

1.0 Overview of Rule

This rule applies to ***all*** public water systems that use surface water or groundwater under the direct influence of surface water. The purpose of the LT2ESWTR is to improve drinking water quality by reducing the occurrence of disease-causing pathogens in drinking water, such as *Cryptosporidium* and *Giardia* (see contaminant specific fact sheets for more information on these organisms). The rule consists of monitoring requirements, bin classification of water systems based on their source water quality, and removal/inactivation requirements.

2.0 Rule Requirements

Source Water Monitoring Source water monitoring is conducted to assess the mean level of *Cryptosporidium* contamination in the water supply. The source water monitoring requirements depend on the size of the public water system (PWS) and whether or not filtration is employed by the PWS. There are four classifications of PWSs identified by LT2ESWTR: small or large (above or below 10,000 people served) and filtered or unfiltered.

Minimum Sampling Requirements (§141.701)

	PWSs serving > 10,000 people	PWSs serving < 10,000 people
Filtered	*Cryptosporidium*, E coli, turbidity monthly for two years	E coli every two weeks for one year. *Cryptosporidium* monitoring is required twice per month for one year or once per month for two years if the annual mean E coli concentration is > 10 E coli/100 mL for lake or reservoir sources or > 50 E coli/100 mL for stream sources.
Unfiltered	*Cryptosporidium* monthly for two years	*Cryptosporidium* twice per month for one year or once per month for two years

Sampling may be conducted more frequently, but must be evenly spaced throughout the two year sampling period. For large filtered systems only, a less conservative calculation/analysis procedure may be used to determine the treatment bin classification if using a more frequent sampling plan. Sampling plans, which include sampling locations and a schedule of sampling dates, must be submitted to the State no less than three months prior to the start of sampling. Data collected prior to the formal monitoring period may be grandfathered (see Part 1, pg 14). Unfiltered systems may choose not to conduct source water monitoring if they will provide a total of at least 3-log *Cryptosporidium* inactivation (§141.701(c)).

A second round of monitoring must be conducted six years after the initial bin classification. Unless changes are made to LT2ESWTR, the second round of sampling must following the same guidelines as mentioned above, for the initial bin classification.

Bin Classification and Removal Credit PWSs are assigned a bin classification based on the results of the source water monitoring. PWS must calculate individual sample concentrations as the total number of oocysts counted divided by the volume assayed. The mean *Cryptosporidium* concentration must be reported to the State. Unless the LT2ESWTR is amended, the bin classification must be recalculated after the second round of sampling to take place six years after the first.

Filtered Systems

For filtered systems that collect more than 24, but less than 47 samples, the bin concentration is the highest arithmetic mean of all samples in 12 consecutive months. For filtered PWSs that collect greater than 48 samples, the bin concentration is the arithmetic mean of all samples (see rule for specific details).

Bin Classification for Filtered PWS (§141.710).

Monitoring Requirements	***Cryptosporidium* Bin Concentration**	**Bin Classification**
Required to monitor Cryptosporidium	< 0.075 oocysts/L	Bin 1
	> 0.075 oocycsts/L and < 1.0 oocysts/L	Bin 2
	> 1.0 oocysts/L and < 3.0 oocysts/L	Bin 3
	> 3.0 oocysts/L	Bin 4
Small PWS with no required Cryptosporidium monitoring	NA	Bin 1

Additional treatment requirements for LT2ESWTR for filtered PWS (§141.711).

Bin Classification	**Conventional treatment, diatomaceous earth filtration, slow sand filtration**	**Direct filtration**	**Alternative filtration technologies**
1	No additional treatment	No additional treatment	No additional treatment
2	1.0-log	1.5-log	As determined by the State
3	2.0-log	2.5-log	As determined by the State
4	2.5 log	3.0 log	As determined by the State

Log removal rates refer to minimum total Cryptosporidium removal and inactivation.

The total Cryptosporidium removal required for plants in Bins 2, 3, and 4 is 4.0-log removal, 5.0-log removal and 5.5-log removal respectively.

Removal Credit for Treatment Plant Types.

Plant Type	**Conventional, diatomaceous earth filtration, slow sand filtration**	**Direct filtration**	**Alternative filtration technologies**
Treatment Credit	3 log	2.5 log	Determine by the State

Unfiltered Systems

Unfiltered PWSs must calculate their bin concentration as the arithmetic mean of all of the samples collected.

Bin Classification for Unfiltered PWS (§141.712)

Mean *Cryptosporidium* Concentration	Required *Cryptosporidium* Inactivation
< 0.01 oocysts/L	2-log inactivation
> 0.01 oocysts/L or PWS chose not to monitor for Cryptosporidium	3-log inactivation

Unfiltered PWS must use at least two different disinfectants to provide 4-log virus, 3-log *Giardia*, and 2- or 3-log *Cryptosporidium* inactivation. Furthermore, each of the two disinfectants must achieve, by itself, the total required inactivation of one of these pathogens for improved reliability and efficacy.

Treatment A microbial toolbox (§141.715**)** was developed to provide guidance on treatment technologies to help PWS meet the log removal requirements outlined above.

Treatment category	Toolbox option	Log Credit	Removal credits[1]
Source protection and management toolbox options	Watershed control program	0.5	For state approved program. Unfiltered PWSs are not eligible for credit.
	Alternative source/ intake management		No prescribed credit.
Prefiltration toolbox options	Presedimentation basin with coagulation	0.5	During any month that presedimentation basins achieve a monthly mean reduction of 0.5-log or greater in turbidity or alternative State-approved performance criteria. See Rule for eligibility requirements.
	2-stage lime softening	0.5	Where chemical addition and hardness precipitation occur in both stages. All plant flow must pass through both stages. Single stage softening is given credit equivalent to conventional treatment.
	Bank filtration	0.5, 1.0	0.5: for 25-foot setback; 1.0: for 50-foot setback; Horizontal and vertical wells only; aquifer must be unconsolidated sand containing at least 10 percent fines (as defined in rule); average turbidity in wells must be less than 1 NTU. PWSs using existing wells followed by filtration must monitor well effluent to determine bin classification and are not eligible for additional credit.
Treatment performance toolbox options	Combined media filter performance	0.5	For combined filter effluent turbidity less than or equal to 0.15 NTU in at least 95 percent of measurements each month.
	Individual media filter performance	0.5	(in addition to 0.5-log combined filter performance credit) if individual filter effluent turbidity is less than or equal to 0.15 NTU in at least 95% of samples each month in each filter and is never greater than 0.3 NTU in two consecutive measurements in any filter.
	Demonstration of performance		Credit awarded to unit process or treatment train based on demonstration of State approved protocol.

Treatment category	**Toolbox option**	**Log Credit**	**Removal credits**[1]
Additional filtration toolbox options	Bag and cartridge filter	Up to 2.0	With demonstration of at least 1-log greater removal in a challenge test when used singly.
		Up to 2.5	With demonstration of at least 0.5-log greater removal in a challenge test when used in series.
	Membrane filtration		Log credit equivalent to removal efficiency demonstrated in challenge test if supported by direct integrity testing.
	2nd stage filtration	0.5	For separate granular media filtration stage if treatment train includes coagulation prior to first filter.
	Slow sand filters	2.5	As secondary filtration step; No prior chlorination.
		3.0	As primary filtration process. No prior chlorination.
Inactivation toolbox	Chlorine dioxide		Log credit based on measured CT in relation to CT table (see Section IV, C. 14).
	Ozone		Log credit based on measured CT in relation to CT table (see Section IV, C. 14).
	UV		Log credit based on validated UV dose in relation to UV dose table (see Section IV, C. 14).

[1] See rule for more specific details regarding removal credit for each toolbox option.

3.0 Compliance Deadlines

PWS Size: Systems that serve…	1st round of source water monitoring	2nd round of source water monitoring	Treatment Compliance Deadline
(1) At least 100,000 people	October 1, 2006	April 1, 2015	April 1, 2012
(2) From 50,000 to 99,999 people	April 1, 2007	October 2015	October 1, 2012
(3) From 10,000 to 49,999 people	April 1, 2008	October 1, 2016	October 1, 2013
(4) Fewer than 10,000 people	October 1, 2008	October 1, 2017	October 1, 2014
(5) Fewer than 10,000 and monitor form Cryptosporidium	April 1, 2010	April 1, 2019	

For more information, please refer to US EPA LT2 website:
http://water.epa.gov/lawsregs/rulesregs/sdwa/lt2/index.cfm

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Revision Date: 09/20/10

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Summary of Contaminants and Respective Treatment Technologies

• = USEPA BAT (Best Available Technology)
X = Existing proven technology

Contaminant			Enhanced Coagulation & Media Filtration	Enhanced Coagulation & MF/UF	Coagulation & Media Filtration	Direct Filtration	Nanofiltration	Reverse Osmosis	Distillation	Ion Exchange	GAC	Lime Softening	Activated Alumina	Electrodialysis	Diatomaceous Earth	Disinfection Process Modification	Air Stripping	Oxidation (Ozone, KMnO4,Chlorine)	Greensand Filtration	Treatment Technique 1 (Conventional $+Cl_2$)	Treatment Technique 2 (Conventional)	Treatment Technique 3 (Cl_2)
Class	**Category**	**Specific Contaminant**																				
Primary Contaminants	Inorganic	Antimony (Sb)			•				•													
		Arsenic (As)			•				•			•	•									
		Asbestos			•	•									•							
		Barium (Ba)							•	•		•		•								
		Beryllium (Be)			•				•	•		•	•									
		Chromium (Cr)			•				•	•		•^{s}										
		Copper (Cu)			•^{i}				•	•		•										
		Cyanide (CN$^-$)							•	•												
		Fluoride (F)							•				•									
		Lead (Pb)			•^{i}				•	•		•										
		Mercury (Hg) & Cadmium (Cd)			•^{i}				•		•	•										
		Nitrate (NO$_3^-$) & Nitrite (NO$_2^-$)							•	•				•								
		Selenium (Se)			•^{s}				•			•	•	•								
		Thallium (Tl)								•			•									
	Radionuclides	Combined Radium (Ra-226 & Ra-228)							•	•		•										
		Gross Alpha (excluding Ra & U)							•^{p}													
		Beta Particle & Photon Radioactivity							•	•												
		Uranium		•					•	•		•										
	DBP	Bromate	•	X				X	X		•	X				•						
		Chlorite	•	X				X	X		•	X				•						
		HAA (5 species)	•	X				X	X		•	X				•						
		THM (total)	•	X				X	X		•	X				•						
	Biological & Fouling Potential	Turbidity & Total Suspended Solids																				•
		Biological: Cryptosporidium & Giardia																		•		
		Biological: Viruses																				
		Biological: Total Coliforms & E-Coli																		•		
	Organic Chemicals	Organic Chemicals (see list in section)									•						•					
Secondary Contaminants		Iron (Fe) & Manganese (Mn)																•	•			
		TDS							•					•								
		Zinc (Zn							•	•		•										
General Water Quality		Alkalinity								•		•										
		Nickel (Ni)							•	•		•										

p = proposed BAT
s = species dependent
i = appropriate for insoluble form only

Revision Date: 09/20/10

RECLAMATION
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Activated Alumina

Activated alumina is an adsorbent used in packed beds to remove fluoride, arsenic, selenium, beryllium, and natural organic matter from water.

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Arsenic.

1.0 Applicable Contaminants

Activated alumina is an EPA listed BAT for the removal of arsenic, fluoride, uranium, and selenium.

2.0 Description of Technology

Pretreatment Cartridge filtration should be used as pretreatment for solids removal with activated alumina. Additionally, pre-oxidation and pH control are recommended [1]. Pre-oxidation or feed water pH adjustment may be necessary to enhance removal of target contaminants. For example, the activated alumina process is more effective in removing As(V) than Arsenic (III) so pre-oxidation of As(III) to As(V) can improve the removal efficiency of activated alumina. The pH of the raw water should be adjusted and maintained between 5.5 and 6.0 to facilitate Arsenic removal. At higher pH values, the activated alumina surface has a net negative charge which can electro-statically repel anions, reducing its efficiency [2].

Technology Description Activated alumina is a granulated form of aluminum oxide. This material is highly porous and has a very large surface area, over 200 m^2/g. Activated alumina adsorption is a physical/chemical process in which ions in solution are removed on the oxide surface. Feed water is passed continuously through one or more activated alumina beds. Loading rates can range from 3 to 5 gpm/ft^2 [3]. Typically filters are greater than 3 feet deep [4]. Periodically, the activated alumina media is backwashed to remove any solids that have accumulated in the system. Backwash rates vary from 8 to 10 gallons per minute depending on the diameter of the filter [4]. When all available sites are occupied, the activated alumina media must either be regenerated with a strong base or disposed of entirely.

Waste Disposal The waste product from the regeneration of spent activated alumina is caustic and contains high concentrations of the contaminant removed and may be considered a hazardous waste.

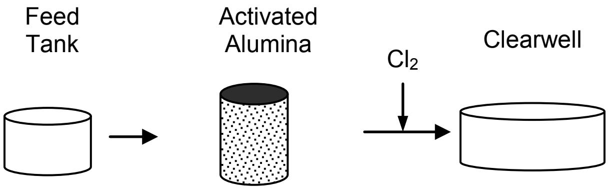
Maintenance Activated alumina processes must be maintained to minimize bacterial growth in the canister or cartridges. System pressure and flowrate checks are necessary to verify effectiveness of backwashing.

Water quality monitoring is necessary to ensure contaminant removal. Regular replacement of media may be required and is based on contaminant type, concentration, and rate of water usage. The manufacturer's recommendations for media replacement should be consulted. Periodic cleaning with an appropriate regenerant such as $Al_2(SO_4)_3$, acid, and/or caustic will extend media life. Activated alumina may need to be replaced approximately every one to three years.

Benefits Activated alumina is well understood, well established, and reliable. Activated alumina is capable of meeting the desired product water requirements for arsenic removal and requires minimal operator involvement.

Limitations Regeneration of resins may generate hazardous waste. Requires routine monitoring to determine when regeneration is necessary.

4.0 Example Treatment Train*



*** Acid addition and pre-oxidation are optional.**

5.0 Safety and Health Concerns

Sodium hydroxide or other caustic solution is often used for resin regeneration. Personal protective equipment is required for handling all chemicals. Regeneration waste and spent media may be characterized as a hazardous waste and must be disposed of properly.

6.0 References

1. AWWA Water Treatment Plant Design. New York, McGraw-Hill, 2005.
2. Wang, L., A. Chen, K. Fields. Arsenic Removal from Drinking Water by Ion Exchange and Activated Alumina Plants. EPA/600/R-00/088, October 2000.
3. Industrial Wastewater Management, Treatment, and Disposal. Water Environment Federation, McGraw-Hill, 2008.
4. Flow and Backwash Chart for Various Filter Media. Pure Water Products, LLC, 2008.

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Revision Date: 09/20/10

RECLAMATION
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Air Stripping

Air stripping is primarily used for removing volatile organic chemicals (VOCs), oxidizing contaminants such as iron and manganese, improving taste, or removing odor.

1.0 Applicable Contaminants

Air stripping is an EPA BAT for some organic chemicals (VOCs) including benzene, toluene, xylene, tri/tetrachloroethylene, trihalomethanes, vinyl chloride and many others.

2.0 Description of Technology

Technology Description Air stripping is the process of transfering a contaminant from the liquid phase to the gas phase. In the air stripping process, air and water are contacted in a packed column designed to maximize the contact surface area between the water and air. Air stripping performance depends on factors such as:

- Characteristics of the volatile material (partial pressure, Henry's constant, gas-transfer resistance, etc.) [1]
- Water and ambient air temperature
- Turbulence in gaseous and liquid phases
- Area-to-volume ratio
- Exposure time
- Use of a bioreactor on the air waste stream [3]

Appropriate design of the packed column is necessary to ensure the desired level of contamiant removal based on the process operating temperature and the Henry's Constant of the target contaminant**.** Scaling can occur when calcium exceeds 40 mg/L, iron exceeds 0.3 mg/L, magnesium exceeds 10 mg/L, manganese exceeds 0.05 mg/L. Biological fouling may also occur depending on the feed water quality [2].

The following is a list of the different types of air stripping technologies:

Waterfall Aeration: spray aerators, multiple-tray aerators, cascade aerators, cone aerators, packed columns

Pressure Aerators: water into pressurized air, compressed air into a pressurized pipeline

Diffusion Type Aerators: diffuser aerators**,** draft-tube aerators**,** in-well aeration

Mechanical Aeration: surface aerators**,** submerged aerators [1].

Spray aerators dissipate water in a vertical or inclined angle breaking the water into small drops. Multiple-tray aerators use uniquely designed trays in order to increase the surface area for aeration. Cascade and cone aerators allow water to flow in a downward direction over a series of baffles or pans [1].

There are two main types of pressure aerators, one that sprays water on top of a tank that is constantly supplied with compressed air, and one that injects compressed air directly into a pressurized pipeline adding fine air bubbles into the flowing water [1].

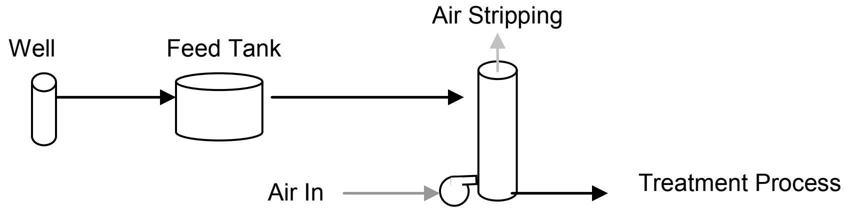
Diffusion type aerators are similar to pressure aerators but are designed to allow air bubbles to diffuse upward through the tank of water in order to help produce turbulence and mixing [1].

Mechanical aerators use a motor driven impeller to achieve air mixing. Occasionally, it is also used in combination with an air injection device [1].

Benefits Proven and experienced technology**,** able to be a low profile addition to a treatment process**,** high percentage of removal (99% and above) [2].

Limitations Proper air flow is necessary to provide the proper air and water balance to prevent flooding or excess air flow [2], scaling and biological fouling may impact the performance of the air stripper

3.0 Example Treatment Train



4.0 Safety and Health Concerns

- Off-gas treatment may be necessary using activated carbon or thermal oxidation. VOC inhalation is possible if not treated properly.
- Hazards associated with compressed air

5.0 References

1. American Water Works Association, and American Society of Civil Engineers. Water Treatment Plant Design. Ed. Edward E. Baruth. Fourth ed. New York: McGraw-Hill Handbooks, 2005.
2. US Army Corps of Engineers. Engineering and Design: Air Stripping. Design Guide No. 1110-1-3. 2001.

3. Speitel, G. E. and D. S. McLay (1993). "Biofilm Reactors for Treatment of Gas Streams Containing Chlorinated Solvents." Journal of Environmental Engineering 119(4): 658-678.

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Revision Date: 09/20/10

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

Chlorine Dioxide

Chlorine dioxide is used in water treatment applications as a disinfectant and as an oxidant.

1.0 Applicable Contaminants

Chlorine dioxide is used to inactivate bacteria, viruses, and protozoa, and oxidize iron, manganese, hydrogen sulfide, and organic compounds.

2.0 Description of Technology

Technology Description Oxidation is the mechanism for chlorine dioxide (ClO_2) disinfection. Chlorine dioxide is extremely soluble in water; approximately 10 times more soluble than chlorine. It is also very volatile and can be easily removed from dilute aqueous streams with minimal aeration. It is highly selective and effective at low concentrations.

Chlorine dioxide is a regulated Primary Drinking Water Contaminant. The Maximum Residual Disinfectant Level Goal (MRDLG) is 0.8 ppm and the Maximum Residual Disinfectant Level (MRDL) is also 0.8 ppm. When chlorine dioxide (ClO_2) is added to water, chlorite ions (ClO_2^-) are formed. The chlorite ion is further reduced to the chloride ion by accepting electrons donated by other species in the water. This transfer of electrons causes the reduction of chlorite to chloride and the oxidation of other species. The following equations show the chemical reaction mechanism for chlorine dioxide oxidation:

$$ClO_2 + e^- \rightarrow ClO_2^- \tag{1}$$

$$ClO_2^- + 2H_2O + 4e^- \rightarrow Cl^- + 4OH^- \tag{2}$$

Chlorite, a disinfection by-product, is currently limited in the NPDWR to a maximum concentration of 1 ppm in drinking water. The MCLG is 0.8 ppm. Therefore, chlorine dioxide should only be used for water sources in which a low ClO_2 dose is required or in applications which use iron-based coagulants since iron can reduce chlorite to chloride. The NSDWR limit for chloride is 250 ppm.

Chlorine dioxide cannot be stored or transported as a gas because it is extremely flammable. Liquid chlorine dioxide will dissociate into oxygen and chlorine when stored for long periods of time. For these reasons, chlorine dioxide is difficult to transport and is typically generated on-site from sodium chlorite and hydrochloric acid by the following chemical reaction:

$$5NaClO_2 + 4HCl \rightarrow 4ClO_2 + 5NaCl + 2H_2O \tag{3}$$

Chlorine dioxide can be decomposed by exposure to sunlight. Tanks and piping must be opaque or shielded from sunlight.

Waste Disposal There is no waste stream produced from the generation of chlorine dioxide or the addition of chlorine dioxide as a disinfectant in water treatment applications.

Maintenance Routine maintenance is required on the chemical feed systems that dose the chlorine dioxide into the water stream and the chemical feed and mixing systems that generate the chlorine dioxide.

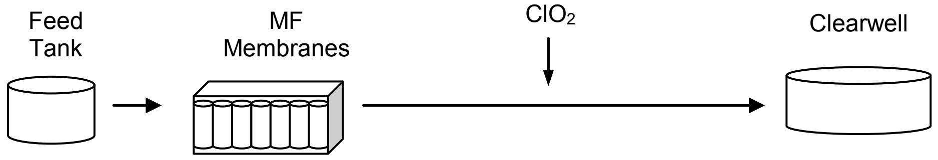
Benefits

- Established
- Low cost
- Reliable
- Effective as a primary disinfectant at low concentrations
- Few organic DBPs produced

Limitations

- Health and safety concerns from chlorine dioxide generation
- Chlorite monitoring required
- Sodium chlorite is expensive
- Not an adequate secondary disinfectant for residual due to its high volatility

3.0 Example Treatment Train



4.0 Safety and Health Concerns

Chlorine dioxide gas is extremely flammable and must be generated on-site and cannot be stored due to its high volatility. Chlorine dioxide generation can produce noxious vapors. Therefore, appropriate personal protective equipment and training is necessary for operators involved in chemical handling and maintenance of the chlorine dioxide generation and dosing equipment.

5.0 References

1 Water Treatment Plant Design, AWWA, 4th Edition, 2005
2 EPA Guidance Manual, Alternative Disinfectants and Oxidants – Chapter 4: Chlorine Dioxide, April 1999.

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Conventional Treatment

Conventional treatment includes the following: pre-sedimentation or screening, chemical coagulation and flocculation, final settling or clarification, filtration, and disinfection. Not all processes are required in every case, so actual process selection depends on careful review of overall raw water quality and characteristics.

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Cryptosporidium and Giardia Fact Sheet.

1.0 Applicable Contaminants

Conventional treatment is used to remove suspended solids, bacteria, protozoa, and natural organic matter. Conventional treatment is an EPA listed BAT for ***Cryptosporidium & Giardia***.

