RECLAMATION
Managing Water in the West

Impacts of Reused/ Reclaimed Water:
Organisms and Chemicals of Concern

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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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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Acronyms and Abbreviations

AAS- atomic absorption spectrometry
AES- atomic emission spectroscopy
BAC-biological activated carbon
BOD_5-biological oxygen demand
CWAR- clean water act requirement
DAPI (4', 6-diamidino-2-phenylindole) staining
DBP- disinfection by-product
DIC-differential interference contrast microscopy
DPD column
EAAS- electro thermal atomic absorption spectrometry
EC- electron capture
ECD- electron capture detector
ELISA- enzyme linked immunosorbent assay
FA- immunofluorescence assay
FAAS- flame atomic absorption spectrometry
FD- fluorescence detector
FID- flame ionization detector
FPD- flame photodiode detector
GAC- granular activated carbon
GC- gas chromatography
HPLC- high performance liquid chromatography
IC- ion chromatography
ICP- inductively coupled plasma
LC- liquid chromatography
IMS- ion mobility spectrometry
IMS- Immunomagnetic separation
MF-membrane filtration
MS- Mass spectroscopy
NF- nanofiltration
PAC- powdered activated carbon
PCR- polymerase chain reaction
PD- photoionization detector
PT- purge and trap
RO- reactive oxygen
SOP- standard operating procedure
SAT- soil aquifer treatment
TDS- total dissolved solids
UF- ultrafiltration
UV- ultraviolet
UV/H_2O_2- ultraviolet hydrogen peroxide
UVPAD- ultraviolet photodiode array detector

Executive Summary

The use of recycled municipal wastewater for drinking and agricultural use will become more common in the Western United States in the presence of drought and population increase. Implementation of water reuse practices is difficult because of the many potential hazards to human, plant and environmental health. Many of the potential hazards are poorly understood and little is known about specific detection and treatment methods. The goal of this literature review is to compile a list of organisms, chemicals, and other issues that may have potential impacts on the recipients of reused and reclaimed water. The following tables list the issue of concern, its known impact on animal, plant, or environmental health, the dose or level of concern, and the known detection and treatment methods

Introduction

Use of recycled municipal wastewater can significantly increase the nation's available water resources, especially in the Western United States, where water supply challenges are occurring as a result of climate change, drought, and increasing population. While many treatment options are available, water reuse is limited in the United States because of safety, technical, and financial challenges. Reused water can contain concentrations of naturally occurring substances or any substance used or excreted by humans. The impacts of this concentrated water on humans and the environment are not completely understood. Treatments need to be redundant, reliable, robust and diverse to function as a barrier for multiple contaminants, and facilities need detection and monitoring plans and the ability to divert water that does not meet standards.

The risks associated with reused water depend on the waters end use. Reused water can be used for human or livestock consumption, agricultural and landscape irrigation, manufacturing, and aquatic ecosystems. Each end use application requires a diverse level of treatment and the impacts of each component on each recipient are different. Continuously recycled water, containing accumulated constituents can become difficult to treat. There are a wide variety of microorganisms, organic chemicals, inorganic chemicals, disinfectants, disinfectant byproducts, pharmaceuticals and other compounds that need to be considered when treating reused water. The challenge is determining what levels are harmful for each end use application and developing effective detection methods for each.

The goal of this literature review is to compile a list of organisms, chemicals, and parameters that may have potential impacts on the recipients of reused and reclaimed water. The following tables list the issue of concern, its known impact on animal, plant, or environmental health, the dose or level of concern, and the known detection and treatment methods. Pathogens and chemicals that are highlighted in blue are currently regulated by the Environmental Protection Agency (EPA). Categories that are not highlighted are either regulated by a state or are of emerging concern. There is an even longer list of chemicals and pathogens of emerging concern that the EPA is studying to determine the potential long-term and short-term impacts. The EPA's list of contaminants of emerging concern can be found at http://www2.epa.gov/ccl/draft-contaminant-candidate-list-4-ccl-4.

It is important to note that some of the pathogens listed in this table are not native to North America and thus do not present an immediate threat to our water supplies. The reason they are included in these tables is because travelers from the countries where the pathogens are endemic could come to the United States and inadvertently release one of these pathogens into the wastewater system. For example, the Ebola patients from the recent outbreak who received treatment in hospitals in the US could have caused a release of this virus into the water.