2.0 Description of Technology

Pretreatment No pretreatment is required for conventional treatment technologies.

Technology Description Conventional treatment consists of pre-sedimentation or screening, chemical coagulation and flocculation, settling, filtration, and disinfection. Conventional treatment is used to reduce total suspended solids and turbidity.

Pre-sedimentation or screening consists of removing the largest/heaviest suspended solids (wood, plastic materials, rags, etc) from the raw water. Screens are usually mechanically cleaned and the screened solids are typically disposed of in a sanitary landfill. Multiple screens are usually employed to minimize downtime for cleaning or maintenance.

Chemical coagulation and flocculation consists of adding a chemical coagulant (aluminum sulfate, ferric sulfate, ferric chloride, polymer, or coagulant aide) and mechanical flocculation (rapid mixing) to allow fine suspended and some dissolved solids to combine together to produce a rapidly settling floc. Settling or clarification is a separation process which utilizes gravity to remove the flocs formed by coagulation and flocculation. Plate settlers can be used instead of conventional clarification. Filtration separates fine suspended solids, flocs, and pathogens by passing the water through a porous medium [1].

Disinfection consists of chemical inactivation (killing) of pathogens, bacteria, and viruses (see Disinfection section). In addition to the unit processes mentioned, the conventional treatment train typically includes raw water pumps, debris screens, and clearwell storage.

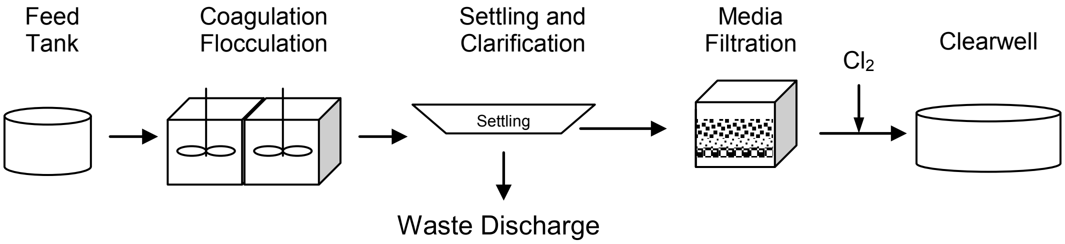
Waste Disposal Settled solids and spent filter material requires approved disposal. Backwash water may either be disposed of or recycled to the head of the plant (see Backwash Rule). Recycled filter backwash may concentrate oocyst/cysts and result in a significant source of increased turbidity and crypto/giardia. As a result, a period of filter-to-waste flow may be required after post-backwash/cleaning periods.

Maintenance Proper monitoring, operation, and maintenance procedures are essential to ensure the reliability of these processes. Periodic recharging or clean installation of media is required.

Benefits Conventional treatment technologies are well understood, well established, and reliable.

Limitations May generate large volumes of sludge. High initial investment and land intensive.

4.0 Example Treatment Train



5.0 Safety and Health Concerns

Chemical handling precautions are required.

6.0 References

1. AWWA Water Treatment Plant Design. New York, McGraw-Hill, 2005.

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Revision Date: 09/21/10

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
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Diatomaceous Earth

Diatomaceous earth (DE) is a type of media filter that can be used to remove many different contaminants.

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; *Cryptosporidium* and *Giardia*.

1.0 Applicable Contaminants

Diatomaceous earth may be used to remove natural organic matter, particulates, synthetic organic chemicals, asbestos, *Cryptosporidium* and *Giardia*. DE is capable of 3.0 log removal of *Cryptosporidium* and *Giardia*.

2.0 Description of Technology

Pretreatment No pretreatment is required for DE.

Technology Description Diatomaceous earth contains fossil-like skeletons of microscopic water plants, diatoms, ranging in size from less than 5 µm to more than 100 µm [1]. DE is used as a standalone media and is not typically used as part of a mixed media filter. DE is supplied to the feed water as a powder and then fed to a filter tank in which the DE is removed by screens. The DE forms a filter cake on the screen which is then backwashed. The use of DE is limited to source waters having turbidity less than 10 NTU. DE filters are typically operated at loading rates of 1 to 2 gpm/ft^2.

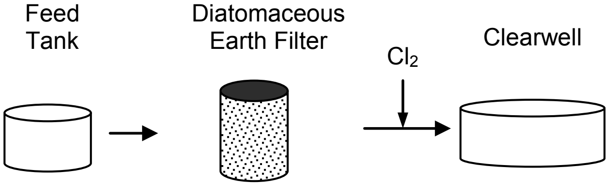
Waste Disposal DE is primarily inert and waste DE slurry may be treated by thickening with polymers and dewatering on belt filters [2]. DE filters require backwash. The water generated during backwash should be directed to a waste stream.

Maintenance Periodic backwashes are required.

Benefits DE is a well established technology. It is portable, reliable, and effective.

Limitations This process requires a continuous supply of DE to form the slurry for the filter tank.

4.0 Example Treatment Train



5.0 Safety and Health Concerns

Gloves should be worn when handling DE because it may contain sharp edges and is an absorbent which can cause drying if in contact with skin. A dust mask should be worn when handling DE because dust is generated.

6.0 References

1. Bhadwaj, V. and M.J. Mirliss. Diatomaceous Earth Filtration for Drinking Water. Techn Brief: A National Drinking Water Clearinghouse Fact Sheet. Morgantown, WV. 2001. (http://www.nesc.wvu.edu/pdf/DW/publications/ontap/tech_brief/TB18_DiatomaceousEarth.pdf)

2. AWWA Water Treatment Plant Design. New York, McGraw-Hill, 2005.

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RECLAMATION
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Disinfection Treatment Technologies

Disinfection to control microorganism population is required in water treatment systems and is typically placed as the last unit operation in the treatment plant. The three most common types of disinfection are chlorine, chloramines, and UV. Chlorine and chloramines are two types of chemical disinfection and UV light is a physical form of disinfection.

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Cryptosporidium and Giardia Fact Sheet.

1.0 Applicable Contaminants

Disinfection techniques, including UV, chlorine, and chloramines can be used to inactivate *Cryptosporidium* and *Giardia*, viruses, and bacteria. Chlorine and chloramines can also oxidize other compounds such as iron, manganese, and some organic chemicals.

2.0 Description of Technology

The choice of disinfectant depends on cost, disinfection by-product formation potential, log inactivation required, cost, and whether it is used for primary disinfection or disinfectant residual. The disinfectant dose depends on log inactivation required which may be influenced by temperature, pH and turbidity. The following table summarizes the relative strengths and oxidation potentials of commonly used disinfectants.

Federal regulations state that all treated water leaving treatment plants must maintain a minimum free chlorine residual of 0.2 mg/L [1], therefore chlorination is required in water treatment regardless of disinfections technology used, if that disinfected water is to be used by the consumer. Free chlorine is the reactive chlorine portion and is not combined with organic nitrogen or ammonia. There are times when the water in the treatment plant requires disinfection for biofouling control and/or oxidation, however it is not distributed to the public without further treatment. For example, some feedwaters to treatment plants require disinfection prior to treatment and UV can be used to disinfect, even though it does not provide chlorine residual.

Chlorine

Pretreatment As disinfection is typically the last treatment step in most water treatment facilities, most suspended solids should have been removed prior to disinfection. NOM presence can exert a substantial chlorine demand along with disinfection by product generation and therefore should be removed as much as possible prior to chlorine disinfection. Tests to determine optimum pH and chlorine dose are required depending on the level of disinfection required.

Technology Description Chlorine is added to the water in different forms. Chlorine gas is typically used for large utilities over 200 gpm [2]. For utilities under that flow rate, chlorine in the form of sodium hypochlorite and calcium hypochlorite dehydrate liquids are recommended, since their handling and storage are much easier than chlorine gas. They still require special handling and storage, but not as much as chlorine gas. Chlorine in gaseous or liquid form is injected into the water systems and stored in a clearwell prior to distribution.

Chlorine concentration in water is controlled via several methods and they include: manual control based on flow and continuous or periodic residual measurements, continuous feed forward control, feedback control and other control regimen depending on the level of sophistication and accuracy required by the user [1].

A large drawback in using chlorine is the generation of disinfection by-products (DBP) when chlorine reacts with natural organic matter present in water. DBPs are classified as carcinogens. See related (DBP) fact sheet for more information.

Waste Disposal There is no waste generated from chlorine addition to water.

Maintenance A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be cleaned periodically.

Benefits Well understood, established, low cost, reliable, effective

Limitations Safety and handling (especially for chlorine gas), potential for DPB Formation, Requires careful monitoring

Chloramines

Pretreatment As disinfection is typically the last treatment step in most water treatment facilities, most suspended solids and/or dissolved ions, if any, should have been removed prior to disinfection. Tests to determine optimum pH, chlorine, and ammonia dose are required depending on the level of disinfection required.

Technology Description The addition of chlorine and ammonia produce chloramines that are used for disinfection. Chloramines are more stable than chlorine and can therefore provide a more stable disinfectant residual. Chlorine can dissipate or be consumed prior to reaching the consumer if it is not dosed properly. The chlorine and ammonia are added separately. The chlorine addition is described more in depth in the chlorine technology description section. The combine chloramine concentration cannot exceed 4.0 mg/L according to USEPA [3].

Waste Disposal There is no waste generated from chlorine addition to water.

Maintenance A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned.

Benefits Far less DBP formation than chlorine, more staple than free chlorine

Limitations

- Safety and handling
- Longer contact time (larger clearwell required) needed for disinfection when compared to chlorine
- Not as reactive as chlorine, therefore larger doses may be required
- Higher cost than chlorine
- More complex process than chlorine
- Potential health effect for some poeple

UV

Pretreatment As disinfection is typically the last treatment step in most water treatment facilities, most suspended solids and/or dissolved ions, if any, should have been removed prior to disinfection.

Technology Description UV light disinfection is a popular form of primary disinfection, because of its ease of use and no DBP formation potential. Water is passed through a UV reactor which is compromised of UV lamps inside the reactor. As pathogens path through the reactor, they are exposed to this light for a certain period of time depending on the desired level of disinfection. UV reactors are typically closed channel for potable water treatment and typically open channel for wastewater treatment. There are several types of lamps that are used in UV reactors with low pressure-high output (LPHO) and medium-pressure (MP) mercury vapor lamps being the most common [1]. The lamps are housed inside of quartz lamp sleeves in the reactor to protect the lamp from breaking.

The mechanism of UV disinfection is inactivation where the UV damages the micro-organisms' DNA and/or RNA. Removal of suspended solids from the feedwater to UV is important, since if the micro-organism goes through the UV reactor hidden behind or around suspended solids and are not exposed to UV rays, then they can pass through the reactor undamaged. This phenomenon is called "shadow effect", where the micro-organism travels though the UV reactor in the shadow of suspended solids. UV disinfection also does not provide a residual. Therefore, addition of chlorine or chloramine is required to meet federal of residual in the product water.

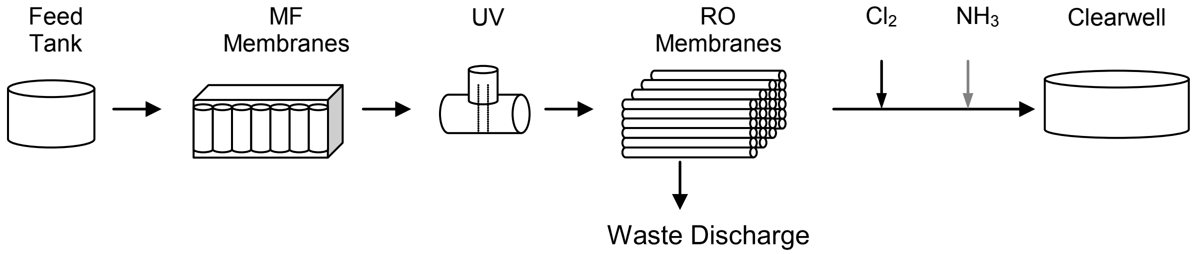
Waste Disposal No waste is generated in UV disinfection

Maintenance UV equipment including lamps must be properly checked to ensure they are working properly. The lamps age with time, so they require periodic replacement. A cleaning system must also be installed on the lamp sleeves, since the sleeve itself reacts with compounds in water and would decrease the UV transmittance if they are not cleaned.

Benefits No DBP formation, ease of use

Limitations No disinfectant residual, shadow effect if particles present (reduced efficiency), expensive capital cost

3.0 Example Treatment Train



4.0 Safety and Health Concerns

Specifically, with chlorination and chloramination, personnel must be aware of the dangers of chlorine gas or liquid, depending on what form of it is used. Ammonia storage and handling also requires extensive care.

5.0 References

1 Water Treatment Plant Design, AWWA, 4th Edition, 2005
2 Osmonics Pure Water Handbook, GE, 2nd Edition, 2001
3 http://www.epa.gov/safewater/disinfection/chloramine/

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Revision Date: 09/20/10

RECLAMATION
Managing Water in the West

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Distillation Treatment Technologies

Distillation is one of the oldest methods of water treatment. The most common distillation technologies are multi-stage flash and multi-effect evaporation units.

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms

1.0 Applicable Contaminants

Distillation is a desalination technology capable of removing dissolved ions from the feed water.

2.0 Description of Technology

Pretreatment Scaling and biofouling decrease the efficiency of distillation processes, therefore pretreatment is often required to remove undesired contaminants from distillation feed waters.

Technology Description Heat is applied to an impaired water source, and the generated steam from the boiling water is condensed to produce high quality product water. Most ionic and large non-volatile organic contaminants in the water do not vaporize at water's boiling point, therefore they remain in the feed solution while clean water is extracted. Biological micro-organisms do not survive the high temperature of distillation units, and are thus removed from the feed as well. Distillation technologies typically contain two chambers, one being the heating unit, and the other being the condensing unit, where the steam in condensed into product water.

Since there is a phase change involved in the heating chamber, distillation is very energy intensive. However technologies such as multi-effect evaporators and multi-stage flash reduce the energy requirements significantly over single evaporation units by taking advantage of repeatedly using the high temperature steam. The multi-effect or multi-stage processes take advantage of thermodynamic laws. Dropping the pressure in a vessel will decrease the boiling temperature of water in that vessel. Distillation processes require heat to turn water into steam. The heated water is introduced into a lower pressure stage or effect. Because of the lower pressure, this water then vaporizes at a lower temperature, hence requiring no additional heating. This phenomenon results in more water evaporation per the same unit of energy input into the water.

Waste heat from other processes such as power plants or geothermal sources has also been used to reduce the energy requirements of distillation units.

Waste Disposal Un-evaporated contaminants remaining in the waste stream of the boiling chamber must be disposed of properly.

Maintenance Regular maintenance is required on the distillation unit, along with scale control/removal depending on the scaling tendency of the feed water. Most waters possess scaling potential; therefore it must be dealt with in distillation units.

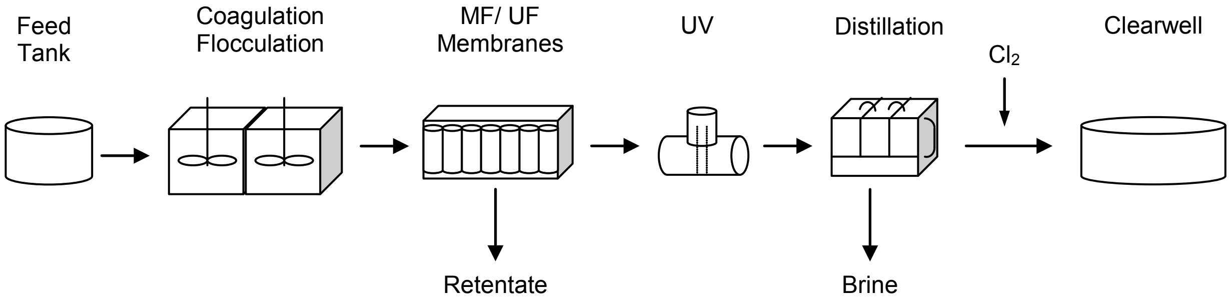
Benefits

- Very high quality water produced
- Can be cost effective, especially if waste heat is used as heating source

- Low pretreatment requirements
- No additional chemicals or water softening agents required

Limitations high captial cost, large footprint, large energy requirement makes distillation processes expensive

3.0 Example Treatment Train



4.0 Safety and Health Concerns

- High temperature can cause severe burns
- Electrical hazard
- Chemical hazard
- Hydraulic pressure hazard
- General industry safety, health, and self protection practices should be followed, including proper use of tools.

5.0 References

[1] Osmonics Pure Water Handbook, Osmonics, 2nd edition, 1997

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RECLAMATION
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Electrodialysis (ED) and Electrodialysis Reversal (EDR)

Electrodialysis (ED) is an electrochemical process in which ions migrate through ion-selective semipermeable membranes as a result of their attraction to two electrically charged electrodes. ED is able to remove most charged dissolved ions.

1.0 Applicable Contaminants

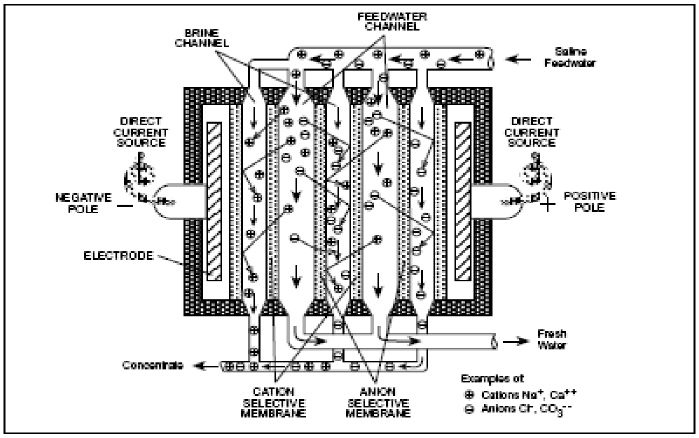
ED/EDR is an EPA BAT for barium, nitrate and nitrite, selenium, and TDS.

2.0 Description of Technology

Pretreatment Typical operation requires: the addition of a scale inhibitor to prevent scaling and reduce the concentrate LSI below 2.1 in the concentrate stream, residual chlorine concentration of 0.5 mg/L to prevent biological growth, and a cartridge filter (10-20 µm) prior to the ED/EDR system. Air stripping can also be used prior to ED/EDR in order to remove H_2S [6]. Also, the feed water must be within the limitations of an ED/EDR system (see section 2.2).

Technology Description Electrodialysis is a process that depends on the principal that most dissolved salts are positively or negatively charged and they will migrate to electrodes with an opposite charge [2]. Selective membranes that are able to allow passage of either anions or cations make separation possible [2]. ED uses these membranes in an alternating fashion to create concentrate and product streams.

The anions are able to pass through the anion-selective membrane, but are not able to pass by the cation-selective membrane, which blocks their path and traps the anions in the brine stream (Figure 1). Similarly, cations move in the opposite direction through the cation-selective membrane under a negative charge and are trapped by the anion-selective membrane [2]. An ED unit is able to remove from 50% to 94% of dissolved solids from a feed water, up to 12,000 mg/L TDS [3,7]. Voltage input, and process configuration (number of stacks or stages dictates the viable percent removal. TDS removal is generally limited by economics. The cost of ED increases as the feed water TDS increases. The typical operating conditions are 1,200 mg/L TDS, high hardness and high silica [4].



Movement of ions in the electrodialysis process *USAID*

Figure 1. Electrodialysis Process [1].

A typical ED system includes a membrane stack with a number of cell pairs, each consisting of a cation transfer membrane, a demineralized flow spacer, an anion transfer membrane, and a concentrate flow spacer. Compartments for the electrodes are at opposite ends of the stack. The electrodes are continually flushed to reduce fouling or scaling.

Recycling the concentrate stream and discharging concentrate to waste, or blowdown, is common and called feed-and-bleed mode [2]. This is necessary because of the fact that there are sharp differences in flow rates between the product and brine streams. Diluate flow is about 10 times the flow of the brine stream; this difference in flows creates pressure imbalances, requiring concentrate recycle [5].

Membranes are usually made out of cation- or anion-exchange resins made into sheet form. ED spacers are made out of HDPE, and the electrodes are composed of an inert metal. Membrane selection is based on careful review of raw water characteristics.

Electrodialysis Reversal (EDR) is similar to ED but the polarity of the electrodes is regularly reversed, thereby freeing accumulated ions on the membrane surface. This process minimizes the effect of inorganic scaling and fouling by converting product streams into waste streams [6]. This process requires additional plumbing and electrical controls, but increases membrane life. EDR does not require added chemicals, and eases cleaning as well.

Maintenance ED membranes are durable, can run under a wide range of pH conditions (pH 2 – 11), and endure high temperatures during cleaning [4]. They can be removed from the unit and scrubbed if necessary. If operated properly, membranes have an average life of 12 to 15 years [4]. Solids can be flushed out by turning the power off and letting water circulate through the stack. The ED stack must be disassembled, mechanically cleaned, and reassembled at regular intervals. They can also be cleaned using a 5% hydrochloric acid solution [8].

Waste Disposal The concentrate waste stream, electrode cleaning flows, and residuals from the pretreatment process will be a part of a typical waste stream flow and will require disposal. Common disposal methods include: surface water discharge, evaporation ponds, etc. Spent membranes will also require disposal.

Benefits

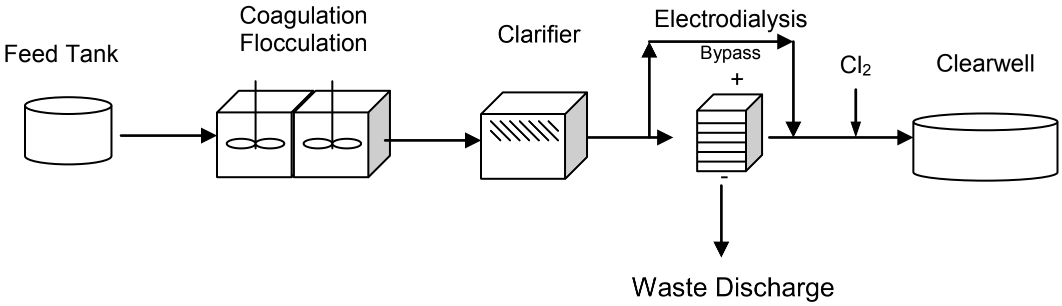
- ED and EDR can operate with minimal fouling or scaling, or chemical addition.
- Low pressure requirements.
- ED and EDR facilities are quieter than RO.
- Long membrane life expectancy.
- Unaffected by non-ionic sealants such as silica[1].
- Low chemical usage for pretreatment[1].
- Ability to treat feed water with higher SDI, TOC and silica concentrations, and more turbidity than RO[1].
- Can operate with up to 0.5 ppm of free chlorine in the feed water to control the biological matter in the feed water.[8]

Limitations

- TDS economical up to 8,000 ppm, but often run at waters of 1,200 ppm [6,9]
- pH: 2.0 to 11.0
- TOC: up to 15 mg/L
- Free Chlorine: 0.5 ppm with spikes up to 15-20 ppm
- Turbidity: up to 2 NTU
- Iron (Fe^{+2}): 0.3 ppm
- Mn ($^{+2}$): 0.1 ppm
- H_2S: up to 1 ppm
- SDI: 15 (5 min SDI)

3.0 Example Treatment Train

The conventional EDR treatment train typically includes raw water pumps, debris screens, rapid mix with addition of an antiscalant, slow mix flocculator, basin or clarifier, gravity filters, EDR membranes, chlorine disinfection, and clearwell storage. Microfiltration (MF) could be used in place of flocculation, sedimentation, and filtration.



4.0 Safety and Health Concerns

- Produces hazardous gasses, such as chlorine, hydrogen, H_2S, etc.
- Electrical hazardous

5.0 References

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Revision Date: 09/20/10

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

Granular Activated Carbon (GAC)

GAC can be used to remove dissolved contaminants from water by adsorption.

Figure 1. Activated Carbon [4]

1.0 Applicable Contaminants

GAC is an EPA BAT for the following contaminants:

- Disinfection Byproducts (DBPs)
- Mercury and Cadmium
- Natural Organic Matter
- Synthetic Organic Chemicals (specifically: benzo(a)pyrene, di(2-ethylhexyl)adipate, di(2-ethylhexyl)phthalate, hexachlorobenzene, dioxin)
- Radionuclides

2.0 Description of Technology

Pretreatment For source water with an unstable amount of bacteria, filtration and disinfection prior to carbon treatment may be required. Filtration prior to GAC may also be required when dealing with high-TSS waters.

Technology Description GAC has an extremely large amount of adsorption surface area, generally around 73 acre/lb (650 m^2/gram) to 112 acre/lb (1000 m^2/gram) [1]. GAC is made of tiny clusters of carbon atoms stacked upon one another, and is produced by heating the carbon source (coal, lignite, wood, nutshells or peat) in the absence of air which produces a high carbon content material [3].

The adsorption isotherm for carbon and the source water will determine the total contaminant removal capacity [2]. The iodine # is also used to represent the small and large pore volumes in a sample of GAC. It is the actual mass of iodine that is absorbed from the carbon sample. GAC is often used for the removal of natural organic mater, as well as disinfection by-products. The physical removal of a contaminant by adsorption on to the carbon surface is done in the mass transfer zone (MTZ). Breakthrough is defined as the point at which the concentration of a contaminant in the effluent adsorption unit exceeds the treatment requirement [1]. This breakthrough time is important to note so that treatment goals are not exceeded, and backwashing rates can be optimized. Backwashing a GAC system follows the same general procedures as a conventional granular gravity filter system. The GAC will typically expand up to 75% to 100% in volume, but may be only as much as 50% [1]. Empty bed contact time (EBCT) is the volume of the empty bed divided by volumetric flow rate of water through the carbon. A typical bed depth can contain up to 50% freeboard, excess capacity beyond the designed capacity, to allow for bed expansion during backwashing. Surface loading rates, or the volume of water that is passing though a given area, typically range from 2 to 6 gpm/ft^2 (5 to 15 m/h) [1].

The American Water Works Association (AWWA) sets standards on the amount of moisture content that GAC contains (no more than 8% by weight). The percent of ash content should also be considered, as a high percentage can cause problems in hard water. Particle size should also be considered, as it impacts the pressure drop across the filter, the backwash rate, the carbon usage rate (CUR), and the overall filtration capabilities. Powdered activated carbon (PAC) is also an option, but is mainly used when carbon filtration is necessary on a seasonal basis.

Biological growth can be desirable within GAC, which results in what is known as biologically active carbon (BAC). BAC can be beneficial by removing assimilable organic carbon (AOC) and other biodegradable compounds. If it is intended to have BAC, the GAC filters are typically preceded by ozonation that breaks down the organic carbon into a more assimable form. This process can enhance the overall contaminant removal of the GAC process. However, the biological growth needs to be controlled with frequent backwashing (once every 5 days). The use of chlorine prior to the beds will not prevent growth, will produce DBPs which take up more GAC adsorption sites, and make the carbon more brittle. Disinfection is recommended after the GAC filters to prevent biological growth in the distribution system, and to achieve the highest removal of AOC within the plant. If biological growth is not controlled and anaerobic conditions develop, odor problems will occur and undesirable organisms will begin to grow. Significant head loss and shorter filter runs can occur with too much biological growth. These two factors will be impacted even with beneficial biological growth and should be accounted for in GAC design [1].

The overall performance of an adsorption treatment process depends on the following factors:

1) Physical properties of the GAC: source of raw carbon, method of activation, pore size distribution, and surface area
2) Chemical and electrical properties of the carbon source or method of activation. The hydrogen and oxygen content in the GAC impacts performance as well.
3) Chemical composition and concentration of contaminants
4) The temperature and pH of the water. Adsorption usually increases as temperature and pH decrease [6].
5) The flowrate and exposure time to the GAC. The lower the contaminant concentration and flowrate tend to increase the life of the GAC [1].

GAC treatment technologies include:

- Pour-through devices for treating small volumes, such as a hand held Brita® filter.
- Faucet-mounted (with or without bypass) for treating water at a single faucet
- In-line filter (with or without bypass) for treating large volumes for several faucets
- High-volume commercial units for treating community water supply systems. Typically they are gravity fed (larger volumes) or pressure driven (smaller volumes) contactors [1]. These high-volume units can be sequenced in parallel or in series. GAC filters can be used alone or can also be combined with media filters.

Careful selection of type of carbon to be used is based on the contaminants in the water and manufacturer's recommendations.

Maintenance Regular reactivation or replacement of carbon media is required. If a GAC plant is large enough regeneration can be done on site, but is typically performed off site. On-site regeneration is typically not effective unless the carbon exhaustion rate is larger than 910 kg/day [1]. Reactivation frequency is dependent on contaminant type, concentration, rate of water usage, and type of carbon used. Careful monitoring and testing to ensure contaminant removal is achieved is necessary around the time of start up and breakthrough. Flushing is required if the carbon filter is not used for several days, and regular backwashing may be required to prevent bacterial growth [1].

Waste Disposal Disposal of spent media is typically the responsibility of the contractor providing the media replacement or reactivation service. Backwash/flush water disposal is a required waste stream if it is included in the design of the filter [1].

Benefits

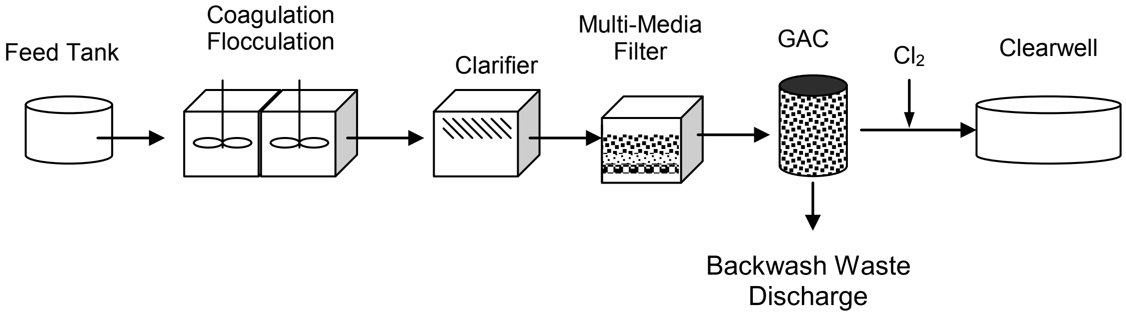
- Well established treatment technique
- Suitable for many organic chemicals, NOM, and trihalomethanes (THMs)
- Suitable for home use
- Able to improves taste and odor, and removes chlorine

Limitations

- Relatively expensive O&M cost for regeneration
- Effectiveness is based on contaminant type, concentration, rate of water usage, and type of carbon used
- Requires careful monitoring when nearing breakthrough times

3.0 Example Treatment Train

The GAC treatment train typically includes raw water pumps, debris screens, gravity filters, GAC units, chlorine disinfection, and clearwell storage.



4.0 Safety and Health Concerns

- Spent carbon may contain high levels of hazardous substances
- Regeneration by-products including toxic gases such as dioxins and furans[1]

5.0 References

1. American Water Works Association, and American Society of Civil Engineers. Water Treatment Plant Design. Ed. Edward E. Baruth. Fourth ed. New York: McGraw-Hill Handbooks, 2005.
2. Corbitt, Robert A. Standard Handbook of Environmental Engineering. Second ed. New York: McGraw-Hill Handbooks, 1999.
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Revision Date: 09/20/10

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Ion Exchange Treatment Technologies

Ion exchange (IX) treatment involves the exchange of an undesired dissolved ion for another less unfavorable ion that is attached to the IX resin. Water softening is the most common application of IX [1].

1.0 Applicable Contaminants

Ion Exchange is an EPA BAT for the following contaminants: barium, beryllium, chromium, copper, cyanide, lead, nitrate and nitrite, thallium, radionuclides, and uranium.

2.0 Description of Technology

Pretreatment Pretreatment prior to IX may be required to reduce excessive amounts of TSS which could plug the resin bed, and typically includes media or carbon filtration. Guidelines are available on accepted limits for pH, organics, turbidity, and other raw water characteristics [2]. These guidelines are based on the desired separation and contaminant present in source water.

Technology Description In solution, salts separate into positively charged cations and negatively charged anions. IX is a reversible chemical process in which ions from an insoluble, permanent, solid resin bed are exchanged for ions in water. The process relies on the fact that water solutions must be electrically neutral, therefore ions in the resin bed are exchanged with ions of similar charge in the water. As a result of the exchange process, no reduction in the total amount of ions is obtained, only an exchange. Operation begins with a fully recharged cation or anion resin bed, having enough positively or negatively charged ions to carry out the cation or anion exchange. A polymer resin bed is typically composed of medium sand grain sized, spherical beads. As water passes through the resin bed, the positively or negatively charged ions are released into the water, being substituted or replaced with the unwanted ions in the water (ion exchange). When the resin becomes exhausted of positively or negatively charged ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the unwanted ions with Na or K ions. Many different types of resins can be used to reduce specific or general dissolved contaminant concentrations. Cation IX is commonly termed water softening, Calcium and magnesium ions that cause scaling are removed from hard waters during water softening [1].

Waste Disposal Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated alkaline solution); occasional solid wastes (in the form of broken resin beads) which are backwashed during regeneration; and if utilized, spent filters.

Maintenance The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the unwanted ion concentration. Preparation of the NaCl (KCl) regenerating solution is required. If utilized, pretreatment filter replacement and backwashing will be required.

Benefits

- Acid addition, degasification, and repressurization is not required.
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.

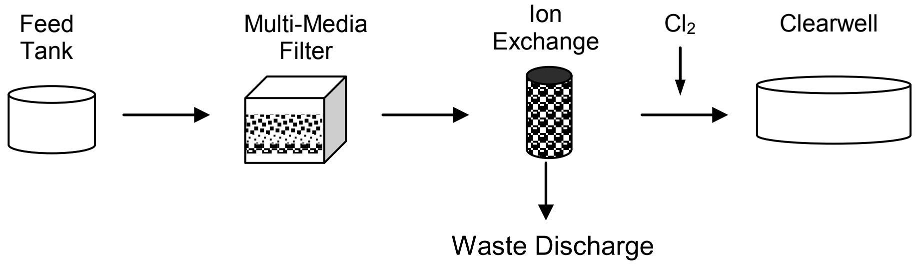
- Effective; widely used.
- Suitable for small and large installations.
- Variety of specific resins are available for removing specific contaminants.

Limitations mostly initial investment and land intensive.

- Pretreatment lime softening may be required.
- Requires salt storage; regular regeneration.
- Concentrate disposal.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.
- No Reduction in the total dissolved solid (TDS) concentration of treated water.
- Does not remove suspended solids.

4.0 Example Treatment Train

The IX treatment train typically includes raw water pumps, debris screens, gravity filters, cation or anion resin beds, chlorine disinfection, and clear well storage.



5.0 Safety and Health Concerns

No specific concerns.

6.0 References

[1] Water Treatment Plant Design, AWWA, 3rd edition, 1998
[2] Osmonics Pure Water Handbook, Osmonics, 2nd edition, 1997

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Revision Date: 09/20/10

Lime Softening

Lime softening is often used to reduce the hardness of water and sometimes to enhance clarification prior to filtration. Hardness is the sum of all multivalent ions, which for typical water treatment applications are mainly of calcium and magnesium. Water is considered to be hard if it contains 150 mg/L as $CaCO_3$ or more [1].

1.0 Applicable Contaminants

Lime Softening is an EPA BAT for the following contaminants arsenic, barium, beryllium, chromium (for Cr III only), copper, fluoride, lead, mercury, cadmium, nickel, and radionuclides.

2.0 Description of Technology

The origin of lime softening dates back to 1841 when lime was added to Thames River water to reduce bicarbonate hardness by precipitation of calcium alkalinity as calcium carbonate and magnesium alkalinity as magnesium hydroxide. Modern day lime softening, referred to as the cold lime process, operates under the same principle.

The softening process typically includes pretreatment, softening, recarbonation, and filtration steps.

Pretreatment Pretreatment consists of either aeration or presedimentation. Aeration is necessary with waters that have high CO_2 concentrations, such as ground water. Presedimentation is used with very turbid surface waters, in order to create a more consistent feed water quality.

Technology Description In the softening step, the first chemical addition is quick lime, or CaO, which combines with H_2O to form calcium hydroxide, or $Ca(OH)_2$. The calcium in the water then reacts with CO_2 to form a calcium carbonate ($CaCO_3$) precipitate. The optimum pH for this process is about 10.3. Magnesium precipitation in the form of magnesium hydroxide, $Mg(OH)_2$, requires a pH of 11.0 to 11.3. This pH can be obtained by using additional lime.

Solids contact clarifiers combine mixing, flocculation and sedimentation in a single basin and are commonly used for lime softening. Raw water and chemicals mix with previously formed lime slurry in a centrally located draft tube with impeller. Quick lime is usually in the form of pebbles, which need to be slaked with mixing equipment. Slaking creates a mixture of 2 parts water and 1 part lime slurry in a separate facility, which is then fed to the solids contact clarifier along with the addition of a coagulant. The coagulant could be iron based (ferric sulfate, ferrous sulfate) or aluminum based (aluminum sulfate or sodium aluminate). Sodium aluminate is the preferred coagulant if the feed water contains high sulfate concentrations. The water depths in solids contact clarifiers usually range from 14 to 19 ft, and contact time is typically 15 to 30 min.[1] Surface loading rates typically range from 1.0 to 1.75 gpm/ft^2. If coagulation for turbidity removal is required the surface loading rate is usually on the lower end of this range.[1]

The water then passes through distinct zones within the basin for reaction, flocculation and clarification. Clarified water is collected in radial effluent launders which direct the flow to an effluent discharge pipe. Solids in the clarification zone settle to the bottom of the basin and are moved to the center by a rotating sludge rake.

Effluent pH from the lime softening process is around 10 to 11. A pH adjustment is required to reduce the pH to around 8. The pH adjustment is particularly important when using MF membranes since high pH water may induce scaling on membrane surfaces. The pH adjustment is performed by injecting sulfuric or hydrochloric acid into the effluent stream with a metering pump. Sulfuric acid is preferred over hydrochloric due to the lower dosages and costs required.

Soda ash (Na_2CO_3) can then be added to remove non-carbonate hardness, in a process known as second stage softening, which is prior to filtration as well.

Recarbonation

After softening is complete, the water must be recarbonated with CO_2 in order to stabilize the water and bring the water up to a minimum calcium hardness. This is performed prior to filtration, and the typical target concentration of bicarbonate alkalinity is 40 mg/L.[1]

Filtration

Conventional media filters are traditionally used after lime softening to capture remaining suspended solids in the lime softening effluent. However, membrane technology is rapidly gaining popularity as an alternative to media filters due to their higher removal efficiencies of microorganisms. The lime softening process typically produces a 1% lime sludge waste stream.

Maintenance A routine check of chemical feed equipment is necessary several times a day to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which can cause plugging and malfunction. Similar procedures also apply to the sludge disposal return system, which takes the settled sludge from the bottom of the clarifier and conveys it to the dewatering and disposal processes.

Waste Disposal The solids content of the sludge produced by the lime softening process is about 2% to 15% by weight. Dewatering of the sludge must take place in order to properly dispose of the solids. The dewaterability of the sludge depends on its magnesium hydroxide content. A low magnesium hydroxide content sludge can be dewatered to 60% solids, but a high magnesium hydroxide content can only be dewatered to 20 to 25% solids.

The total amount of dry weight solids that is produced by the excess lime softening process is about 2.5 times the hardness that is removed, and 2.0 times for the straight lime process.[1] Some lime sludges may be recycled by reclacination if the sludge is of sufficient quality[2]. The lime sludge can be permanently lagooned, landfilled after dewatering, or used for fill in strip mine areas or borrow pits[2].

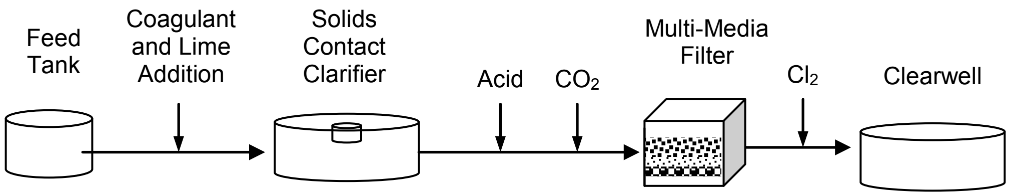
Benefits

- Reduces dissolved minerals and scale forming tendencies
- Removes heavy metals, such as arsenic
- Removes radium 226 and 228
- Removes certain organic compounds and NOM
- Removes inorganic compounds such as: silica, iron and manganese
- Reduces turbidity
- A proven and reliable treatment process
- Little or no pretreatment required

Limitations

- Operator care required with chemical handling
- Produces high sludge volume
- Filtration is usually required after lime treatment
- Waters high in sulfate may cause significant interference with removal efficiencies

3.0 Example Treatment Train



4.0 Safety and Health Concerns

- Chemical storage and handling (acids, bases, lime, etc.)
- Sludge production hazards (base)

5.0 References

1. American Water Works Association, and American Society of Civil Engineers. Water Treatment Plant Design. Ed. Edward E. Baruth. Fourth ed. New York: McGraw-Hill Handbooks, 2005.
2. Corbitt, Robert A. Standard Handbook of Environmental Engineering. Second ed. New York: McGraw-Hill Handbooks, 1999.
3. Perry, Robert H., Don W. Green, and James O. Maloney. Perry's Chemical Engineers Handbook. Seventh ed. New York: McGraw-Hill, 1997.

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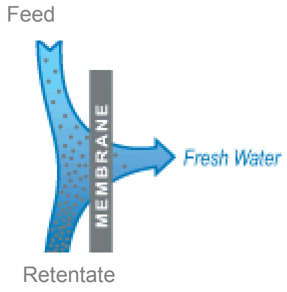
Microfiltration (MF) and Ultrafiltration (UF)

Microfiltration (MF) and Ultrafiltration (UF) are filtration processes that operation on a physical sieving separation process. They are best used for the removal of suspended solids, *Giardia*, C*ryptosporidum* and the reduction of turbidity. They are also used as a pretreatment to desalination technologies such as nanofiltration and reverse osmosis.



1.0 Applicable Contaminants

Both MF and UF are not currently listed as a BAT, but are widely used in the industry.

2.0 Description of Technology

MF has the largest pore size (0.1 – 3 microns) of the wide variety of membrane filtration systems. UF pore sizes range from 0.01 to 0.1 micron. In terms of pore size, MF fills in the gap between ultrafiltration and granular media filtration. In terms of characteristic particle size, this MF range covers the lower portion of the conventional clays and the upper half of the range for humic acids. This is smaller than the size range for bacteria, algae and cysts, and larger than that of viruses. MF is also typically used for turbidity reduction, removal of suspended solids, giardia and cryptosporidum. UF membranes are used to remove some viruses, color, odor, and some colloidal natural organic matter [1]. Both processes require low transmembrane pressure (1–30 psi) to operate, and both are now used as a pretreatment to desalination technologies such as reverse osmosis, nanofiltration, and electrodialysis [1].

MF membranes can operate in either crossflow separation or dead-end filtration. Cross flow separation is where only part of the feed stream is treated and the remainder of the water is passed through the membrane untreated. In dead-end separation, all of the feed water is treated. There are also two pump configurations, either pressure driven or vacuum-type systems. Pressure driven membranes are housed in a vessel and the flow is fed from a pump. Vacuum-type systems are membranes submerged in non-pressurized tanks and driven by a vacuum created on the product side. Typical recoveries can range from 85% to 95% [2]. Flux rates range from 20 to 100 gpd/ft^2 depending on the application. Backwashes are usually carried out for short durations (3 to 180 s) and occur in relatively frequent intervals (5 min to several hours) [2]. The frequency and duration depend on the specific application. A clean in place (CIP) can also be performed as a periodic major cleaning technique. Typical cleaning agents are sodium hypochlorite, citric acid, caustic soda and detergents. They can be initiated manually, and automatically controlled. CIP's occur when backwashing and chemically enhanced backwashes are not sufficient enough.

Factors influencing membrane selection are, cost, percent recovery, percent rejection, raw water characteristics, and pretreatment requirements.

Factors influencing performance are raw water characteristics, trans-membrane pressure, temperature, and regular monitoring and maintenance.

Pretreatment A self backwashing 100 um strainer is often necessary to protect the membranes and moderate particulate loading. Depending on the raw water, a coagulant such as ferric chloride may be added to form pinfloc and help improve rejection.

Maintenance It is necessary to monitor filtrate turbidity to give a rough indication of membrane integrity. Membrane integrity can be tested through a pressure decay test. In this test, pressurized air is applied to the membranes at a pressure less than would cause the air to flow through the membrane, and the pressure decay is measured. Regular monitoring of membrane performance is necessary to ensure the membrane system is operating at the most effective loading rate and backwash regime. Membrane life is typically estimated at 7+ years with manufacturer warranties covering 5 years.

Waste Disposal Waste includes pretreatment waste, backwash flow, retentate flow (if applicable), and CIP waste. Waste streams are either discharged to the sewer or treated if discharging to surface waters. Waste streams being discharged to surface waters are typically processed for turbidity removal through settling ponds or other treatment systems. CIP waste is neutralized and usually combined with the rest of the waste.

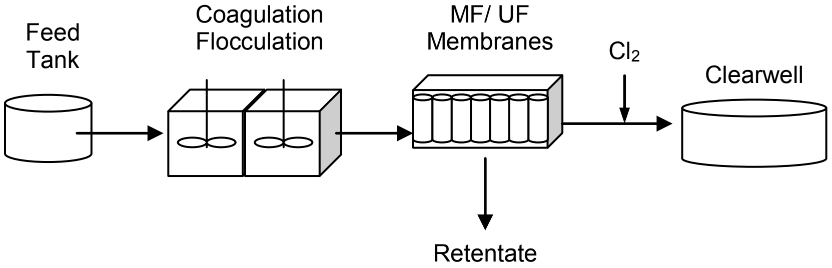
Benefits

- A low pressure process
- Can typically produce water of satisfactory turbidity with feed waters exceeding 100 NTU.
- MF and UF can receive state removal credits for *Giardia* and viruses up to 3 log and 4 log, respectively. However, virus removal is typically 0.5 log or less due to the smaller pore size of MF and UF.[3]

Limitations

- Membrane integrity and testing protocols are still under development.
- Some regulatory agencies are slow to accept MF applications.