The infectious dose of pathogens is not always known, but for many, exposure to a single organism can be enough to cause illness. There are a variety of pathogens that cause illness that have not yet been described or named. Indicator organisms are commonly used to detect pathogens because it is not efficient to test for every pathogen of concern due to the large number of pathogens in the environment.

There are a variety of chemicals that can cause human and environmental health issues, through either short term or chronic exposure. Often, the effect of long term exposure to many chemicals is unknown because long term animal studies are expensive and can be hard to analyze. The list compiled here is of chemicals of known concern. Finally, even though they might not cause human health issues there are chemicals and organisms that can change the taste, odor, and appearance of water. These are of concern because the consumer would not want to drink water that appears substandard. The following tables do not contain all potential issues of concern, and will need to be updated as new research becomes available.

The following references were used throughout the entire document [1][2][3][4][5]–[22]

The EPA's standard methods for detection can be found at: http://water.epa.gov/scitech/drinkingwater/labcert/analyticalmethods.cfm

Bacteria

Example	Human Disease	Infectious Dose (# of organisms)	EPA Regulation	Specific Detection Methods
Acinetobacter spp. [23]	Nosocomial	Unknown, low virulence	Heterotrophic plate count (HPC): Total Coliforms (TC)	
Aeromonas spp. (aeromonads) [24]	Septicemia, gastrointestinal illness (unconfirmed)		HPC:TC	
Atypical mycobacteria	Respiratory illness: hypersensitivity pneumonitis (do not cause TB or leprosy)	Widespread in the environment	HPC:TC	
Bacillus spp.	*B. cereus* (food poisoning) *B. anthracis* (anthrax)		HPC:TC	
Burkholderia pseudomallei	melioidosis		HPC:TC	
Campylobacter jejuni [25]	Campylobacteriosis, gastroenteritis, reactive arthritis, Guillain-Barre syndrome,	10^3-10^4 (although 10-500 can be enough to infect humans)	HPC:TC	PCR method [26]
Clostridium perfringens [27]	Gastroenteritis	1-10^{10}	HPC:TC	PCR methods [28]
Enteropathogenic *Escherichia coli* (not all strains of *E. coli* are harmful)	Hemorrhagic diarrhea gastroenteritis and septicemia, hemolytic uremic syndrome (HUS), from drinking water	10^6-10^{10}	HPC:TC MCL: repeat any sample that is fecal coliform-positive or E. coli-positive, positive repeats violate MCL	EPA method: 1103.1, 1603, 1604 PCR methods [29]–[32]
Helicobacter pylori [33]	Chronic gastritis, ulcers, gastric cancer, drinking water	10^4	HPC:TC	
Legionella (*L. pneumophila*) [34]	Legionellosis (Legionnaire's disease) Respiratory illness, pneumonia, Pontiac fever when	Has not been calculated, the quantitative counts	HPC:TC TT: No limit but should be removed with *Giardia* and	Culture methods reference [38], [39]

	bacteria is aerosolized	of Legionella do not correlate with incidence [35]–[37]	virus control	
Leptospires (Leptospira and Leptonoma)	Leptospirosis	Unknown	HPC:TC	
Mycobacterium avium intracellular (MAC)	Chronic lung diseases, thoracic skeletal abnormalities, people with AIDS, or lymph reticular malignancies, and post transplantation immunosuppressive therapy most at risk Fevers, diarrhea, and malabsorption, drinking water	Unknown	HPC:TC	
Pseudomonas aeruginosa	Skin eye, ear infections		HPC:TC	
Salmonella typhii [40] Salmonella: 1700 serotypes	Salmonellosis, gastroenteritis reactive arthritis, typhoid fever, from drinking water	10^4-10^7	Total Coliforms (TC): No more than 5.0% of samples total coliform-positive in a month. If a sample is positive must be analyzed for fecal coliforms or *E. coli*	EPA method: 1604, 1680, 1681, 1682 [41]
Shigella (4 spp.) (*S. dysenteriae, S. flexneri, S.boydii, S. sonnei*) [42]	Shigellosis (dysentery), from drinking water	180 (*S. flexneri* 2A) 10 (*S. dysentariae*)	HPC:TC	
Staphylococcus aureus	Skin, eye, ear infections, and septicemia		HPC:TC	

Vibrio cholera [43]	Gastroenteritis, wound infection cholera	10^3-10^7	HPC:TC	EPA method: 600/R-10/139
Yersinia enterocolitica (naktin beavis 1999)	Yersiniosis, gastroenteritis, and septicemia	100-20,000 organisms	HPC:TC	

Bacteria are single cellular prokaryotes that lack organelles. An issue of emerging concern with bacteria is antibiotic resistance. The genes that code for antibiotic resistance can be transferred between bacteria.