3.0 Example Treatment Train



4.0 Safety and Health Concerns

- Concerns with high water pressures
- Electrical concerns

5.0 References

1. Trussell Technologies. "Desalination Technologies". Pasadena, 2008. Trussell Technologies. 6/11/2008. <http://www.trusselltech.com/tech_desalination.asp>.
2. American Water Works Association, and American Society of Civil Engineers. Water Treatment Plant Design. Ed. Edward E. Baruth. Fourth ed. New York: McGraw-Hill Handbooks, 2005.
3. United States Environmental Protection Agency (2005). Technologies and Costs Document for the Final Long Term 2 Enhanced Surface Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule. Office of Water, United States Environmental Protection Agency.

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Revision Date: 09/20/10

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Chemical Oxidation

Chemical oxidation is a method of removing metals by changing the oxidation state to make them less soluble in water. Chemical oxidation can also be used to inactive bacteria and viruses in drinking water.

1.0 Applicable Contaminants

Cryptosporidium & Giardia Oxidation is an EPA listed BAT
Chemical oxidation can be used to remove iron, manganese, sulfur, color, tastes, odor, and synthetic organic chemicals. Chemical oxidation is also an EPA listed BAT for the removal of *Cryptosporidium* and *Giardia* and is often used for virus inactivation.

2.0 Description of Technology

Pretreatment No pretreatment is required for oxidation.

Technology Description Chemical oxidation relies on oxidation/reduction reactions which consist of two half reactions: the oxidation reaction in which a substance loses or donates electrons, and a reduction reaction in which a substance accepts or gains electrons. Oxidation and reduction reactions will always occur together since free electrons cannot exist in solution and electrons must be conserved [1]. Oxidants commonly used in water treatment applications include chlorine, chlorine dioxide, potassium permanganate, oxygen/air, and ozone. The appropriate oxidant for a given application depends on many factors including raw water quality, specific contaminants present in the water, and local chemical and power costs [1]. Oxidation can be used to form hydroxides of some metals such as iron and manganese, causing them to precipitate from the feed water. For other constituents, such as organic chemicals, oxidation can degrade contaminants.

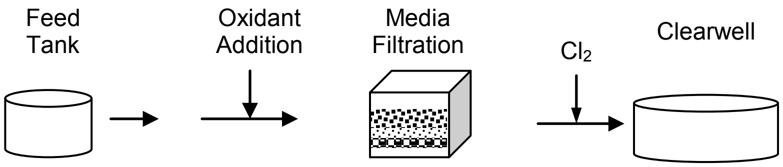
Waste Disposal No waste is generated from oxidation processes.

Maintenance Periodic calibration and maintenance of chemical meter pumps is required.

Benefits Chemical oxidation is well established. reliable, and requires minimal equipment.

Limitations Chemical dosing and metering is required. Chemical costs may be high. Oxidation with some chemicals may cause DBP formation.

3.0 Example Treatment Train



4.0 Safety and Health Concerns

Personal protective equipment is required for handling oxidizing agents.

5.0 References

1. AWWA Water Treatment Plant Design. New York, McGraw-Hill, 2005.

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Revision Date: 09/30/09

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Ozone

Ozone is a strong oxidant and is primarily used as a disinfectant.

1.0 Applicable Contaminants

Ozone is used as a disinfectant and is sometimes used to oxidize metals such as iron and manganese and some organic chemicals. Ozone has been used in industrial applications to remove phenols, cyanides, and heavy metals.

2.0 Description of Technology

Technology Description
Ozone is a good choice for the disinfection because ozone rapidly degrades to oxygen leaving no toxic residuals and oxygen levels in the ozone treated water are often at saturation. Current research is focused on characterizing byproducts from the use of ozone. The reaction of ozone with pesticides may produce a more toxic material. The reaction of ozone and organic chemicals often produces a more biodegradable compound [1].

Ozone is relatively unstable, having a half life of 20 to 30 minutes in distilled water at 20°C. The presence of oxidant demanding materials in solution can further reduce the half life. Ozone cannot be stored and therefore, must be generated on-site. The two most common methods for ozone generation are corona-discharge and ultraviolet ozone generation. In the UV method, air passes over the UV lamp which splits oxygen molecules into O^- atoms. O^- atoms are highly unstable and will react with O_2 molecules to form ozone, O_3. This method is limited to smaller applications. For larger applications, the corona discharge method is used. In this method, dehumidified air is passed through an electric field. The electrical current splits oxygen molecules into O^- atoms, which combine with oxygen molecules to form ozone.

Waste Disposal There is no waste produced from the generation of ozone or the addition of ozone as a disinfectant in water treatment applications.

Maintenance Routine maintenance is required on the ozone generation and dosing systems.

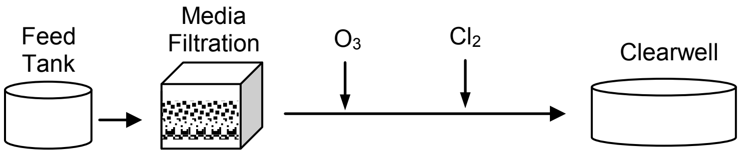
Benefits

- Good technology for wastewater applications
- Ozone rapidly degrades to oxygen; therefore, no toxic residuals are generated

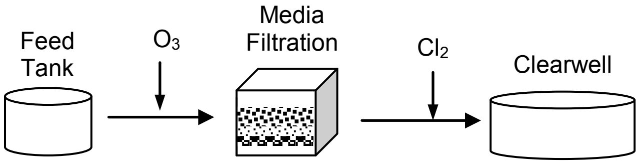
Limitations

- Potential byproduct formation
- No residual for secondary disinfection
- Conditioned, dehumidifier required

3.0 Example Treatment Trains



Used as a disinfectant.



Used as an oxidant

4.0 Safety and Health Concerns

No specific health and safety concerns are associated with the use of ozone for water treatment applications.

5.0 References

1. Reynolds, T. D., Richards, P.A., Unit Operations and Processes in Environmental Engineering, 2nd Edition, Boston, MA: PWS Publishing Company, 1996.

2. Water Treatment Plant Design, AWWA, 4th Edition, 2005

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Revision Date: 09/20/10

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

Alkalinity Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Chemical Data Alkalinity is the quantitative capacity of water to neutralize an acid. In practice, alkalinity is determined as the amount of strong acid needed to titrate a water sample to a pH of 4.7 [1]. Alkalinity is the sum of the strong bases minues the sum of strong acids in water, therefore, alkalinity can be either positive or negative. If the concentration of strong acids exceeds the concentration of strong bases, alkalinity is negative [2]. Water does not have to be strongly basic (high pH) to have high alkalinity. Total alkalinity, typically expressed as $CaCO_3$ equivalent, is the sum of HCO_3^-, CO_3^{2-}, HPO_4^{2-}, PO_4^{3-}, $H_3SiO_4^-$, $H_2BO_2^-$, CH_3COO^-, OH^- minus H^+. The constituents of alkalinity commonly found in drinking water applications are: HCO_3^-, CO_3^{2-}, and OH^-. Bicarbonate (HCO_3^-) in surface waters at neutral pH is typically >95% of the total alkalinity. There are three different tests used for measuring alkalinity, usually performed in this order: pH (to obtain OH- alkalinity), phenolphthalein test (to obtain OH- and CO3-2 alkalinity), and methyl orange test (to obtain total alkalinity). In most waters, alkalinity and hardness (the concentration of divalent ions) have similar values because HCO_3^- and CO_3^{2-} are usually derived from $CaCO_3$ or $MgCO_3$.

Source in Nature In the environment, alkalinity in the soil (limestone) and ground and surface waters is a combination of the naturally occurring alkalis: CO_3^{2-}, HCO_3^-, and OH^- salts of Ca, Mg, K, and Na. Most natural waters have an alkalinity in the range of 10 to 500 mg/L. Wastewater is normally alkaline, receiving alkalinity from the water supply, ground water, and materials added during domestic use including detergents and soap-based products which are alkaline. Acid rain also contributes to the alkalinity of waters.

SDWA Limits Alkalinity is not a primary or a secondary drinking water contaminant. No federal limits exist.

Health Effects Alkalis, when dissolved in water, create a bitter taste and a slippery feel. Highly alkaline waters, above pH 7.0, can cause drying of the skin. Alkalinity is important for fish and aquatic life because it protects or buffers against rapid pH changes and makes water less vulnerable to acid rain, protecting a major source of human consumption.

Removal Techniques

USEPA BAT BAT's are not assigned to secondary contaminants.

Alternative Methods of Treatment Generally, there are three processes for reducing alkalinity: nanofiltration, lime softening, Cl- anion exchange (dealkalization), and weak acid cation exchange (dealkalization).

- **Nanofiltration** NF uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or divalent ions, to pass through the membrane. *Benefits*: produces high degree and consistent alkalinity removal, along with high quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.

- **Lime Softening** Lime softening to reduce alkalinity results in a partial reduction of water hardness, and uses controlled amounts of $Ca(OH)2$ in sufficient quantity to raise the pH to about 10 to precipitate $CO3-2$ hardness, after which the precipitated alkalinity is filtered out. The precipitated alkalinity is then removed as a sludge. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal

- **Ion Exchange** Anion IX to reduce alkalinity uses charged anion resin to exchange acceptable ions from the resin for the undesirable alkalinity in the water. *Benefits*: acid addition, degasification, and repressurization is not required; effective; well developed. *Limitations*: pretreatment lime softening may be required; restocking of regenerate supply; regular regeneration; concentrate disposal.

  Cation IX to reduce alkalinity uses charged cation resin to exchange acceptable ions from the resin for hardness ions (Ca and Mg) plus some of the undesirable alkalinity in the water. *Benefits*: most suitable for low flows. *Limitations*: requires a hardness-to-alkalinity ratio greater than 1.

References

[1] Benjamin, Mark. Water Chemistry. New York: McGraw-Hill, 2002.
[2] Hemond, Harold, and Elizabeth Fechner-Levy. Chemical Fate and Transport in the Environment, 2nd Edition. San Diego, California: Elsevier Science, 2000.

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Revision Date: 09/30/09

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
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Antimony Fact Sheet

Contaminant Data

Sb

Chemical Data Antimony (Sb) is a member of the group 5A elements; atomic number: 51, atomic weight: 121.75, is a silvery-white, brittle, semimetallic element. It exists mainly as Sb(III) and Sb(V). Antimony is similar to arsenic in chemical properties and toxicity; however, its behavior in the environment, removal characteristics, and solution chemistry are different. Antimony is commonly found in natural deposits as ores containing other metals [1]. Antimony oxides are amphoteric, meaning they can react as either an acid or a base [2].

Source in Nature Antimony occurs in the environment as a result of natural processes and human activities. Antimony trioxide is used as a flame retardant and is found in batteries, pigments, ceramics, and glass [1]. It is found at very low levels throughout the environment, the general population is exposed to low levels of it everyday, primarily in food, drinking water, and the air. More antimony is found in food and air than water. The major sources of antimony in drinking water result from discharges from petroleum refineries, fire retardants, ceramics, electronics, and solder [1]. Exhausts from oil fuels are the main sources of antimony in urban air, where it eventually finds its way to lakes and streams, adhering to the sediments. Antimony trioxides are also released into the atmosphere by factories that convert antimony ores into metal by smelting, molding, and incineration of the antimony materials. Antimony may appear in water from corrosion of lead pipes and fittings, but is rarely detectable. Typical concentrations of dissolved antimony in non-polluted waters are less than 1.0 µg/L [3].

SDWA Limits MCLG/MCL for Sb is 0.006 mg/L. Issues with raw water antimony concentrations exceeding MCLs are rare.

Health Effects Antimony, in short-term exposure levels above the MCL: gastrointestinal disorders, nausea, vomiting, and diarrhea can occur. In long-term exposures at levels above the MCL: decreased longevity, cardiovascular problems, and altered blood levels of glucose and cholesterol can be expected [1]. Antimony is not known to be or classified as a carcinogen.

Removal Techniques

USEPA BAT Coagulation and filtration or reverse osmosis are BAT technologies for antimony removal [1].

Refer to individual treatment technique fact sheet for general treatment technology information.

- **Coagulation and Filtration** Coagulation and filtration uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration. Ferric chloride ($FeCl_3$) was observed to be most effective at pH 4.5 to 5.5 with some Sb removal obersved over the range of pH from 4.0 to 10.0. Aluminum sulfate $Al_2(SO_4)_3$ is much less effective and may not be practicle for Sb removal [4]. Sb(III) is more easily removed with coagulation than Sb(V), however, Sb(V) removal effiencies can be as high as 98% with sufficient concentraiton of coagulant at optimal pH [4]. ***Benefits***: low capital costs for proven, reliable process. ***Limitations***:

operator care required with chemical usage; sludge disposal, Sb(V) removal is impaired by the presence of phosphate and humic acid [4].

- **Reverse Osmosis** Reverse osmosis (RO) can be used to remove antinomy from water sources. Reverse osmosis can reject compounds by either size exclusion or charge. Approximatly 80% removal of Sb(V) can be achieved over the pH range 3 to 10. Sb(III) removal decreases with increasing pH. Removal efficiency of Sb(III) with RO is apprimately 30 to 60% [5]. *Benefits*: produces high quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.

References

1. US Environmental Protection Agency. Basic Information about Antimony in Drinking Water. http://water.epa.gov/drink/contaminants/basicinformation/antimony.cfm

2. John McMurry and Robert C. Fay (1998). Chemistry, 2nd Edition. Upper Saddle River, New Jersey: Prentice Hall.

3. Filella, M., N. Belzile, Y.W. Chen. Antimony in the environment: a review focused on natural waters: 1. Occurrence. Earth-Science Reviews, Volume 57, Issues 1-2. 2002.

4. Guo, X., Z. Wu, M. He. Removal of antimony (V) and antimony (III) from drinking water by coagulation-flocculation-sedimentation (CFS). Water Research, 43, 17, p. 4327-4335. 2009.

5. Kang, M., M. Kawasaki, S. Tamada, T. Kamei, Y. Magara. Effect of pH on the removal of arsenic and antimony using reverse osmosis membranes. Desalination, 131, p. 293-298. 2000.

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Revision Date: 09/22/10

RECLAMATION
Managing Water in the West
U.S. Department of the Interior
Bureau of Reclamation

Arsenic Fact Sheet

Contaminant Data

As

Chemical Data Arsenic (As), inorganic element, semi-metal, stable and sparingly soluble, atomic number 33, atomic weight 74.92. Inorganic oxidation states (in water): +3 (Arsenite—most toxic) and +5 (Arsenate). Arsenic has no taste, smell, or color in water.

Source in Nature Arsenic is a naturally occurring element found in soils, surface water, and groundwater. Arsenic is present in nearly all geologic materials at concentrations typically ranging from 1 to 5 ppm [1]. In the Western U.S., ground water with elevated arsenic concentrations is known to be associated with geothermal environments and areas with gold and uranium deposits [1]. Higher levels of arsenic tend to be found in groundwater sources than in surface water sources [2]. The Western States have more water systmes with arsenic levels greater than 10 ppb than the rest of the U.S. [2]. In industry, arsenic is used in the production of pesticides and herbicides, from cotton and wool processing, as a wood preservative, a feed additive, in various metal alloys, and in mining. Arsenic can result from pesticide runoff from seepages from hazardous waste sites. Arsenic is ingested by either drinking contaminated water, eating food that has been washed in the water, or ingestion in small doses by way of the human food chain.

SDWA Limits MCL for arsenic is 0.01 mg/L. MCLG is 0 mg/L for drinking water. See Arsenic Rule for more information [3].

Health Effects Arsenic is a known teratogen and carcinogen; poisoning can be either acute or chronic. Acute poisoning results from ingestion of large quantities of arsenic at one time and can result in stomach pain, nausea, vomiting, or diarrhea, which may lead to shock, coma, and even death. Chronic poisoning occurs over long periods of time and can often result in skin lesions, thickening or discoloration of the skin, and numbness in the feet and hands (neuritis). Arsenic poisoning has been linked to higher rates of cancer of the lungs, bladder, kidney, liver, and skin. Young children, the elderly, unborn babies, and people with long-term illnesses are at greater risk of arsenic poisoning.

Removal Techniques

Optimal arsenic removal is dependent on many individual water characteristics, including source water pH, TDS, sulfides, other salts, and amount of arsenic present. As^{+5} is most effectively removed, therefore As^{+3} may be converted through preoxidation with Cl_2, $FeCl_3$, or $KMnO_4$ to As^{+5}. Preoxidation with Cl_2 may create undesireable concentrations of disinfection by-products.

USEPA BAT Oxidation/Coagulation/Filtration, lime softening, reverse osmosis, ion exchange, greensand filtration, and activated alumina are BAT technologies for the removal of arsenic[4].

Refer to: individual treatment technique fact sheet if available for further information.

- **Oxidation/Coagulation/Filtration** This process involves the adsorption of contaminants to an aluminum or ferric hydroxide precipitate and removal of these particles by filtration. Coagulation and filtration uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration. $Fe_2(SO_4)_3$ has been proven to be the most effective coagulant for As^{+5} removal. *Benefits*: low capital costs for proven, reliable process. *Limitations*: operator care required with chemical usage; sludge disposal.

- **Lime Softening** Lime softening for arsenic treatment uses two types of chemical additions. First, $Ca(OH)_2$ is added in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness. Next, Na_2CO_3 is added to precipitate non-carbonate hardness. *Benefits*: proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal; high cost; may not be a cost-effective alternative for small systems.

- **Reverse Osmosis** RO uses a semipermeable membrane, and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids, to pass through the membrane. *Benefits*: produces highest As removal, along with high-quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.

- **Ion Exchange** Ion exchange is a proocess in which ions are swapped between the liquid phase and the solid resin phase. The solid resin adsorbs anions and releases an ion of similar valence into the water. *Benefits*: low cost, easy to operate. *Limitations*: removal of As(III) will require preoxidation to As(V) before ion exchange; regeneration results in creation of hazardous waste requiring disposal; other ions may competitively absorb; removal of multiple ions will require more frequent regeneration and careful monitoring to prevent breakthrough [4].

- **Greensand Filtration** Greensand filtration uses manganese-coated filter media to oxidize and adsorb contaminants. Arsenic removal by greensand requires a $pH > 6.8$. The presence of iron is beneficial to arsenic adsorption. *Benefits*: easy to operate, requires minimal operator attention and maintenance. *Limitations*: No specific limitations. [4].

- **Activated Alumina** Activated alumina (AA) uses extremely porous and highly adsorptive aluminum ore media to adsorb As^{+5}. AA is performs optimally at a pH of 6.0 to 6.5. *Benefits*: containment of As^{+5} in adsorption bed, low cost, easy to operate. *Limitations*: removal of As(III) will require preoxidation to As(V) before AA, regeneration results in creation of hazardous waste requiring disposal, other ions may competitively absorb, removal of multiple ions will require more frequent regeneration and careful monitoring to prevent breakthrough [4].

Alternative Treatment Alternative treatment technologies are effective for removal of arsenic, but not currently listed as BAT.

- **Iron-Oxide Coated Sand** Iron-oxide coated sand filtration is an adsorption process. Iron-oxide coated sand can be used in a fixed bed column to remove As^{+3} and As^{+5} from drinking water to levels less than 5 µg/L.

References

1. Jon Spencer. 2002. Natural Occurrence of Arsenic in Southwest Ground Water. Arizona Geological Survey.

2. US Environmental Protection Agency. Basic Information About the Arsenic Rule. http://water.epa.gov/lawsregs/rulesregs/sdwa/arsenic/Basic-Information.cfm

3. US Environmental Protection Agency. 2001. Arsenic and Clarifications to Compliance and New Source Monitoring Rule: A Quick Reference Guide. http://water.epa.gov/drink/info/arsenic/upload/2005_11_10_arsenic_quickguide.pdf

4. US Environmental Protection Agency. 2007. Removing multiple contaminants from Drinking Water: Issues to Consider.

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Revision Date: 09/22/10

Asbestos Fact Sheet

Contaminant Data

Chemical Data Asbestos consists of six different fibrous minerals (amosite, chrysotile, crocidolite, tremolite, actinolite, and anthophyllite) and occurs in natural deposits. Asbestos fibers are very strong and are resistant to heat, corrosion, thermal effects, and most chemicals. Asbestos fibers are very stable in the environment, do not evaporate into the air or dissolve in water, and are not biodegradable by aquatic organisms.

Source in Nature The primary sources of asbestos in drinking water are the decay of asbostos cement water mains and the erosion of natural asbestos deposits [1]. Because asbestos fibers are resistant to heat and most chemicals, they have been mined for use in more than 3,000 products, including roofing material, brake pads, and cement pipe often used in distributing water to communities.

SDWA Limits MCLG/MCL for asbestos is 7 million fibers per liter. (Fibers > 10 microns in length for MCLG). Issues with raw water asbestos concentrations exceeding MCLs are rare.

Health Effects Asbestos is a known carcinogen. No health advisories are established for short-term exposures. At levels above the MCL, asbestos has the potential to cause lung disease, Asbestosis (cancer of the lung tissue), Mesothelioma (cancer of the thin membrane surrounding the lung), and cancer to other internal organs from a lifetime exposure.

Removal Techniques

USEPA BAT Coagulation/filtration, direct filtration, or diatomaceous earth filtration

Refer to individual treatment technique fact sheets for further information.

- **Coagulation/Filtration** Coagulation and filtration uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration. Ferric chloride and polyelectrolytes used together with sand filtration can provide 99% removal of asbestos [2]. *Benefits*: low capital costs for proven, reliable process. *Limitations*: operator care required with chemical usage and sludge disposal.

- **Direct Filtration** Direct filtration is a process for separating solid particles from the liquid in which they are suspended using chemical addition, coagulation/flocculation, and dual media filtration. *Benefits*: proven; reliable. *Limitations*: initial investment.

- **Diatomaceous Earth** Diatomaceous earth filtration uses a thin coat of diatomaceous earth over a fabric to screen out particles. *Benefits*: significant savings in equipment cost and required space. *Limitations*: Does not remove smaller particles, such as viruses.

Alternative Methods of Treatment Corrosion control reduces the amount of asbestos in water by changing the water chemistry to reduce the asbestos solubility.

References

1. US Enviromental Protection Agency. Basic Information About Asbestos in Drinking Water. http://water.epa.gov/drink/contaminants/basicinformation/asbestos.cfm

2. Lawrence, J., H.M. Tosine, and H.W. Zimmermann. Removal of asbestos fibres from potable water by coagulation and filtration. Water Research, 9, p. 397-400. 1975.

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Revision Date: 09/22/10

RECLAMATION
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Barium Fact Sheet

Contaminant Data

Ba

Chemical Data Barium (Ba) , atomic number: 56, atomic weight: 137.327, oxidation state: +2, metallic element, soft, and when pure is silvery white similar to lead. Oxidizes very easily and is decomposed by water and alcohol.

Source in Nature Barium is a naturally occurring alkaline earth metal found primarily in the Midwest, in combination form with other chemicals such as sulfur or carbon and oxygen. Traces of the element are found in most surface and ground waters. It can also be produced by industry in oil and gas drilling muds, smelting of copper, waste from coal-fired power plants, jet fuels, and automotive paints and accessories. The primary sources of barium in drinking water are from dilling wastes (discharges from metal refineries) and erosion of natural deposits [1].

SDWA Limits MCL/MCLG for Ba is 2.0 mg/L. Barium concentrations exceeding MCLs in unpolluted water sources are rare.

Health Effects Long-term exposure to elevated barium concentration in drinking water may cause high blood pressure.

Removal Techniques

USEPA BAT Ion exchange, reverse osmosis, lime softening, and electrodialysis have been proven effective for removing barium to below 2 mg/L [1].

Refer to individual treatment technology fact sheets for further information.

- **Ion Exchange** Ion exchange for soluble barium uses a charged cation resin to exchange acceptable ions from the resin for undesirable forms of barium in the water. *Benefits*: effective; well developed. *Limitations*: requires restocking of salt supply; regular regeneration; concentrate disposal.

- **Reverse Osmosis** RO for soluble barium uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids (soluble barium), to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.

- **Lime Softening** Lime softening for soluble barium uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like barium. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal; insoluble barium compounds may be formed at low carbonate levels, requiring coagulation and flocculation.

- **Electrodialysis Reversal** EDR uses semipermeable membranes in which ions migrate through the membrane from a less concentrated to a more concentrated solution as a result of the ions' representative attractions to direct electric current. *Benefits*: contaminant-specific removal. *Limitations*: electrical requirements; concentrate disposal.

References

1. US Environmental Protection Agency. Basic Information About Barium in Drinking Water. http://water.epa.gov/drink/contaminants/basicinformation/basicinformation_barium.cfm

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Revision Date: 09/23/10

RECLAMATION
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Beryllium Fact Sheet

Contaminant Data

Be

Chemical Data Beryllium (Be), atomic number: 4, atomic weight: 9.01218, oxidation state: +2, a brittle, hard grayish metal. Some beryllium compounds have a sweet taste, but no particular smell. Some beryllium compounds are water soluble, but most are suspended.

Source in Nature Beryllium is found in compounds in silicate mineral rocks, coal, soil, and volcanic dust. Not found naturally in surface water, but enters waters by erosion from rocks and soil, and industrial waste by coal combustion from slag and ash dumps [1].

SDWA Limits MCL/MCLG for Be is 0.004 mg/L. Issues with unpolluted raw water beryllium concentrations exceeding MCLs are rare.

Health Effects Long tern exposure to elevated levels of beryllium in drinking water may cause intentinal lesions, and damage to the bones and lungs. There is limited evidence to suggest that beryllium may pose a cancer risk to humans via drinking water exposure [2].

Removal Techniques

USEPA BAT Activated alumina, coagulation and filtration, ion exchange, lime softening, and reverse osmosis have been shown to reduce beryllium concnetrations to below 0.004 mg/L.

Refer to individual treatment technology fact sheet for further information.

- **Activated Alumina** AA uses extremely porous and highly adsorptive aluminum ore media to adsorb beryllium. *Benefits*: containment of beryllium in adsorption bed. *Limitations*: when used with Be^{+4}, results in creation of hazardous waste requiring disposal.
- **Coagulation/Filtration** Coagulation and filtration use the conventional treatment processes of chemical addition, coagulation, and dual media filtration. *Benefits*: low capital costs; proven, reliable process. *Limitations*: operator care required with chemical usage; sludge disposal.
- **Ion Exchange** IX for soluble beryllium uses charged cation resin and exchanges acceptable ions from the resin for undesirable forms of beryllium in the water. *Benefits*: effective; well developed. *Limitations*: restocking of salt supply; regular regeneration; concentrate disposal.
- **Lime Softening** Lime softening for soluble beryllium uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like beryllium. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal; insoluble beryllium compounds may be formed at low carbonate levels requiring coagulation and flocculation.

- **Reverse Osmosis** RO for soluble beryllium uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids (soluble beryllium), to pass through the membrane. ***Benefits***: produces high quality water. ***Limitations***: cost; pretreatment/feed pump requirements; concentrate disposal.

References

1. US Environmental Protection Agency. Basic Information About Beryllium in Drinking Water. http://water.epa.gov/drink/contaminants/basicinformation/beryllium.cfm
2. New Hampshire Department of Environmental Services. Environmental Fact Sheet. 2007. http://des.nh.gov/organization/commissioner/pip/factsheets/dwgb/documents/dwgb-3-3.pdf

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Revision Date: 09/30/09

RECLAMATION
Managing Water in the West

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Biological: Cryptosporidium and Giardia Fact Sheet

Contaminant Data

Chemical Data *Cryptosporidium parvum* and *Giardia lamblia* are waterborne, pathogenic, parasitic, single-celled, animal-like organisms called protozoa. Both species are resistant to adverse environmental factors and can survive months under optimum environmental conditions. *Cryptosporidium* and *Giardia* are generally resistant to most chemical disinfectants, like chlorine or iodine, at usual treatment doses, contact times, temperature, and pH.

Source in Nature *Cryptosporidium* and *Giardia* are parasitic disease-producing organisms commonly found in the environment. The most common sources of *Cryptosporidium* and *Giardia* in the environment are sewage treatment plant discharge, municipal storm sewer discharge, runoff from manure storage, feedlots, livestock operations, and livestock manure entering streams. Cattle are a major source of *Cryptosporidium*; however, it can also be found a number of other types of animals including raccoons, beaver, mice, birds, and deer. Treatment plant process contamination can occur as a result of filter breakthrough; improper coagulation; use of recycled, concentrated backwash water; process overload; or improper maintenance. Distribution system contamination can occur as a result of cross-connection, broken or leaking waterlines, or back-siphonage.

SDWA Limits The MCLG for *Cryptosporidium* and *Giardia* is 0 cysts/oocysts per 100 mL sample of finished drinking water, using the Presence/Absence rule procedures for indicator organisms. The LT1ESWTR and IESWTR require 2-log removal of *Cryptosporidium* for systems using filtration. Unfiltered systems must update their watershed control programs to minimize the potential for contamination by *Cryptosporidium* oocyst. The LT2ESWTR requires additional monitoring of source water to determine if a source is vulnerable to contamination and may require additional treatment. Under this rule, filtered and unfiltered systems must conduct 24 months of source water monitoring for *Cryptosporidium*. Installation of additional treatment may be required for both filtered and unfiltered systems if *Cryptosporidium* is detected in the source water. The LT2ESWTR implemented a bin classification for filtered systems. See the following table:

Cryptosporidium Concentration (oocysts/L)	Bin Classification	Additional Cryptosporidium Treatment Required			Alternative Filtration
		Conventional Filtration	Direct Filtration	Slow Sand or Diatomaceous Earth Filtration	
< 0.075	Bin 1	No additional treatment required	No additional treatment required	No additional treatment required	No additional treatment required
0.075 to < 1.0	Bin 2	1 log	1.5 log	1 log	(1)
1.0 to < 3.0	Bin 3	2 log	2.5 log	2 log	(2)
≥ 3.0	Bin 4	2.5 log	3 log	2.5 log	(3)

(1) As determined by the state (or primary agency) such that the total removal/inactivation > 4.0-log
(2) As determined by the state (or primary agency) such that the total removal/inactivation > 5.0-log
(3) As determined by the state (or primary agency) such that the total removal/inactivation > 5.5-log

The following table describes the inactivation requirements for unfiltered systems:

Cryptosporidium Concentration (oocyst/L)	Required *Cryptosporidium* Inactivation
≤ 0.01	2-log
> 0.01	3-log

Health Effects Cryptosporidiosis and Giardiasis are contagious waterborne diseases characterized by acute gastrointestinal illness, including diarrhea and abdominal discomfort, fever, weight loss, malabsorption, or anemia. Although not life threatening to healthy adults, both diseases can be fatal to infants, the elderly, pregnant women, and immuno-compromised persons. Both diseases are transmitted through fecal-oral ingestion of the cysts/oocysts, through direct ingestion (i.e. drinking), primary contact recreation (i.e. swimming), or secondary contact (i.e. fishing).

Removal Techniques

USEPA BAT For community surface and ground water (under the direct influence of surface water) systems, treatment technique is applied. In this case, the accepted treatment techniques are as follows: enhanced coagulation and media filtration, direct filtration, slow sand filtration, and diatomaceous earth filtration. Refer to individual treatment technique fact sheet for further information.

Alternative Methods of Treatment

Treatment Technologies - Membranes can also be used to remove *Cryptosporidium* and *Giardia* from drinking water and are considered acceptable for treatment credit under the LT2ESWTR.

Source Water Management - Raw water quality can be improved through complex planning of waste treatment/disposal methods, public watershed, and land management, especially during periods of high precipitation or heavy runoff. Improving well casing/sealing or drilling deeper wells can also improve ground water quality.

Point of Use - Boiling water for 1 minute (5 minutes at higher elevations) is the traditional POU treatment method. Bottled water may be used, although is not regulated for testing for microbial contaminants.

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Revision Date: 09/30/09

Biological: Total Coliform and E-Coli Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Chemical Data Fecal bacteria are single-celled microorganisms, virtually always associated with fecal contamination of water, but not always harmful. Fecal indicator bacteria are used in determining (indicating) the microbial quality of water. Total coliform bacteria and fecal coliform *Escherichia coli* 0157:H7 (E-Coli) are two types of fecal indicator bacteria. Total coliform bacteria, a particular group of waterborne microbiological contaminants regulated by the SDWA, is the most common indicator organism applied to drinking water. E-Coli is one type of pathogenic fecal coliform bacteria, and the most common facultative, disease-causing bacteria in the feces of warm-blooded animals.

Source in Nature By definition, several bacteria can be classified as coliform and are commonly found in soil, on the surface of leaves, in decaying matter, and can grow in water distribution mains. These types of coliform bacteria are not fecal contamination related and do not necessarily indicate unsafe water. The fecal coliform bacterium, E-Coli, occurs naturally in the intestines and feces of most warm-blooded animals, including humans, and when found in water is a direct result of fecal contamination. Almost all surface waters contain some bacteria, while ground waters are generally free of bacteria unless under the direct influence of surface water. Surface and ground water contamination can occur as a result of surface runoff through urban areas, woodlands, pastures, or feedlots; on-site septic tank/sewage disposal system leakage/failure; sewage treatment plant/disposal system overload or malfunction; or raw sewage deep well injection. Treatment plant process contamination can occur as a result of filter breakthrough; improper coagulation; use of recycled, concentrated backwash water; process overload; or improper maintenance. Distribution system contamination can occur as a result of cross-connection, broken or leaking waterlines, or back-siphonage.

SDWA Limits The TT MCLG for both total coliform and E-Coli is 0 mg/L. The total coliform MCL is less than 5% of the samples may be positive (for >40 samples/month) and less than one sample may be positive (for <40 samples/month). If a total coliform sample is positive, two consecutive daily check samples are required. This daily check sample also requires analysis for E-Coli., the Positive Repeat Sample criteria is applied for MCL. Sampling frequency and quantity is determined by the population size the system serves (see rule for details).

Health Effects Self-limiting effects of bacterial ingestion include abdominal cramps and diarrhea. Hemorrhagic colitis (HC) is the acute disease caused by E-Coli. HC results in severe abdominal cramps, watery diarrhea, and lower intestinal bleeding with occasional vomiting and fever. In some cases, hemolytic uremic syndrome or renal failure can occur. Although not life threatening to healthy adults, these diseases can be fatal to young children, the elderly, and immunocompromised persons. E-Coli is transmitted through fecal-oral ingestion of the bacteria by direct ingestion (i.e. drinking), primary contact recreation (i.e. swimming), or secondary contact (i.e. fishing).

Removal Techniques

USEPA BAT For community surface and ground water (under the direct influence of surface water) systems, a treatment technique is applied. In this case, the accepted TT is use of the conventional treatment processes filtration and disinfection. *Benefits*: proven; reliable. *Limitations*: initial investment. Refer to individual treatment technique fact sheets for further information

Alternative Methods of Treatment Through proper siting of wells and waste disposal systems, manage, find, or eliminate the source of the contamination. Improving well casing/sealing or drilling deeper wells can improve groundwater quality. Distillation is effective. UV, ozone, and iodine can be effective disinfection methods. Boiling water for 1 minute (5 minutes at higher elevations) is the traditional POU treatment method. Bottled water may be used, although it is not regulated for testing for microbial contaminants. Raw water quality can also be improved through complex planning of waste treatment/disposal methods, public watershed, and land management, especially during periods of high precipitation and heavy runoff.

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Revision Date: 09/30/09

RECLAMATION
Managing Water in the West
U.S. Department of the Interior
Bureau of Reclamation

Biological: Viruses Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheets.

1.0 Contaminant Data

General Information Viruses are a major class of microorganisms but lack many of the attributes of cells. Only when a virus infects a cell does it acquire the ability to reproduce [1]. Some viruses, such as the Norwalk virus and those that cause infectious hepatitis, poliomyelitis, meningitis, and gastroenteritis, can be waterborne. Viruses range in size from 0.01 to 0.1 µm (or 20,000 to 200,000 Daltons) [2].

Source in Nature Waterborne viruses can be found in the feces of infected people and animals. Ground water and surface water supplies that are exposed to wastewater seepages or discharges can become contaminated by viruses [3]. More than 50% of waterborne disease outbreaks in the United States are due to the consumption of contaminated groundwater [4]. Viruses can travel in water and through soil to contaminate drinking water supplies. Human enteric viruses are the most common viruses in drinking water supplies. These viruses are able to exist for extended periods of time in the environment and may survive through conventional water and wastewater treatment processes [5].

SDWA Limits The MCLG for viruses is zero. Additionally, all public treatment systems using surface water or ground water under directed influence of surface water must ***filter*** and ***disinfect*** their water to achieve 99.99%, or 4-log removal/inactivation of viruses [6].

Health Effects Health effects from viruses in drinking water include diseases such as hepatitis and gastroenteritis. Some of the symptoms of the waterborne viral infections include nausea, vomiting, diarrhea, abdominal pain, weakness, and fever. Symptoms usually occur within 4 to 48 hours after consumption of contaminated water. No specific treatment is available for those infected. People who become severely dehydrated as a result of their illness may require rehydration therapy [7]. Not all waterborne outbreaks are reported or traced back to a water supply, therefore there is probably significantly more illness in the population due to viral contamination than is recognized [5].

2.0 Removal Techniques

USEPA BAT: **Filtration** The following treatment technologies are considered BAT for virus removal [8]:

- **Conventional Filtration (and specific variations)** Enhanced coagulation and media filtration for removal/inactivation of viruses includes coagulation, flocculation, sedimentation, and filtration. Benefits: proven technology, low cost. Limitations: Operator care required, sludge disposal.
- **Direct Filtration** Direct filtration includes coagulation and filtration, but excludes sedimentation. Benefits: proven technology, low cost. Limitations: generates sludge for disposal and requires operator care.
- **Slow Sand Filtration** Slow sand filtration is a physical and biological process in which removal/inactivation of viruses is possible. Benefits: simple and cost-effective. Limitations: requires low particulate concentrations in feed water.

- **Diatomaceous Earth Filtration** Diatomaceous earth is another type of filtration approved for removal/inactivation of viruses. Benefits: simple to operate, low cost. Limitations: Continual monitoring of filter effluent turbidity and pressure loss through filters [9].

Alternative Filtration Methods

- **Membranes** Membrane treatment including ultrafiltration, nanofiltration, and reverse osmosis can be used to physically separate viruses from the water. Benefits: produces high quality water, can effectively treat a wide range of contaminants. Limitations: relatively expensive to install, frequent monitoring required.

- **Filters** Cartridge filters and bag filters can also be used to physically separate viruses from the water. Benefits: inexpensive, easy to maintain. Limitations: variable virus removal, disinfection required for virus removal credit, requires frequent monitoring and replacement of spent filters.

USEPA BAT: **Disinfection** The following disinfection treatment technologies are considered BAT for virus removal [8]. Please refer the technology fact sheets for more information.

- **Free Chlorine** Chlorine is dosed into the water in the form of sodium hypochlorite, calcium hypochlorite, or chlorine gas. Benefits: proven technology, low cost. Limitations: generation of disinfection by-products (DBP), requires special handling and storage.
- **Ozone** Ozone works as an oxidant to damage microbial species. Benefits: less corrosive than chlorine in water and does not affect pH. Limitations: high cost, more difficult to install and use, potential for DBP formation, no residual.
- **Chloramines** The addition of chlorine and ammonia to water produces chloramines that are used for disinfection. Benefits: More stable than chlorine, easier to maintain required residual, less DBP formation than chlorine. Limitations: requires mixing of two chemicals in correct proportion, more difficult to implement and requires more infrastructure and longer contact time.
- **Ultraviolet Radiation** To accomplish disinfection with UV technology, water is passed through a reactor containing UV lamps. Pathogens exposed to the UV light are rendered inactive. Benefits: simple to operate, no DBP formation. Limitations: No disinfectant residual, shadow effect if particles present (reduced efficiency), expensive capital cost.
- **Chlorine Dioxide** Chlorine dioxide reacts with water through an oxidation/reduction reaction to reduce chlorite to chloride while oxidizing other species in the water and creating a disinfection potential. Benefits: fewer DBPs formed, established, effective at low concentrations. Limitations: health and safety concerns associated with chlorine dioxide generation, chemicals are expensive, highly volatile therefore, does not provide suitable residual.

3.0 References

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Revision Date: 03/28/11

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Chromium Fact Sheet

Contaminant Data

Cr

Chemical Data Chromium (Cr), atomic number: 24, atomic weight: 51.996, a steel-gray metallic element. It is odorless and tasteless. It is a micronutrient (essential trace element).

Source in Nature Chromium is a naturally occurring ubiquitous element found in the air, water, rocks, soil, animals, and in volcanic dust and gases. Cr is found in the environment in three major forms or oxidation states: trivalent Cr (III), hexavalent Cr (VI), and metallic Cr (0), the first two being the most important and most common. The form depends on the pH level. Very small amounts of Cr III are found in vegetables, fruits, meats, grains, and yeast. Cr(VI) and Cr(0) are generally produced by industrial processes. Cr(0) is used mainly for making steel and other alloys [1]. Cr(III) and Cr(VI) are used for chrome plating, dyes, pigments, and leather and wood preservation [1]. Cr may be found in tap water as a result of plumbing fixtures.

SDWA Limits MCL/MCLG for total chromium is 0.1 mg/L. Issues with non-polluted drinking water supplies with chromium concentrations exceeding MCLs are rare.

Health Effects In very small amounts, Cr (III) is an essential nutrient in our diet, helping maintain normal metabolism of glucose, cholesterol, and fat in human bodies. Cr(III) has low toxicity and would be a concern in drinking water only at very high levels. Cr(VI) and Cr(0) are more toxic and pose potential health risks to people. Some people who use water contianing high concentrations of total chromium may develop dermatitis, damage to the liver, kidney circulation and nerve tissue damage, and death in large doses. Cr(VI), when present at high a high level in drinking water is a probably human carcinogen [2].

Removal Techniques

USEPA BAT Coagulation/filtration, ion exchange, reverse osmosis, and lime softening have been shown to reduce total chromium concentrations below 0.1 mg/L.

Refer to individual treatment technique fact sheet for further information.

- **Coagulation and Filtration** Coagulation and filtration uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration. Chromium removal efficiency is higher when the initial chromium concnetration is low and the pH is high. Higher coagulant dosages do not significantly increase chromium removal. Coagulation with ferric chrloide was shown to produce better removal rates than aluminum sulfate for removal of chromium [3]. The optimal pH for chromium removal is 7.5 [3]. *Benefits*: low capital costs, proven, reliable. *Limitations*: operator care required with chemical usage; sludge disposal.

- **Ion Exchange** IX for Cr uses a charged anion resin to exchange acceptable ions from the resin for chromium in the water. Commercial resins may be used such as Diaion CR11 and Amberlite IRC 86 [4]. Pretreatment may be required because of interference by other ions [4]. *Benefits*:

acid effective; well developed, commercially available resins. ***Limitations***: pretreatment lime softening may be required; restocking of regenerate supply; regular regeneration; concentrate disposal.

- **Reverse Osmosis** RO for soluble Cr uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or most dissolved solids (soluble Cr), to pass through the membrane. Das et al. demonstrated a chromium removal efficiency of 91-98% using nanofiltraiton and 98.8-99.7% using reverse osmosis [5]. ***Benefits***: produces high quality water. ***Limitations***: cost; pretreatment/feed pump requirements; concentrate disposal.

- **Lime Softening** Lime softening for soluble Cr uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Cr. ***Benefits***: lower capital costs; proven and reliable. ***Limitations***: operator care required with chemical usage; sludge disposal; insoluble Cr compounds may be formed at low carbonate levels requiring coagulation and flocculation.

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Revision Date: 09/30/09

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Copper Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Cu

Chemical Data Copper (Cu), atomic number: 29, atomic weight: 63.546, most stable oxidation state is +2, is a reddish-brown, ductile, malleable metal. Cu is distributed in an elemental state; and in sulfides, arsenates, chlorides, and carbonates.

Source in Nature Cu is widely distributed in the natural environment, constituting about 70 ppm of the earth's crust. Cu is found in some natural waters, particularly in areas where copper and ore deposits have been mined, and where municipal incineration and smelting operations are active. Excessive amounts of Cu usually occur in drinking water sources as a result of contamination, or more commonly, in copper distribution systems by leaching as a result of corrosion.

SDWA Limits TT action level for Cu is 1.3 mg/L.

Health Effects Cu, in small amounts, is an essential nutrient which can be obtained from eating a balanced diet. Excessive Cu can give drinking water an undesirable taste. Studies have shown that Cu may cause nausea, vomiting, diarrhea, headache, and dizziness in children. Persons with Wilson's disease, a hereditary disorder in which excessive and lethally toxic amounts of Cu accumulate in the liver and brain, are at a higher risk of Cu toxicity.

Removal Techniques

USEPA BAT Ion exchange, reverse osmosis, lime softening, or coagulation and filtration. Refer to: Individual Treatment Technique Fact Sheet if available for further information.

- **Ion Exchange** IX for soluble Cu uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Cu in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.

- **Reverse Osmosis** RO for soluble Cu uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids (soluble Cu), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.

- **Lime Softening** Lime softening for soluble Cu uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Cu. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal; insoluble Cu compounds may be formed at low carbonate levels, requiring coagulation and flocculation.

- **Coagulation and Filtration** Coagulation and filtration for insoluble Cu uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration. Benefits: low capital costs for proven, reliable process. Limitations: operator care required with chemical usage; sludge disposal.

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Revision Date: 09/30/09

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Cyanide Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

CN

Chemical Data Cyanide is a carbon-nitrogen radical, which may be found in a wide variety of organic and inorganic compounds. Cyanide may exist as an ion with a valence of -1, and when combined carries a positive or negative charge. Cyanide, in some forms, is a very powerful and fast acting toxin. When combined with metals and organic compounds, it forms simple and complex salts and compounds, the most commonly used forms being hydrogen cyanide, sodium cyanide, and potassium cyanide.

Source in Nature Cyanide can enter surface water through releases from metal finishing industries, iron and steel mills, runoff from disposal of cyanide wastes in landfills, pesticides, and the use of cyanide-containing road salts. Cyanide can also enter water sources through natural processes, but in very low concentrations. Most cyanide in surface water will form hydrogen cyanide and evaporate.

SDWA Limits MCL/MCLG for cyanide is 0.2 mg/L. Issues with raw water CN concentrations exceeding MCLs are rare.

Health Effects All forms of cyanide can be toxic at high levels, but hydrogen cyanide is the deadliest form of the toxins. At short-term exposure levels above the MCL, cyanide causes rapid breathing, tremors, and other neurological effects. Long-term exposure at levels above the MCL, cyanide can cause weight loss, thyroid effects, nerve damage and death. Skin contact with liquids containing cyanide may produce irritation and sores.