Infectious dose-the amount of pathogen (measured in number of microorganisms) required to cause an infection in the host

Water treatment methods for bacteria:

High efficiency: Reverse osmosis, chlorine, ozone, UV, UV/H_2O_2, soil aquifer treatment (SAT), riverbank filtration

Low efficiency: PAC/GAC (activated carbon), chloramine, BAC, direct inj. wetlands, reservoirs [35]–[37], [44]

General Detection Methods:

Total coliform samples (TC): No more than 5% of samples collected can be total coliform-positive in a month, heterotrophic plate count (HCP): an analytical method used to measure the presence of a variety of bacteria, polymerase chain reaction (molecular methods), direct immunofluorescence (antibody staining)

Common microbial indicator organisms used to detect other bacteria include:

Escherichia coli, *Clostridium perfringens*, enteric bacteria (*Campylobacter)*

End Use Concerns:

People can easily get infected and sick from drinking infected water. Farm workers can get infected and sick from indirect water reuse via agricultural irrigation. Bacteria are able to get onto agricultural products via reused water and people can get infected and sick from consumption.

Immunocompromised individuals (children, pregnant women, the elderly, etc.) are more vulnerable populations than healthy individuals.

General references for bacteria table: [21], [35]–[37], [44]–[76]

Protozoa

Example	Human Disease	Infectious Dose	EPA Regulation	Specific Detection Methods
Balantidium coli [77]	Balantisiasis (dysentery)			
Cryptosporidium[78]	Cryptosporidiosis, diarrhea, fever	1-10 units	TT: 99% removal (filter systems), required control	Method 1632.1 [79][80] Filtration/IMS/FA
Cyclospora [81]	Cyclosporiasis (diarrhea, bloating, fever, stomach cramps, and muscle aches)	1-10^2 organisms		Microscopy [82]
Entamoeba histolytica most prevalent worldwide [83]	Amebiasis (amebic dysentery)	20 units		PCR, ELISA [84]–[89]
Giardia lamblia (also called: G. intestinalis, or G. duodenalis)[90]	Giardiasis (gastroenteritis)	<10 units	TT: 99.9% removal/ inactivation	Method 1632.1 [80] , Filtration/IMS/FA
Microsporidia (general term for a large group of primitive, obligate, intracellular protozoa, almost 1000 species identified [91]	Microsporidiosis, for AIDS patient's severe enteritis with chronic diarrhea, dehydration and weight loss.			PCR, microscopy [92]–[94]
Naegleria fowleri [95]	Brain eating amoeba, fatal, primary amoebic meningoencephalitis (PAM)			Molecular and immunological methods [92] [93]

Protozoa are their own kingdom of organisms. They are unicellular eukaryotes that have motility and can be predatory. The free living forms are able to form cysts to survive drying out. Some of them are parasites and can cause human disease that can be transmitted by water, food, or insects.
Infectious dose-the amount of pathogen (measured in number of microorganisms) required to cause an infection in the host

Water treatment methods for protozoa:

High efficiency: MF/UF, NF/RO, UV, UV/H_2O_2, SAT, riverbank filtration
Low efficiency: PAC/GAC, Chloramine, BAC granular media, membrane filtration, may be resistant to disinfection, Wetlands, Reservoirs
Treated with either a “removal” or an “inactivation” process the occurrence of infectious cryptosporidium oocysts in raw, treated, and disinfected water, can be inactivated using UV disinfection [3]

Indicator Organisms

Giardia lamblia, Cryptosporidium parvum

General Detection methods: PCR, microscopy, immunological methods such as ELISA
End use concerns:
Direct reuse- people get infected and sick from drinking water. Indirect reuse- people get infected and sick from consuming plant products that were watered with reused water.
General references for protozoa table: [35], [51], [67], [68], [71], [98]–[105]