Removal Techniques

USEPA BAT Ion exchange, reverse osmosis, or chlorine. Refer to individual treatment technique fact sheet for further information.

- **Ion Exchange** IX for cyanide uses a charged anion resin to exchange acceptable ions from the resin for the undesirable cyanide in the water. *Benefits*: acid addition, degasification, well developed. *Limitations*: pretreatment lime softening may be required; restocking of regenerate supply; regular regeneration; concentrate disposal.

- **Reverse Osmosis** RO for soluble cyanide uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or most dissolved solids (soluble cyanide), to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.

- **Chlorine Treatment** For community surface and ground water (under the direct influence of surface water) systems, treatment technique is applied. In this case, the accepted TT is the use of chlorine (Cl_2). Inorganic materials, such as cyanide, are oxidized by Cl_2 and converted to more manageable insoluable forms. Cl_2 reacts with organic matter breaking it down to simpler substances. *Benefits*: proven; reliable. *Limitations*: product water has objectionable taste; can react to organic compounds to form DBPs.

Process Depending on raw water quality and characteristics, Cl_2 can effectively treat cyanide. In chlorination treatment, Cl_2 reacts with inorganic materials such as hydrogen sulfide, iron, or manganese and with natural organic matter. Chlorination can be accomplished by using liquid, tablet, or gaseous Cl_2.

Pretreatment Removal of natural organic matter may be advised to reduce DBP formation.

Maintenance Proper monitoring, operation, and maintenance procedures are essential to ensure the reliability of the treatment processes. Periodic cleaning of metering pump, tubing, injector, and mix tank along with metering pump calibration is recommended.

Waste Disposal None

Advantages

- Well established, conventional treatment process; readily available.
- Reliable, if properly operated and maintained; provides residual disinfectant.
- Suitable for community or on-site systems.

Disadvantages

- Requires proper Cl_2 contact times; can give a chlorine after-taste and smell.
- Requires careful handling and proper storage of chlorine.
- Cl_2 may combine with organic precursors, natural organic material, to form DBPs.

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Revision Date: 09/30/09

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DBP: Bromate Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet, DBP Fact Sheets.

Contaminant Data

BrO_3

Chemical Data Bromate (BrO_3^-) is primarily the result of disinfection with ozone. Bromate is an inorganic ion which is tasteless, colorless and has a low volatility. Bromate dissolves easily in water and is fairly stable. MW = 127.90 g/mol.

Source in Nature Bromate is not typically derived from natural sources. It forms when ozone reacts with the naturally occurring bromide ion commonly found in raw water supplies such as streams, lakes and reservoirs. The amount of bromate formed is influenced by the quantity of bromide in the water.

SDWA Limits Bromate is one of four regulated disinfection byproducts (DBPs). The MCL for bromate is 0.01 mg/L (annual average). Significant monitoring requirements are also included in the SDWA regulations.

Health Effects Short-term exposure to bromate at levels above the MCL has not been shown to cause ill health effects. At long-term exposure levels above the MCL, bromate may increase the risk of cancer.

Removal Techniques

Bromate control focuses primarily on:

- reducing the oxidant demand (e.g. NOM removal), and consequential reduction in dosage applied.
- source water selection
- optimization of the disinfection process
- decreasing pH to less than 7
- ammonia addition

The removal of bromate is usually a final solution when other methods cannot achieve required reductions.

USEPA BAT
Refer to individual treatment process fact sheets for further information.

- **Enhanced Coagulation and Media Filtration** Enhanced coagulation and media filtration for NOM removal uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration. *Benefits*: low capital costs for proven, reliable process. *Limitations*: operator care required with chemical usage; sludge disposal.
- **Granular Activated Carbon** A granular activated carbon (GAC) filter can be used to remove NOM. GAC uses extremely porous carbon media in a process known as adsorption. As water

passes through the media, the dissolved contaminants are attracted and held (adsorbed) on the solid surface. *Benefits*: well established; suitable for home use. *Limitations*: effectiveness based on contaminant type, concentration, rate of water usage, and type of carbon used; requires careful monitoring.

- **Optimization of the Disinfection Process** The type and location of disinfection can greatly affect the amount of bromate formed. This must always be checked against providing required CT values. Moving the ozonation point to a location following a NOM removal process (e.g. coagulation) will reduce the ozone demand. Staging the ozonation with ozone addition in smaller doses from multiple locations can reduce the ozone to DOC and ozone to bromide ratio, and consequently reduce the bromate formation. Reducing the pH to less than 7 will minimize the bromate formation, but will increase the brominated organic compound formation. The addition of ammonia or hydrogen peroxide can also decrease bromate formation.

Alternative Methods of Treatment

- **NOM Removal**
    - Enhanced coagulation and microfiltration (MF) or ultrafiltration (UF) for NOM removal uses the membrane filtration of coagulated NOM. *Benefits*: low capital costs for fairly new, but proven process. *Limitations*: higher operator care than for sand filtration, higher O&M costs.
    - Nanofiltration (NF) for NOM removal uses the membrane to physically separate the NOM from the water. *Benefits*: less operator care than with coagulation and microfiltration, consistent low NOM product water. *Limitations*: membrane fouling, operator care, higher O&M costs than microfiltration, concentrate disposal.
    - Reverse osmosis (RO) for dissolved NOM removal uses a semipermeable membrane and high pressure pump to cause the water, but not suspended or most dissolved solids to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: high cost; membrane fouling, pretreatment/feed pump requirements; concentrate disposal.
    - Lime softening uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and trap NOM in the process. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal. pH readjustment needed.

- **Source Water Selection**
    - The selection of a source water, when possible, can significantly reduce bromate formation. The quantity and type of NOM in the source water impacts the amount of bromate formed. The amount of bromide and pH will also affect the amount of bromate formed.

- **Bromate Removal**
    - RO is also effective for bromate removal (see “NOM Removal” section above).

- **Alternate Disinfection Process**
    - When process modifications fail to reduce bromate levels sufficiently, changing the disinfection process to a chlorine based system such as free chlorine or chlorine dioxide is an option. However, there are associated DBPs with these processes. Switching to UV disinfection eliminates all bromate formation. A disinfectant residual using chloramines

or free chlorine still needs to be provided in the distribution system following UV treatment.

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Revision Date: 09/30/09

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DBP: Chlorite Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet, DBP Fact Sheets.

Contaminant Data

$$ClO_2$$

Chemical Data Chlorite (ClO_2^-) is a result of disinfection with chlorine dioxide and is a unique concern to only this process. Chlorite is an inorganic ion which is colorless, odorless, tasteless, and dissolves easily in water. Chlorite is fairly stable unless it comes in contact with other chemicals such as free chlorine. MW = 83.45 g/mol.

Source in Nature Chlorite is not typically derived from natural sources. Chlorite is one of the two or three chemicals involved in the process of generating chlorine dioxide for water treatment. Chlorite enters the water when it is incompletely converted to chlorine dioxide. Chlorite is also the byproduct of disinfection with chlorine dioxide, with 70% of the chlorine dioxide converted to chlorite and ~30% converted to chlorate (ClO_3^-) and chloride (Cl^-). Other major sources of chlorite in the environment come from the bleaching of wood pulp by paper mills and the disinfection of municipal wastewater.

SDWA Limits Chlorite is one of four regulated disinfection byproducts (DBPs). The MCL for chlorite is 1.0 mg/L (monthly average). MCLG for chlorite is 0.8 mg/L. Significant monitoring requirements are also included in the SDWA regulations. Chlorate (ClO_3^-), a similar byproduct, is currently unregulated.

Health Effects Exposure to chlorite at levels above the MCL, may have nervous system effects in infants and young children along with fetuses in pregnant women. Chlorite exposure may also cause anemia.

Removal Techniques

Chlorite (and chlorate) control focuses primarily on:

- Reducing the oxidant demand (e.g. NOM removal), and consequential reduction in dosage applied.
- Control of chemical reactions.
- Minimizing exposure to UV and sunlight.

Changing disinfection processes and the removal of chlorite is usually a final solution when other methods can not achieve required reductions.

USEPA BAT
Refer to: Individual Treatment Technique Fact Sheet if available for further information.

- **NOM Removal**
    - Enhanced coagulation and media filtration for NOM removal uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration. *Benefits*: low capital costs for proven, reliable process. *Limitations*: operator care required with chemical usage; sludge disposal.
    - A granular activated carbon (GAC) filter can be used to remove NOM. GAC uses

extremely porous carbon media in a process known as adsorption. As water passes through the media, the dissolved contaminants are attracted and held (adsorbed) on the solid surface. *Benefits*: well established; suitable for home use. *Limitations*: effectiveness based on contaminant type, concentration, rate of water usage, and type of carbon used; requires careful monitoring.

- **Control of Chemical Reactions**
  - A dose of sodium chlorite above the stoichiometric ratio with chlorine can result in unreacted chlorite passing into the treated water stream. In turn, a dose of excess chlorine can result in chlorate formation. Hence, the blending ratios and subsequent mixing should be optimized and rechecked periodically. In addition, chlorate can be formed by a similar conversion of chlorite to chlorate via free chlorine used elsewhere in the treatment process. In this case, the amount and location of free chlorine addition should be examined. Chlorate can also be formed via the photochemical decomposition of chlorine.

- **Minimizing exposure to UV and sunlight**
  - The occurrence of photochemical decomposition of chlorine dioxide can affect the ultimate concentrations of chlorine dioxide, chlorite, and chlorate in water treated with chlorine dioxide. Sunlight may increase chlorate concentrations in uncovered storage basins containing water with chlorine dioxide residuals. Exposure to ultraviolet light will also change the potential reactions between chlorine dioxide and the bromide ion, possibly leading to brominated byproducts.

Alternative Methods of Treatment

- **NOM Removal**
  - Enhanced coagulation and microfiltration (MF) or ultrafiltration (UF) for NOM removal uses the membrane filtration of coagulated NOM. *Benefits*: low capital costs for fairly new, but proven process. *Limitations*: higher operator care than for sand filtration, higher O&M costs.
  - Nanofiltration (NF) for NOM removal uses the membrane to physically separate the NOM from the water. *Benefits*: less operator care than with coagulation and microfiltration, consistent low NOM product water. *Limitations*: membrane fouling, operator care, higher O&M costs than microfiltration, concentrate disposal.
  - Reverse osmosis (RO) for dissolved NOM removal uses a semipermeable membrane and high pressure pump to cause the water, but not suspended or most dissolved solids to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: high cost; membrane fouling, pretreatment/feed pump requirements; concentrate disposal.
  - Lime softening uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and trap NOM in the process. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal. pH readjustment needed.

- **Alternate Disinfection Process**
  - When process modifications fail to reduce chlorite levels sufficiently, changing the disinfection process is one option. Changing to free chlorine is an option, however, there are also associated DBPs with this process. Changing the disinfection process to

ozonation is effective in eliminating chlorite, but it is fairly expensive and there is a problem with bromate and other brominated DBP formation in high bromide waters. Switching to UV disinfection eliminates chlorite formation and is less expensive than ozonation. A disinfectant residual using chloramines or free chlorine still needs to be provided in the distribution system for both ozone and UV treatment.

- **Chlorite Removal**
    - Chlorite can be removed by reduction with ferrous iron added to the drinking water; the by-product being chloride. Complete reduction occurs within 3 to 5 seconds at pH 5 to 7. Special consideration should be given to ferrous iron doses as to not exceed the secondary standard (0.3 mg/L) for iron.
    - Adsorption with a GAC filter or powdered activated carbon is another removal technique (see "NOM Removal" section above). However, the capacity of either of these is low with high amounts and doses needed for effective removal.
    - RO is also effective for chlorite and chlorate removal (see "NOM Removal" section above).

References

USEPA BAT (Coagulation, GAC, Optimization)

USEPA. The Stage 1 Disinfectants and Disinfection Byproducts Rule, What Does it Mean to You? EPA 816-R-01-014. June 2001. http://www.epa.gov/safewater/mdbp/stage1dbprwhatdoesitmeantoyou.pdf

USEPA. National Primary Drinking Water Regulations: Disinfectants and Disinfection Byproducts; Final Rule. RIN 2040-AB82. 40 CFR Parts 9, 141, and 142. Section II E. December 1998. http://www.epa.gov/OGWDW/mdbp/dbpfr.html

USEPA BAT (Reaction Control, Minimize exposure to light)

USEPA. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014. Chapter 4. April 1999. http://www.epa.gov/safewater/mdbp/mdbptg.html#disinfect

Alternative Method (Chlorite Removal via ferrous iron and GAC)

USEPA. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014. Chapter 4. April 1999. http://www.epa.gov/safewater/mdbp/mdbptg.html#disinfect

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Revision Date: 09/30/09

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

DBP: Haloacetic Acids Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet, DBP Fact Sheets.

Contaminant Data

Chemical Data Haloacetic Acids (HAAs) are a result of the disinfection process that forms these and other disinfection by-products (DBPs). HAAs are one of a family of organic compounds named as derivatives of a benzene ring. There are nine species of HAAs (HAA_9); five of which are currently regulated (HAA_5), see table 1.

Table 1. HAA_5 and

HAA_9	HAA_5	Monochloroacetic acid (MCAA)
		Dichloroacetic acid (DCAA)
		Trichloroacetic acid (TCAA)
		Monobromoacetic acid (MBAA)
		Dibromoacetic acid (DBAA)
	▨	Bromochloroacetic acid (BCAA)
		Bromodichloroacetic acid (BDCAA)
		Dibromochloroacetic acid (DBCAA)
		Tribromoacetic acid (TBAA)

HAAs are colorless, have a low volatility, dissolve easily in water, and are fairly stable.

Source in Nature HAAs are not typically derived from natural sources. They form when a chlorine containing disinfectant reacts with naturally occurring organic matter, such as humic acids from decaying vegetation commonly found in raw water supplies, particularly lakes and reservoirs. The bromide containing species are influenced by the quantity of naturally occurring bromide in the water. Other major sources of HAAs in the environment come from chemical and pharmaceutical manufacturing processes such as, the bleaching of wood pulp by paper mills, the disinfection of drinking water and municipal wastewater upstream of the water treatment plant, and cooling water.

SDWA Limits HAAs are one of four regulated DBPs. The MCL for HAA_5 is 0.06 mg/L (annual average). Significant monitoring requirements are also included in the SDWA regulations. The MCLG is 0.000 mg/L for DCAA and 0.3 mg/L for TCAA. Future regulations will likely reduce the TCAA MCLG to 0.02 mg/L and add an MCLG for MCAA of 0.03 mg/L. MCLGs have not yet been established for MBAA and DBAA.

Health Effects HAAs at short-term exposure levels above the MCL may increase the chance of spontaneous abortions in pregnant women, but evidence is inconclusive. At long-term exposure levels above the MCL, HAAs may cause an increased risk of cancer.

Removal Techniques

HAA control focuses primarily on:

- Removing HAA precursors

- Reducing the oxidant demand (e.g. NOM removal), and consequential reduction in dosage applied.
- Source water selection
- Optimization of the disinfection process

The removal of HAAs is usually a final solution when other methods cannot achieve required reductions.

USEPA BAT

Refer to: Individual Treatment Technique Fact Sheet if available for further information.

- **NOM Removal**
    - Enhanced coagulation and media filtration for NOM removal uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration. *Benefits*: low capital costs for proven, reliable process. *Limitations*: operator care required with chemical usage; sludge disposal.
    - A granular activated carbon (GAC) filter can be used to remove NOM. GAC uses extremely porous carbon media in a process known as adsorption. As water passes through the media, the dissolved contaminants are attracted and held (adsorbed) on the solid surface. *Benefits*: well established; suitable for home use. *Limitations*: effectiveness based on contaminant type, concentration, rate of water usage, and type of carbon used; requires careful monitoring.

Alternative Methods of Treatment

- **NOM Removal**
    - Enhanced coagulation and microfiltration (MF) or ultrafiltration (UF) for NOM removal uses the membrane filtration of coagulated NOM. *Benefits*: low capital costs for fairly new, but proven process. *Limitations*: higher operator care than for sand filtration, higher O&M costs.
    - Ultrafiltration (UF) and nanofiltration (NF) for NOM removal uses the membrane to physically separate the NOM from the water. *Benefits*: less operator care than with coagulation and microfiltration, consistent low NOM product water. *Limitations*: membrane fouling, operator care, higher O&M costs than microfiltration, concentrate disposal.
    - Reverse osmosis (RO) for dissolved NOM removal uses a semipermeable membrane and high pressure pump to cause the water, but not suspended or most dissolved solids to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: high cost; membrane fouling, pretreatment/feed pump requirements; concentrate disposal.
    - Lime softening uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and trap NOM in the process. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal. pH readjustment needed.

- **Source Water Selection**
    - The selection of a source water, when possible, can significantly reduce HAA formation. The quantity and type of NOM in the source water impacts the amount of HAAs formed. The amount of bromide will affect the amount of brominated HAA species formed. The pH can affect the quantity and species of HAAs formed.

- **Optimization of the Disinfection Process**
    - The type and location of disinfection can greatly affect the amount and species of HAAs formed. This must always be checked against providing required CT values. When free chlorine is used, moving the disinfection point farther down in the process train will reduce HAA formation time. Also, if chlorination is after coagulation, there will be less NOM present to react with. Raising the pH before disinfectant addition lowers HAA formation, but may have other adverse effects on the treatment process. The most common modification of free chlorine to reduce HAAs occurs in converting free chlorine to chloramines in the distribution system. Chloramines have a very low HAA formation potential and are ideal for maintaining a constant chlorine residual. Changing the disinfection process to ozonation can be very effective in reducing HAAs, but it is fairly expensive and there is a problem with bromate formation in high bromide containing waters. Switching to UV disinfection eliminates all HAA formation and is less expensive than ozonation. A disinfectant residual using chloramines or free chlorine still needs to be provided in the distribution system for both ozone and UV treatment. Use of chlorine dioxide, a strong oxidant, does not produce significant HAAs, but will produce some amount of chlorite, which is another regulated DBP.

- **HAA Removal**
    - HAAs can be removed by adsorption with an activated carbon filter (see "NOM Removal" section above).
    - RO is also effective for HAA removal (see "NOM Removal" section above).

- **Point of Use Systems**
    - Solid block or precoated absorption filters made with carbon or activated alumina certified to reduce HAAs are available for point of use systems.

References

USEPA BAT (Coagulation and GAC):

USEPA. The Stage 1 Disinfectants and Disinfection Byproducts Rule, What Does it Mean to You? EPA 816-R-01-014. June 2001. http://www.epa.gov/safewater/mdbp/stage1dbprwhatdoesitmeantoyou.pdf

USEPA. National Primary Drinking Water Regulations: Disinfectants and Disinfection Byproducts; Final Rule. RIN 2040-AB82. 40 CFR Parts 9, 141, and 142. Section II E. December 1998. http://www.epa.gov/OGWDW/mdbp/dbpfr.html

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Revision Date: 09/30/09

RECLAMATION
Managing Water in the West
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Bureau of Reclamation

DBP: Trihalomethanes Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet, DBP Fact Sheets.

Contaminant Data

Chemical Data Trihalomethanes (THMs) are formed during the disinfection process when a chlorine-containing disinfectant combines with organic matter in the water, forming a disinfection byproduct (DBP). THMs are one of a family of organic compounds named as derivatives of methane. There are four common THMs: trichloromethane (chloroform) - the most common in most water systems, dibromochloromethane - the most serious cancer risk, dichlorobromomethane, and tribromomethane (bromoform). THMs are colorless, volatile, dissolve easily in water, and are fairly stable.

Source in Nature THMs are found naturally in small amounts in most waters. The majority of THMs are anthropogenic. Major sources of THMs in the environment come from bleaching of wood pulp by paper mills and disinfection of drinking water, municipal wastewater upstream of the water treatment plant, and cooling water. They form when chlorine containing compounds/disinfectants react with naturally occurring organic materials such as humic acids from decaying vegetation.

SDWA Limits THMs are one of four regulated DBPs. The MCL for total THMs is 0.08 mg/L (annual average). Significant monitoring requirements are also included in the SDWA regulations. The MCLG is 0.00 mg/L for dichlorobromomethane, 0.00 mg/L for bromoform, and 0.06 mg/L for dibromochloromethane. Future regulations will likely add an MCLG for chloroform of 0.07 mg/L.

Health Effects THMs at short-term exposure levels above the MCL have not been shown to cause ill health effects. At long-term exposure levels above the MCL, THMs may cause liver, kidney, or central nervous systems problems, and may cause an increased risk of cancer.

Removal Techniques

THM control focuses primarily on:

- Removing THM precursors
- Reducing the oxidant demand (e.g. NOM removal), and consequential reduction in dosage applied.
- Source water selection
- Optimization of the disinfection process

The removal of THMs is usually a final solution when other methods cannot achieve required reductions.

USEPA BAT
Refer to: individual treatment technique fact sheet if available for further information.

- **NOM Removal**
    - Enhanced coagulation and media filtration for NOM removal uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration.

Benefits: low capital costs for proven, reliable process. *Limitations*: operator care required with chemical usage; sludge disposal.

  - Granular activated carbon (GAC) filters can be used to remove NOM. GAC uses extremely porous carbon media in a process known as adsorption. As water passes through the media, the dissolved contaminants are attracted and held (adsorbed) on the solid surface. *Benefits*: well established; suitable for home use. *Limitations*: effectiveness based on contaminant type, concentration, rate of water usage, and type of carbon used; requires careful monitoring.

Alternative Methods of Treatment

- **NOM Removal**
  - Enhanced coagulation and microfiltration (MF) or ultrafiltration (UF) for NOM removal uses membrane filtration of coagulated NOM. *Benefits*: low capital costs for fairly new, but proven process. *Limitations*: higher operator care than for sand filtration, higher O&M costs.
  - Nanofiltration (NF) for NOM removal uses membranes to physically separate the NOM from the water. *Benefits*: less operator care than with coagulation and microfiltration, consistent low NOM product water. *Limitations*: membrane fouling, operator care, higher O&M costs than microfiltration, concentrate disposal.
  - Reverse osmosis (RO) for dissolved NOM removal uses a semipermeable membrane and high pressure pump to cause the water, but not suspended or most dissolved solids to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: high cost; membrane fouling, pretreatment/feed pump requirements; concentrate disposal.
  - Lime softening uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and trap NOM in the process. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal. pH readjustment needed.

- **Source Water Selection**
  - The selection of a source water, when possible, can significantly reduce THM formation. The quantity and type of NOM in the source water impacts the amount of THMs formed. The amount of bromide will affect the amount of brominated THM species formed. The pH can affect the quantity and species of THMs formed.

- **Optimization of the Disinfection Process**
  - The type and location of disinfection can greatly affect the amount and species of THMs formed. This must always be checked against providing required CT values. When free chlorine is used, moving the disinfection point farther down in the process train will reduce THM formation time. Also, if chlorination is after coagulation, there will be less NOM present to react with. The most common modification of free chlorine to reduce THMs occurs in converting free chlorine to chloramines in the distribution system. Chloramines have a very low THM formation potential and are ideal for maintaining a constant chlorine residual. Changing the disinfection process to ozonation can be very effective in reducing THMs, but it is fairly expensive and there is a problem with bromate and other brominated DBP formation in high bromide waters. Switching to UV disinfection eliminates all THM formation and is less expensive than ozonation. A disinfectant residual using chloramines or free chlorine still needs to be provided in the

distribution system for both ozone and UV treatment. Use of chlorine dioxide, a strong oxidant, does not produce significant THMs, but will produce some amount of chlorite, which is a regulated DBP.

- **THM Removal**
    - THMs can be removed by adsorption with an activated carbon filter (see "NOM Removal" section above).
    - RO is also effective for THM removal (see "NOM Removal" section above).
- **Point of Use Systems**
    - Solid block or precoated absorption filters made with carbon or activated alumina certified to reduce THMs are available for point of use systems.

References

USEPA BAT (Coagulation and GAC):

USEPA. The Stage 1 Disinfectants and Disinfection Byproducts Rule, What Does it Mean to You? EPA 816-R-01-014. June 2001. http://www.epa.gov/safewater/mdbp/stage1dbprwhatdoesitmeantoyou.pdf

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Revision Date: 09/30/09

RECLAMATION
Managing Water in the West

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Fluoride Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

F

Chemical Data Fluoride (F^-) monatomic, inorganic anion. F^- represents ions or compounds containing the element Fluorine (F), atomic number: 9, atomic weight 19.0. Common compounds include: sodium fluoride (NaF), sodium silicofluoride (Na_2SiF_6), and calcium fluoride (CaF_2). F^- is the most reactive nonmetallic element and forms salts when combined with metals.

Source in Nature The most common source of F^- in the environment is the natural mineral fluorapatite, which is a fluorinated calcium phosphate rock. Fluorapatite is mined as the primary source of phosphate fertilizer. F^- is used in the manufacture of glass and steel and may be a contaminant in industrial discharges. F^- may be added to drinking water supplies or toothpastes for prevention of tooth decay. This may result in high concentrations in discharges from sewage treatment plants. Seawater naturally contains about 1.3 mg/L of F^-. Inorganic F, or NaF, is a waste product of aluminum and is used in some rat poisons.

SDWA Limits MCL for F^- is 4.0 mg/L and the SMCL is 2.0 mg/L (may be less if regulated by an individual state).

Health Effects Municipal water treatment plants commonly add F^- compounds to water to achieve a desired concentration of about 1.0 mg/L for prevention of tooth decay; however, tooth discoloration or dental fluorosis can develop from concentrations in excess of 2.0 mg/L. Prolonged consumption of water containing F^- at 4.0 mg/L or greater causes skeletal fluorosis, a serious bone crippling disorder resembling osteoporosis, as well as dental malformation, decalcification, mineralization of tendons, and digestive and nervous disorders. These conditions occur in different people at very different levels of F^- content.

Removal Techniques

USEPA BAT Not yet specified in regulation; however, technologies with the highest removal efficiencies are reverse osmosis and activated alumina.
Refer to: individual treatment technique fact sheet if available for further information

- **Reverse Osmosis** RO for soluble F^- uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids (soluble F^-), to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.
- **Activated Alumina** AA uses extremely porous and highly adsorptive aluminum ore media to adsorb F^-. *Benefits*: suitable for small or large systems; containment of F^- in adsorption bed. *Limitations*: careful selection/design required. AA cost curves will be included in a future revision.

Alternative Methods of Treatment Lime softening for F^- treatment can be used provided the water has a sufficient Mg content, since it is the Mg that adsorbs the F. The water may be enriched with $MgSO_4$ or dolomitic lime. Lime softening uses two types of chemical additions. First, $Ca(OH)_2$ is added in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness. Next, Na_2CO_3 is added to precipitate noncarbonate hardness. *Benefits*: proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal.

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Revision Date: 09/30/09

RECLAMATION
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Iron and Manganese Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Fe Mn

Chemical Data Iron (Fe), atomic number: 26, atomic weight: 55.847; and Manganese (Mn), atomic number: 25, atomic weight: 54.938. Both minerals are soluble in their reduced state (+2), and insoluble in their oxidized state (+3).

Source in Nature Both minerals are naturally occurring and present in varying quantities in most soils and rocks, and in surface water and ground water. The ferrous and manganous (+2) soluble ions are present in water and, when exposed to oxygen in air (oxidized), turn into the ferric and manganic (+3) insoluble ions, which will precipitate. While the soluble forms are usually colorless, the ferric precipitate is usually reddish-brown, and the manganic precipitate is usually brownish-black. Additionally, Fe comes from corroded distribution system water pipes. Mn can occur as a result of landfills or other waste disposal sites which acidify ground water and reduce its oxygen content.

SDWA Limits SMCL for Fe is 0.3 mg/L, and 0.05 mg/L for Mn.

Health Effects As secondary drinking water contaminants, neither Fe or Mn pose any health risks, and in small concentrations are essential to human health. Higher concentrations will give water a medicinal or metallic taste; are a nuisance and will cause staining problems in laundry and plumbing fixtures; may precipitate and clog distribution piping; or may cause the development of Fe or Mn bacteria, harmless bacteria that may give water an offensive taste or color, although it will still be safe to drink.

Removal Techniques

USEPA As secondary drinking water contaminants, BATs are not assigned.
Refer to: individual treatment technique fact sheet if available for further information.

Alternative Methods of Treatment The most common treatment process for removing Fe and Mn is oxidation with $KMnO_4$ followed by greensand filtration. Oxidation of Fe^{+2} and Mn^{+2} ions with $KMnO_4$ occurs after a brief retention time, when an insoluble solid particle is formed which can be removed by the greensand filter. *Benefits*: proven; reliable. *Limitations*: chemical dosages and metering required.

Oxidation with $KMnO_4$ followed by Greensand Filtration

Process Oxidation is a chemical process and filtration is a physical process. $KMnO_4$ is added to the raw water which oxidizes the soluble Fe and Mn into insoluble ferric and manganic oxides which will settle and are filterable. $KMnO_4$ (without prechlorination) is usually used according to the following stoichiometry:

0.94 mg/L $KMnO_4$ per mg/L of Fe^{+2} removed and
1.92 mg/L $KMnO_4$ per mg/L of Mn^{+2} removed.

After the oxidation process is complete, the greensand filter removes the insoluble material. Greensand is a green clay material whose active mineral is glauconite, a natural zeolite with ion exchange properties. Greensand is layered loosely to form the media bed. As water passes through the filter, any remaining soluble Fe and Mn are pulled from the solution by the ion exchange properties of the greensand, and the insoluble Fe and Mn are filtered by the greensand media. Periodically, the greensand media is regenerated by continually feeding $KMnO_4$ just before the filter to recharge the glauconite, regenerating the ion exchange properties. Additionally, periodic backwashing of the filter media to remove the Fe and Mn is required.

Pretreatment Feeding chlorine ahead of the $KMnO_4$ can make the process more economical. $Ca(OH)_2$ addition may be necessary to achieve the desired pH level or to remove CO_2.

Maintenance Tests should be conducted at least monthly on samples of the water entering the filter to ensure the Fe and Mn are in their insoluble oxidized states (+3) and to verify $KMnO_4$ dosages. Regeneration and backwashing should be done in accordance with the greensand media manufacturer's recommendations. Perform system pressure and flowrate checks to verify backwashing capabilities. Perform routine maintenance checks of valves, pipes, and pumps.

Waste Disposal Filter regeneration and backwash waters, and spent media require approved disposal.

Advantages

- Low cost.
- Efficient; proven; reliable.

Disadvantages

- $KMnO_4$ dosage must be exact; bench scale tests are required to determine exact dosage; monitoring of performance to ensure proper dosage.
- Sufficient pressure and flowrate required for backwashing; backwash disposal required.
- Regeneration required; regeneration disposal required.

Alternative oxidation processes include aeration with oxygen, chlorine, ozone, and hydrogen peroxide. Simple aeration may be the most economical, but may not be as effective.

In-home water softeners may be used when centralized treatment is not available, when the combined Fe and Mn concentrations are below 1 mg/L, and when the Fe and Mn are still in their soluble reduced states (+2).

Related Publications
Reclamation WTTP Report #8, “Lake Havasu City Water Treatment Research Study.” This report pilot tested two processes, including $KMnO_4$ oxidation followed by greensand filtration and nanofiltration to remove Mn^{+2}.

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Revision Date: 09/30/09

RECLAMATION
Managing Water in the West

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Lead Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Pb

Chemical Data Lead (Pb), atomic number: 82, atomic weight: 207.2, most stable oxidation state is +2, is a soft, malleable heavy metal resistant to physical deterioration.

Source in Nature Pb is generally not present in source waters, but is usually introduced into the water by corrosive water leaching Pb from household plumbing (lead pipe, lead solder, or galvanized pipes). Corrosive (acidic or low pH) and higher temperature waters can dissolve Pb materials within the distribution, plumbing, and wastewater conveyance systems. Pb in the environment is a result of chemical and physical weathering of igneous and metamorphic rocks and soils. Domestic wastewater and industrial effluents can contribute to Pb concentrations in surface water (more common) and groundwater.

SDWA Limits TT action level for Pb is 0.015 mg/L.

Health Effects Chronic exposure over long periods to even low concentrations of Pb can have severe health effects, especially on infants, children, and pregnant women. Pb is accumulated and stored in the bone. When Pb exposure is so high that the bone become saturated, Pb displaces calcium in the blood effecting the central nervous system. Excessive levels of Pb in the blood contribute to reduced metal and skeletal development, interference with kidney and neurological functions, and hearing loss, especially in children under the age of 6.

Removal Techniques

USEPA BAT Ion exchange, reverse osmosis, lime softening, or coagulation and filtration.
Refer to: individual treatment technique fact sheet for further information.

- **Ion Exchange** IX for soluble Pb uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Pb in the water. *Benefits*: effective; well developed. *Limitations*: restocking of salt supply; regular regeneration; concentrate disposal.
- **Reverse Osmosis** RO for soluble Pb uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids (soluble Pb), to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.
- **Lime Softening** Lime softening for soluble Pb uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10, keeping the levels of alkalinity relatively low, to precipitate carbonate hardness and heavy metals, like Pb. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal; insoluble Pb compounds may be formed at low carbonate levels requiring coagulation and flocculation.
- **Coagulation and Filtration** Coagulation and filtration for insoluble Pb uses the conventional

treatments processes of chemical addition, coagulation, and dual media filtration. ***Benefits***: low capital costs for proven, reliable process. ***Limitations***: operator care required with chemical usage; sludge disposal.

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Revision Date: 09/30/09

RECLAMATION
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Mercury and Cadmium Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Chemical Data Mercury (Hg), atomic number: 80, atomic weight: 200.59, most stable oxidation state +2, lustrous silver-liquid heavy metal. Cadmium (Cd), atomic number: 48, atomic weight: 112.41, oxidation state +2, lustrous silver-white heavy metal.

Hg	Cd

Source in Nature Hg and Cd are both naturally occurring in the environment in ores, rocks, and soils in limited quantities. Hg is introduced into the environment by natural and anthropogenic processes, including: volcanic activity; incineration of coal, heating oil, and rubbish; mining and smelting; industrial use; and the manufacture of thermometers, batteries, and electrical equipment. Cd is introduced into the environment by corrosion of galvanized pipes; refining and electroplating; mining and smelting; manufacture of polyvinyl chloride products and nickel-cadmium batteries. Hg and Cd primarily enter surface waters through runoff or contaminated industrial disposal.

SDWA Limits MCL for Hg is 0.002 mg/L, and 0.005 mg/L for Cd. Issues with raw water Hg and Cd concentrations exceeding MCLs are rare.

Health Effects Chronic exposure over long periods to even low concentrations of Hg and Cd can have severe health effects. Both Hg and Cd bio-accumulate in the food chain, are absorbed in the human body, and accumulate there. Hg poisoning includes kidney damage, brain and nerve damage, birth defects, and skin rash. Long-term effects from Cd poisoning include kidney damage and changes to the constitution of the bone, liver, and blood.

Removal Techniques

USEPA BAT Coagulation and filtration, lime softening, and reverse osmosis are the BATs for Hg at concentrations <10 µg/L; and granular activated carbon is a BAT at any concentration. Coagulation and filtration, lime softening, ion exchange, and reverse osmosis are the BATs for Cd at any concentration. Refer to individual treatment technique fact sheet for further information.

- **Coagulation and filtration** Coagulation and filtration for insoluble Hg and Cd uses the conventional treatments processes of chemical addition, coagulation, and dual media filtration. *Benefits*: low capital costs for proven, reliable process. *Limitations*: operator care required with chemical usage; sludge disposal.

- **Lime Softening** Lime softening for soluble Hg and Cd uses $Ca(OH)_2$ in sufficient quantity to precipitate carbonate hardness and heavy metals. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal; insoluble Hg and Cd compounds may be formed at low carbonate levels requiring coagulation and flocculation.

- **Reverse Osmosis** RO for soluble Hg and Cd uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids (soluble Hg and Cd), to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.

- **Granular Activated Carbon** GAC uses extremely porous carbon media in a process known as adsorption. As water passes through the media the dissolved contaminants are attracted and held (adsorbed) on the solid surface. *Benefits*: well established; suitable for home use. *Limitations*: effectiveness based on contaminant type, concentration, rate of water usage, and type of carbon used; requires careful monitoring. GAC cost curves will be included in a future revision.

- **Ion Exchange** IX for soluble Cd uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Cd in the water. *Benefits*: effective; well developed. *Limitations*: restocking of salt supply; regular regeneration; concentrate disposal.

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Revision Date: 09/30/09

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

Nickel Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Ni

Chemical Data Nickel (Ni), atomic number: 28, atomic weight: 58.70, oxidation states: +2, and +3, silvery-white, hard, magnetic, malleable, ductile metallic element. Ni is corrosion resistant and maintains its mechanical and physical characteristics in a wide range of temperatures. Combined with other metals, it forms mixtures (alloys). The most important alloying elements are iron, chromium, copper, and molybdenum. Most salts of Ni, including Ni chloride, Ni sulfate, and Ni nitrate are soluble in water. Ni and its compounds have no characteristic odor or taste. Ni is one of the transition elements.

Source in Nature Ni makes up 0.007 percent of the earth's crust and is found in all soils in a combined form. Ni is emitted from volcanoes and is a principal metal in meteors. Combined with oxygen (oxides) or sulfur (sulfides) in varying proportions in weathered ore is its more natural form. Ni occurs in several minerals, including pentlandite and pyrrhotite, the principal ores of Ni. Soil-borne Ni may enter waters by surface runoff or by percolation into ground water. Ni carbonate, found in the mineral zaratite, is a potential surface water pollutant.

SDWA Limits The MCL/MCLG for Ni were remanded on February 9, 1995. There is currently no EPA legal limit on the amount of Ni in drinking water. EPA is reconsidering the limit on Ni.

Health Effects Ni at short-term exposure levels above the MCL has not been found to cause adverse health effects. Ni at long-term exposure at levels above the MCL, can cause weight loss, heart and liver damage, stomachaches, effects to the blood and kidneys, and dermatitis.

Removal Techniques

USEPA BAT Ion exchange, lime softening, or reverse osmosis.
Refer to individual treatment technique fact sheet if available for further information.

- **Ion Exchange** IX for soluble Ni uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Ni in the water. *Benefits*: effective; well developed. *Limitations*: restocking of salt supply; regular regeneration; concentrate disposal.

- **Lime Softening** Lime softening for soluble Ni uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Ni. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal; insoluble Ni compounds may be formed at low carbonate levels, requiring coagulation and flocculation.

- **Reverse Osmosis** RO for soluble Ni uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids (soluble Ni), to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: high cost; pretreatment/feed pump requirements; concentrate disposal.

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Revision Date: 09/30/09

RECLAMATION
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Nitrate & Nitrite Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Chemical Data Nitrate (NO_3^-) and nitrite (NO_2^-) are inorganic anions. NO_3^- has an oxidation state of elemental nitrogen gas, molecular weight 62.00. NO_3^- and NO_2^- are water-soluble, colorless, odorless, and tasteless. NO_3^- is a macronutrient that is an essential part of proteins manufactured by bacteria and algae in water. NO_2^- is a nitrogen-oxygen radical.

Source in Nature Nitrogen is a naturally occurring gas in the earth's atmosphere, at approximately 78% by volume. NO_3^- is a naturally occurring nitrogen-oxygen unit which combines with various organic and inorganic compounds in both water and plants. Natural sources of NO_3^- in waters include direct fixation of nitrogen gas by algae and bacteria, photochemical fixation, electrical discharge, and oxidation of ammonia and nitrite by nitrifying bacteria. NO_3^- is used by bacteria to form amino acids used in the synthesis of proteins for all plants and animals. Elevated levels of NO_3^- in today's surface water and ground water are a result of overuse of nutrient-rich chemical fertilizers, municipal and industrial wastewaters, refuse dumps, and improper disposal of human and animal wastes. Both NO_3^- and NO_2^- are added to meat products as preservatives. NO_3^- is reduced to NO_2^- in the saliva of the mouth and upper GI tract.

SDWA Limits MCL for NO_3^- as nitrogen is 10 mg/L (for NO_3^- as nitrate, MCL is 45 mg/L). MCL/MCLG for NO_2^- is 1 mg/L.

Health Effects The health effects of excessive NO_3^-/NO_2^- include methemoglobinemia (blue baby syndrome — oxygen deprivation in infants under 6 months), which is generally considered a concern for children under age 5. Older children and adults are generally only susceptible if they also experience enzyme or erythrocyte metabolism deficiency, chronic anemia, or gastric diseases.

Removal Techniques

USEPA BAT Ion exchange, reverse osmosis, or electrodialysis.
Refer to: Individual Treatment Technique Fact Sheet if available for further information.

- **Ion Exchange** IX uses charged anion resin to exchange acceptable ions from the resin for undesirable NO_3^- in the water. *Benefits*: effective; well developed. *Limitations*: restocking of salt supply; regular regeneration; competing ions.

- **Reverse Osmosis** RO uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids, to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.

- **Electrodialysis Reversal** EDR uses semipermeable membranes in which ions migrate through the membrane from a less concentrated to a more concentrated solution as a result of the ions' representative attractions to direct electric current. *Benefits*: contaminant specific removal. *Limitations*: electrical requirements; concentrate disposal.

Alternative Methods of Treatment

- **Biological Denitrification** Biological denitrification is a natural process in which bacteria use nitrate as an electron acceptor in a series of enzymatic reactions leading to the evolution of nitrogen gas.

- **Distillation** See related treatment technology fact sheet. *Benefits*: established technology. *Limitations*: energy intensive.

- **Dilution** Dilution of the source water by blending with higher quality water can be used to reduce nitrate and nitrite concentrations. *Benefits:* simple, straight-forward. *Limitations*: A higher quality water source must be available for blending.

- **Water Source Relocation** Water source relocation involves siting the water source so that nitrate and nitrite contamination does not occur. Benefits: simple, straight-forward. Limitations: logistical factors associated with the relocation of the water source.

Related Publications

Reclamation WTTP Report #14, "Brighton ED Testing with Asahi Monovalent Selective Membranes." This report summarizes the pilot testing of an ED water treatment system with special membranes tailored for nitrate removal from water.

Reclamation WTTP Report #15, "Maricopa Groundwater Treatment Study." This report summarizes the field study performed to determine the suitability of several water treatment processes, including RO, ED, and NF, on groundwater containing high levels of nitrate, chloride, and TDS; recommends the use of NF or ED for study area.

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Revision Date: 09/30/09

RECLAMATION
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Organic Chemicals Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Chemical Data Anthropogenic organic substances are called synthetic organic chemicals (SOC) and are synthesized from carbon and other elements such as hydrogen, nitrogen, and chlorine. SOCs commonly include the complete range of pesticides, various industrial chemicals and solvents, and household products. SOCs that are capable of vaporizing at relatively low temperatures are called volatile organic chemicals (VOCs). SOCs vary in water solubility and may not necessarily result in odor, color, or taste changes. SOCs are the subject of this Fact Sheet.

Source in Nature SOCs in ground water and surface water result from the widespread use of pesticides (herbicide, fungicide, insecticide, bactericide, etc.), chemicals, and solvents (petroleum, detergents, etc.) and from the manufacture and disposal of products (styrofoam, plastics, cleaning compounds, paints, fire retardants, hair spray). SOCs occur both intentionally (pesticide application or manufacturing and industrial drainage) and accidentally (leaking USTs, chemical spills, backflow, or boating operations). SOC contamination also occurs as a result of leaching from industrial waste dumps and municipal landfills and storm runoff from urban areas. SOCs that leach into ground water are a particular concern because the lack of light, heat, and oxygen retards chemical breakdown, and dilution is less likely.

SDWA Limits Refer to the following section for contaminant-specific MCLs. Occurrence of raw water with SOC concentrations exceeding MCLs is rare.

Health Effects Health effects vary based on contaminant toxicity level; contaminant concentration in the water; amount consumed; contaminant absorption efficiency; and age, weight, and health of the person exposed. Health effects can range from minor to severe and can be acute or chronic. Some minor effects can include: nausea, vomiting, dizziness, drowsiness, lung/mucous membrane irritation, and skin rash. Some severe effects can include: cancer, vital organ damage, birth defects, nervous system disorders, and immune system damage. Contaminants are metabolically broken down (detoxified), excreted (urine, feces, exhalations, or sweat), or accumulated by the body. Those contaminants that accumulate in the body fat or tissue of fish, birds, or animals may be passed on through the food chain. Exposure routes include direct ingestion, respiratory inhalation, and skin absorption.

Removal Techniques

USEPA BAT Granular activated carbon or packed tower aeration (air stripping). (Glyphosate, Acrylamide, Epichlorohydrin, and THMs are exceptions, requiring alternate treatments, and are not discussed in this Fact Sheet.) Refer to the following section for contaminant-specific BATs. Consult with the equipment manufacturer and specifications to ensure the contaminant present will be removed. Refer to individual treatment technique fact sheet for further information.

- **Granular Activated Carbon** GAC uses extremely porous carbon media in a process known as adsorption. As water passes through the media the dissolved contaminants are attracted and held (adsorbed) on the solid surface. *Benefits*: well established; suitable for home use. *Limitations*: effectiveness based on contaminant type, concentration, rate of water usage, and type of carbon used; requires careful monitoring.

- **Air Stipping** Packed tower AS uses a tower filled with packing material; water enters the top of the tower and is sprayed over the packing material, exposing a thin layer of water to countercurrent air being blown in at the bottom. The process allows for mass transfer of the VOCs from water into air. AS off-gas is either discharged to the atmosphere or treated by vapor phase GAC. *Benefits*: well established; best suited for VOCs and large installations. *Limitations*: requires ample space; requires careful monitoring. GAC cost curves will be included in a future revision.

Alternative Methods of Treatment Alternative AS types are available, including countercurrent plate. Alternative treatment methods include carbon filtration, ultraviolet radiation, RO, ED, NF, and diatomaceous earth filtration.

SOCs Limits and BAT

CONTAMINANT	MCL (mg/L)	BAT
VOCs:		
Benzene	0.005	GAC, AS
Carbon Tetrachloride	0.005	GAC, AS
Dichlorobenzene (p-)	0.075	GAC, AS
Dichlorobenzene (o-)	0.6	GAC, AS
Dichloroethane (1,2-)	0.005	GAC, AS
Dichloroethylene (1,1-)	0.007	GAC, AS
Dichloroethylene (cis-1,2-)	0.07	GAC, AS
Dichloroethylene (trans-1,2-)	0.1	GAC, AS
Dichloromethane	0.005	AS
Dichloropropane (1,2-)	0.005	GAC, AS
Ethyl Benzene	0.7	GAC, AS
Monochlorobenzene	0.1	GAC, AS
Styrene	0.1	GAC, AS
Tetrachloroethylene	0.005	GAC, AS
Toluene	1	GAC, AS
Trichloroethane (1,1,1-)	0.2	GAC, AS
Trichloroethane (1,1,2-)	0.005	GAC, AS
Trichloroethene (TCE)	0.005	GAC, AS
Trichlorobenzene (1,2,4-)	0.07	GAC, AS
Vinyl Chloride	0.002	AS
Xylenes (Total)	10	GAC, AS
Pesticides/PCBs:		
Alachlor	0.002	GAC
Atrazine	0.003	GAC
Carbofuran	0.04	GAC
Chlordane	0.002	GAC
2,4-D	0.07	GAC

CONTAMINANT	MCL (mg/L)	BAT
Dalapon	0.2	GAC
1,2-Dibromo-3-Chloropropane (DBCP)	0.0002	GAC, AS
Dinoseb	0.007	GAC
Diquat	0.02	GAC
Endothall	0.1	GAC
Endrin	0.002	GAC
Ethylenedibromide (EDB)	0.00005	GAC, AS
Glyphosate	0.7	Oxidation (chlorine or ozone)
Heptachlor	0.0004	GAC
Heptachlor Epoxide	0.0002	GAC
Lindane	0.0002	GAC
Methoxychlor	0.04	GAC
Oxamyl (Vydate)	0.2	GAC
Picloram	0.5	GAC
Polychlorinated byphenols (PCBs)	0.0005	GAC
Pentachlorophenol	0.001	GAC
Simazine	0.004	GAC
Toxaphene	0.003	GAC
2,4,5-TP (Silvex)	0.05	GAC
Other Organic Chemicals:		
Acrylamide	none set	TT with polymer
Benzo(a)pyrene (PAH)	0.0002	GAC
Di(2-ethylhexyl)adipate	0.4	GAC, AS
Di(2-ethylhexy)phthalate	0.006	GAC
Epichlorohydrin	none set	TT with polymer
Hexachlorobenzene	0.001	GAC
2,3,7,8-TCDD (Dioxin)	0.00003	GAC
THMs (Chloroform, Bromoform, Bromodichloromethane, Dibromochloromethane)	0.08	Chloramines, Chlorine Dioxide, improved clarification for THM precursor reduction, moving chlorination point to reduce TTHM, or powdered activated carbon.

The SDWA regulates contaminants in community water supply systems; therefore contamination is more likely to go undetected and untreated in unregulated private water systems.

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Revision Date: 09/30/09

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

Radionuclides Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Chemical Data Radioactive elements are often called radioactive isotopes or radionuclides. Radionuclides emit radiant atomic energy caused by the spontaneous disintegration of the nuclei of their atoms, resulting in radioactive particles or decay products that are members of the radioactive elements. As radionuclides decay, they emit ionizing radiation in the form of alpha (α) or beta (β) particles and gamma (γ) photons. Alpha particles are relatively massive and easy to stop. They typically travel 100 µm into tissue while beta particles may travel several centimeters. Gamma rays, having no charge or mass, are simply a form of electromagnetic radiation that travel at the speed of light. Gamma rays have short wavelengths and therefore are capable of causing ionizations; as such they are biologically damaging. Generally, the soluble radionuclides of concern in water include: radon (Rn), atomic number 86, atomic weight 222, a gas; uranium (U), atomic number 92, atomic weight 238.03, a metal; and combined radium-226/228 (radium (Ra), atomic number 88, atomic weight 226.03, a metal). The three forms of radioactivity, α, β, and γ are also a concern.

Source in Nature Radionuclides are both natural and man-made and are found in air, water, soil, plants, and the human body. Rn gas is especially widespread in soils, rocks, and granite, and is created by the decay of the U and Ra series. Several small sources of radiation exist in the home and persons in many occupations encounter radiation. Medical uses for radiation include therapy and diagnosis. This Fact Sheet is concerned with the soluble natural radionuclides found in water. Radionuclides in water are ingested by either drinking contaminated water or eating food that has been washed in the water. In the case of Rn, exposure occurs from inhalation of the gas or decay products released from water during household use. Higher levels of Rn are generally found in ground water rather than surface water.

SDWA Limits MCLs are: combined radium (Ra-226/Ra-228) = 5 pCi/L; gross alpha (excluding Ra and U) = 15 pCi/L; beta particle / photon emitters = 4 mrem/yr; uranium = 30 ug/L. Regulations are pending for Rn.

Health Effects Radionuclides are known human carcinogens. All three forms of radiation are dangerous to living things. Rn is associated with lung cancer; radium-226 is associated with bone sarcomas and head carcinomas; and radium-228 is associated with bone sarcomas. Other health effects include kidney damage and birth defects. Low level exposures can cause somatic and/or genetic defects. Somatic defects may include a higher risk of cancer, sterility, cataracts, or reduced life span. Genetic defects may include chromosome damage.

Protection against the three forms of radiation differ significantly. Our skin is sufficient protection for α emitters external to the body; however, taken internally (as through inhalation), α particles can be extremely dangerous. Beta particles can be stopped with shielding (i.e., 1 cm of aluminum). Gamma rays may require several centimeters of lead to provide adequate shielding.

Removal Techniques

USEPA BAT
Refer to individual treatment technique fact sheet for further information.

		BAT					
		AS	**GAC**	**IX**	**RO**	**Lime softening**	**Coagulation & filtration**
Radionuclide	**Rn**	X	X				
	U			anion	X	X	X
	α				X		
	β			mixed bed	X		
	Ra			cation	X	X	

- **Air Stripping** AS uses towers filled with material; water enters the top of the tower and is sprayed over the material, exposing a thin layer of water to countercurrent air being blown in at the bottom. The process allows for mass transfer of the Rn from water into air. AS off-gas is either discharged to the atmosphere or treated by vapor phase GAC. *Benefits*: removal efficiencies greater than 99.9%; best suited large installations. *Limitations*: risks associated with off-gassed Rn; requires ample space; requires careful monitoring.

- **Granular Activated Carbon** GAC uses extremely porous carbon media in a process known as adsorption. As water passes through the media, the dissolved contaminants are attracted and held (adsorbed) on the solid surface. *Benefits*: well established; suitable for home use. *Limitations*: too expensive for large systems; less effective than aeration; requires careful monitoring. GAC cost curves will be included in a future revision.

- **Ion Exchange** IX uses selectively charged resins to exchange acceptable ions from the resin for radionuclides in the water. *Benefits*: effective; well developed. *Limitations*: restocking of salt supply; regular regeneration; concentrate disposal.

- **Reverse Osmosis** RO uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids (radionuclides), to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.

- **Lime Softening** Lime softening uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Ra. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal.

- **Coagulation and filtration** Coagulation and filtration use the conventional treatment processes of chemical addition, coagulation, and dual media filtration. *Benefits*: low capital costs for proven, reliable process. *Limitations*: operator care required with chemical usage; sludge disposal.

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Revision Date: 09/30/09

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

Selenium Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Se

Chemical Data Selenium (Se), inorganic element, solid nonmetal, stable and sparingly soluble, atomic number 34, atomic weight 78.96. Oxidation states (in water): +4 (Selenite SeO_3^{2-}), +6 (Selenate SeO_4^{2-}), and -2 (Selenide Se^{2-}); +7 (Perselenate SeO_5^{2-}) is less common.

Source in Nature Se is a naturally occurring element found in soils, surface water, and ground water. The weathering of rocks and soils is the major naturally occurring source of Se in the environment. For industry and manufacturing, Se is not mined, but rather produced as a byproduct of copper refinery slimes. Se in various forms is used in dyes, insecticides, pigments, electronic devices, photocopying, glass manufacturing, veterinary medicine, anti-dandruff shampoos, feed additives, and pharmaceuticals. It is also a byproduct of mining, smelting, and coal/oil combustion processes. NPDES permits regulate Se effluent discharges from industry and manufacturing. Consequently, elevated concentrations of Se from anthropogenic sources in surface and ground water are typically a result of the irrigation of infertile land in arid areas where the parent soil materials are sedimentary rocks of marine origin. Se concentrations in agricultural runoff are a result of the leaching of the naturally occurring alluvial deposits in combination with the evaporation of the irrigation water.

SDWA Limits MCL for Se is 0.05 mg/L.

Health Effects Received in minute quantities as part of a normal nutritional diet, Se is an important antioxidant, key in maintaining the immune system. Exposure to toxic levels can result in liver and nervous system damage; growth inhibition; psychological disorders; digestive problems; irritation to mucous membranes; and dermatitis or skin discoloration.

Removal Techniques

USEPA BAT Coagulation and filtration; lime softening; reverse osmosis; electrodialysis; or activated alumina.
Refer to individual treatment technique fact sheet for further information.

- **Coagulation and filtration** Coagulation and filtration use the conventional treatment processes of chemical addition, coagulation, and dual media filtration. In general, Se^{+6} behaves like sulfate and is not easily removed as Se^{+4}, which forms insoluble complexes with iron, alum, etc. *Benefits*: low capital costs for proven, reliable process. *Limitations*: operator care required with chemical usage; not suitable for Se^{+6}; sludge disposal.

- **Lime Softening** Lime softening for Se treatment uses two types of chemical additions. First, $Ca(OH)_2$ is added in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness. Next, Na_2CO_3 is added to precipitate noncarbonate hardness. *Benefits*: proven and reliable. *__Limitations__*: operator care required with chemical usage; sludge disposal; does not remove SeO_4^{2-}.

- **Reverse Osmosis** RO uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids, to pass through the membrane. *__Benefits__*: produces highest (>99%) removal of SeO_4^{2-}, along with high quality water; concentrates SeO_4^{2-} with other solutes for removal from concentrate by other methods. *__Limitations__*: cost; pretreatment/feed pump requirements; concentrate disposal.

- **Electrodialysis Reversal** EDR uses semipermeable membranes in which ions migrate through the membrane from a less concentrated to a more concentrated solution as a result of the ions' representative attractions to direct electric current. *__Benefits__*: removes SeO_4^{2-}, more selective on contaminant removal, concentrates SeO_4^{2-} with other ionic solutes for removal from concentrate by other methods. *__Limitations__*: electrical requirements; concentrate disposal.

- **Activated Alumina** AA uses extremely porous and highly adsorptive aluminum ore media to adsorb Se. *__Benefits__*: containment of Se in adsorption bed. *__Limitations__*: when used with Se^{+4}, results in creation of hazardous waste requiring disposal; does not remove SeO_4^{2-}

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Revision Date: 09/30/09

Sulfate

Contaminant Data

Chemical Data Sulfate is a commonly occurring anion in groundwater and surface water. Low concentrations (<0.5 mg/L) of sulfate can encourage algal growth, however, sulfate concentrations greater than 250 mg/L can cause water to have a salty taste and may cause pipe and fixture corrosion.

Source in Nature Sulfate in water sources is often leached from rock or soil containing gypsum and other sulfate containing minerals. Sulfate can also come from wastewater plant or industrial plant discharges or from agricultural runoff. Sulfate salts with low molecular weight metals such as sodium, potassium, and magnesium are very soluble in water.

SDWA Limits Sulfate is included in the National Secondary Drinking Water Regulations which control contaminants in drinking water that primarily affect the aesthetic quality relating to public acceptance of drinking water. These regulations are not Federally enforceable, but are intended to serve as guidelines [1]. The Secondary MCL for sulfate is 250 mg/L.

Health Effects There are no known chronic adverse health effects from exposure to sulfate [2]. Elevated sulfate levels can cause health concerns when there is an abrupt change from drinking water with a low sulfate concentration to drinking water with a high sulfate concentration. Diarrhea is the main health effect caused by ingestion of drinking water with a high sulfate concentration [3].

Removal Techniques

USEPA BAT There is no BAT identified for sulfate removal.

Alternative Methods of Treatment Nanofiltration and ion exchange are the most commonly employed treatment techniques for sulfate removal.

- **Nanofiltration** Nanofiltration membranes for targeted sulfate removal are commercially available. These membranes reject other divalent ions such as calcium and magnesium and will also reject an anion (like sulphate) to maintain the water charge balance. These membranes are capable of approximately 98% removal of sulfate.

- **Ion Exchange** Sulfate selective ion exchange resins can also be used to selectively remove sulfate. Sulfate ions are exchanged with other anions from the resin, usually chloride.

References

1. § 143.2 40 CFR Ch. I (7–1–02 Edition)
(http://www.access.gpo.gov/nara/cfr/waisidx_02/40cfr143_02.html)

2. An Innovative Approach to Regulating a Naturally Occurring Contaminant, Fact Sheet, US EPA 811:F-94-006, November 1994.

3. Health Effects from Exposure to High Levels of Sulfate in Drinking Water Study and Sulfate Workshop, Federal Register, Volume 64, Number 28, 1999
(http://www.epa.gov/safewater/standard/sulfr.html)

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Revision Date: 09/22/10

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

Thallium Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Tl

Chemical Data Thallium (Tl), atomic number: 81, atomic weight: 204.37, oxidation states: +3 and +1; soft, malleable, inelastic metal resembling lead in appearance; assumes a bluish-gray tinge when exposed to air; very poisonous; not many uses; odorless and tasteless; gives no warning of its presence; member of the aluminum family of metals. Tl and its compounds have water solubilities ranging from low to high, depending on the salt formed. Tl alone is highly persistent in water, as it has only slight solubility.

Source in Nature Tl does not occur in the elemental state, but is found in trace amounts in the earth's crust as ores in potash minerals or as a byproduct from the smelting of metals such as pyrites, zinc, blende, and hematite. It can also combine with other substances such as bromine, chlorine, fluorine, and iodine. Tl has been detected in volcanic rocks, meteorites, and plants. It occurs in small amounts in all living organisms.

SDWA Limits MCL for Tl is 0.002 mg/L, and the MCLG is 0.0005 mg/L. Issues with raw water Tl concentrations exceeding MCLs are rare.

Health Effects Tl at short-term exposure levels above the MCL can cause vomiting, diarrhea, gastrointestinal irritation, peripheral neuropathy. Long-term exposure to Tl at levels above the MCL, can cause changes in blood chemistry, liver and kidney damage, damage to intestinal and testicular tissues, and hair loss. Contact between the metal and skin is dangerous and has caused death.

Removal Techniques

USEPA BAT Activated alumina or ion exchange.
Refer to: Individual Treatment Technique Fact Sheet if available for further information.

- **Activated Alumina** AA uses extremely porous and highly adsorptive aluminum ore media to adsorb Tl. *Benefits*: containment of Tl in adsorption bed. *Limitations*: when used with Tl^{+4}, results in creation of hazardous waste requiring disposal. AA cost curves will be included in a future revision.

- **Ion Exchange** IX for soluble Tl uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Tl in the water. *Benefits*: effective; well developed. *Limitations*: restocking of salt supply; regular regeneration; concentrate disposal.

Contact Information

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Revision Date: 09/30/09

RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

Total Dissolved Solids Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheets.

Contaminant Data

TDS

Chemical Data Total dissolved solids (TDS) or filterable residue are all of the dissolved solids in water. TDS consists of inorganic minerals (salts) in ionic (e.g., Na^+, Ca^{2+}, Cl^-, HCO_3^-) and organic material. TDS is measured on a sample of water that has been passed through a very fine filter (usually 0.45 micron) to remove the suspended solids. The water passing through the filter is evaporated (usually 103-105^{o}C) and the residue represents the TDS concentration (in mg/L). A conductivity test of water provides only an estimate of TDS, as conductivity is not directly proportional to the weight of an ion, and non-conductive substances cannot be measured by electrical tests.

Source in Nature Inorganic minerals (salts) are commonly found in nature through the weathering and dissolution of rocks. Organic material is also naturally occurring in nature, as a result of decaying organisms, plants, and animals, and a portion of this will be in dissolved form. Most TDS sources are anthropogenic in nature through agricultural runoff, point source water pollution, and industrial and sewage discharge. Higher concentrations of TDS may occur during and after precipitation events.

SDWA Limits SMCL for TDS is 500 mg/L.

Health Effects As a secondary drinking water contaminant, TDS does not pose substantial health risks at drinking water concentrations. Na_2SO_4 concentrations above 250 mg/L may produce a laxative effect. Excess sodium may affect those restricted to low-sodium diets or pregnant women suffering from toxemia. TDS concentrations above the SMCL may impart an objectionable taste, odor, and color to drinking water. Other aesthetic concerns include an indicator of corrosivity, scaling, and limiting the effectiveness of detergents.

Removal Techniques

USEPA BAT As TDS is a secondary drinking water contaminant, BATs are not assigned.
Refer to individual treatment technique fact sheets for further information.

Alternative Methods of Treatment: The most common treatment processes for removing TDS are reverse osmosis and electrodialysis.

- **Nanofiltration/Reverse Osmosis** NF/RO uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids, to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.
- **Electrodialysis Reversal** EDR uses semipermeable membranes in which ions migrate through the membrane from a less concentrated to a more concentrated solution as a result of the

ions' representative attractions to direct electric current. *Benefits*: contaminant-specific removal. *Limitations*: electrical requirements; concentrate disposal.

- **Freezing and Distillation** Freezing and distillation can be used for higher concentrations of TDS, as found in sea water or brackish water (<3000 mg/L); ion exchange can also be used but has limited effectiveness in concentrations <3000 mg/L.

Related WTTP Publications

1. WTTP Report #6, "Preliminary Research Study of a Water Desalination System for the East Montana Area Subdivisions of El Paso County, El Paso, Texas." This report summarizes the field study performed to determine the economics of several water treatment processes, including RO, ED, and multistage flash distillation, on brackish groundwater; concluded RO with surface water reject disposal was the most economical for the study area.
2. WTTP Report #15, "Maricopa Groundwater Treatment Study." This report summarizes the field study performed to determine the suitability of several water treatment processes, including RO, ED, and NF, on groundwater containing high levels of nitrate, chloride, and TDS; recommends the use of NF or ED for study area.

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Turbidity and Total Suspended Solids Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheet.

Contaminant Data

Chemical Data Turbidity is the reduction of clarity in water due to the presence of suspended or colloidal particles. Turbidity is measured by the amount of light that is reflected by the particles. Turbidity is commonly used as an indicator for the general condition of the water.

The suspended or colloidal particles, commonly referred to as total suspended solids (TSS), are the particles in water that will not settle out by gravity. TSS is measured on a sample of water that has been settled and consists of those particles that will not pass through a very fine filter (usually 0.45 micron). The filter is pre-weighed prior to passing of the water, and post-weighed. The difference in the two weights is the TSS concentration (in mg/L).

Source in Nature Turbidity in surface water consists of several naturally occurring or introduced types of organic matter and inorganic minerals, including clays, silts, industrial wastes, sewage, algae, and plankton. Turbidity increases during spring runoff and during rainstorms as a result of increased overland flow and erosion. Ground water is usually less susceptible to turbidity because of the natural filtering capabilities of the earth layers it passes through. Turbidity in a water distribution system can result from a water-main disturbance, excessive flow rates causing scouring, or chemical and biological processes.

SDWA Limits For systems required to use the treatment technique (TT), the MCL is <5.0 NTU at all times; <0.5 NTU in 95% of all samples using conventional and direct filtration; and <1.0 NTU in 95% of all samples using diatomaceous earth, slow sand, and all other filtration techniques. EPA requires daily monitoring for turbidity.

Health Effects Turbidity is an indicator of potentially harmful water constituents The major concern with turbidity is that it interferes with the disinfection process by consuming the disinfectant intended for the pathogens in the water. Turbidity can harbor or carry pathogens which, if not killed, can result in several waterborne diseases.

Removal Techniques

USEPA BAT For community surface and ground water (under the direct influence of surface water) systems TT is required. In this case, the accepted treatment technique is the use of the conventional treatment processes of chemical addition, coagulation and flocculation, clarification, and dual media filtration. *Benefits*: proven; reliable. *Limitations*: initial investment.
Refer to: Individual Treatment Technique Fact Sheet if available for further information.

Alternative Methods of Treatment Direct filtration may be substituted for the complete treatment where the utility has demonstrated, through adequate pilot-plant studies, that the water will consistently meet the USEPA MCL. Microfiltraton and ultrafiltration can also be used to remove turbidity.

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Zinc Fact Sheet

See related information: Acronyms & Abbreviations; Glossary of Terms and Treatment Technology Fact Sheets.

Contaminant Data

Chemical Data Zinc (Zn), atomic number: 30, atomic weight: 65.38, a bluish-white, lustrous metal extracted from certain ores. Oxidation state is +2. Used to form numerous alloys with other metals and as a galvanizing agent.

Zn

Source in Nature Zn is found in natural deposits in the environment. Zn is found in paints and dyes and may also come from industrial/mining contamination. Zn can be found in water distribution systems as a result of leaching of brass and galvanized iron pipes and fittings. Excessive Zn in water supply systems can result in corrosion of plumbing materials.

SDWA Limits SMCL for Zn is 5.0 mg/L.

Health Effects Zn, in small amounts, is an essential and beneficial element in human and animal metabolism. As a nutrient, Zn can be obtained from eating a balanced diet or taken as an additional supplement. Excessive Zn can give drinking water an undesirable, metallic taste and may cause water to appear milky. Upon boiling, water may appear to have a greasy surface scum. At concentrations of 40 mg/L or greater and with prolonged consumption, Zn poisoning is possible. Although Zn is not considered to be toxic, it may act as a gastrointestinal irritant.

Effects on Aquatic Life Zn, in concentrations as low as 0.05 mg/L, may become toxic to fish and invertebrates, resulting in reduced breeding and/or death of aquatic life.

Removal Techniques

USEPA BAT As Zn is a secondary drinking water contaminant, BATs are not assigned. Refer to individual treatment technique fact sheets for further information.

Alternative Methods of Treatment The treatment method used to remove Zn will be a function of the treated water requirements and flow rates. The most common methods of treatment to remove Zn include distillation, ion exchange, reverse osmosis, and lime softening. For individual well systems, distillation or IX may be the best selections. For municipal water systems, IX or RO may be the best selections. Lime softening is used when Zn concentrations must be reduced to 0.05 mg/L or below to meet the aquatic standard.

- **Distillation** Distillation heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The Zn remains in the boiler section. Generally, distillation for Zn removal is considered a POU process. *Benefits*: kills bacteria and viruses; well established. *Limitations*: high energy requirements; postfiltration may be required.

- **Ion Exchange** IX for soluble Zn uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Zn in the water. *Benefits*: effective; well developed. *Limitations*: restocking of salt supply; regular regeneration; concentrate disposal.

- **Reverse Osmosis** RO for soluble Zn uses a semipermeable membrane and the application of pressure to a concentrated solution, which causes water, but not suspended or most dissolved solids (soluble Zn), to pass through the membrane. *Benefits*: produces high quality water. *Limitations*: cost; pretreatment/feed pump requirements; concentrate disposal.

- **Lime Softening** Lime softening for soluble Zn uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Zn. *Benefits*: lower capital costs; proven and reliable. *Limitations*: operator care required with chemical usage; sludge disposal; insoluble Zn compounds may be formed at low carbonate levels, requiring coagulation and flocculation.

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