Helminthes

Example	Human Disease	Infectious Dose	Detection Methods
Ancylostoma duodenale	Ancylostomiasis (hookworm infection)		PCR [106]
Ancylostoma	Cutaneous larva migrams (hookworm infection)		
Ascaris lumbricoides	Ascariasis (roundworm infection)	1-10 units	
Dracunculus medinensis	Guinea worm, eradication program, now restricted to a central belt of countries in sub-Saharan Africa, ingested by many species of Cyclops which in turn are then swallowed in drinking water. Only pathogen solely transmitted through drinking water		
Echinococcus granulosis	Hydatidosis (tapeworm infection)		
Enterobius vermicularis	Enterobiasis (pinworm infection)		
Fasciola	Liver flukes		
Necator americanus	Necatoriasis (roundworm infection)		PCR [106]
Strongyloides stercoralis	Strongyloidiasis (threadworm infection)		
Taenia (spp.)	Taeniasis (tapeworm infection), neurocysticercosis		
Trichuris trichiura	Trichuriasis (whipworm infection)		

Helminthes are free living nematodes. In some cases, the motile larvae are pathogens such as hookworms and threadworms. Some are capable of moving themselves through sand filters and may be introduced into the drinking water distribution system as a result of fecal contamination [22]. The concentration of free living nematodes in raw water generally corresponds to the turbidity of the water. The higher the turbidity, the larger the concentration of free-living nematodes there will be [22]. Note: none of these organisms are currently regulated by the EPA. The infectious dose of these organisms is hard to find, it is possible that a single organism is enough to cause a parasitic infection.
Infectious dose-the amount of pathogen (measured in number of microorganisms) required to cause an infection in the host

Treatment methods:

Effective: Secondary treatment, supplemented by finishing ponds, filtration, disinfection Sedimentation, filtration, UV
Some may be resistant to disinfection

General Detection Methods:

Visual identification using microscopy, molecular methods

End use concerns:

Drinking contaminated water and directly getting sick. Eating produce that was watered with reused water and then becoming sick.

General references for helminth table: [22], [35], [59], [71], [99], [107]–[114]

Viruses

Example	Human Disease	Infectious Dose	EPA Regulation	Detection Methods
Adenovirus (47 types)	Conjunctivitis, gastroenteritis, respiratory disease, pharyngoconjunctival fever	1-10 units	TT: 99.99% removal/ inactivation	EPA Method: 1615 [115], [116]
Astrovirus (5 types)	Gastroenteritis	1-10 units		Tissue culture, PCR [117]
Caliciviruses (including Norovirus and Sapovirus)	Gastroenteritis	1-10 units		
Coronavirus (ex SARS)	Gastroenteritis	1-10 units		
Coxsackieviruses	Meningitis, pharyngitis, conjunctivitis, encephalitis	1-10 units		
Echoviruses	Gastroenteritis, encephalitis, meningitis	1-10 units		
Enteroviruses (72 types)(polio, echo, coxsackie, new enteroviruses, serotype 68 to 71)[118]	Gastroenteritis, heart anomalies, meningitis, respiratory illness, nervous disorder, others	1-10 units		EPA Method: 1615 [115]
Hepatitis A and E	Infectious hepatitis	1-10 units		
Norwalk agent	Diarrhea, vomiting, fever	1-10 units		
Parvovirus (3 types)	Gastroenteritis	1-10 units		PCR [119]
Reovirus (3 types)	Not clearly established	1-10 units		
Rotavirus (4 types) and Orthoreoviruses	Gastroenteritis	1-10 units		

Over 100 enteric viruses are excreted from humans that are capable of causing an infection or disease. This table contains families of viruses that cause disease. Few laboratories possess the expertise for proper analysis [120]

Treatment methods:

High efficiency: NF/RO, chlorine, ozone, UV/H_2O_2

Low efficiency: Filtration, PAC/GAC, MF/UF, chloramine, BAC, direct inj., wetlands, reservoirs

General Detection Methods:

Molecular methods such as polymerase chain reaction, cell and tissue culture methods

General references for virus table: [64], [69], [71], [98], [121]–[140]

Critical Water Quality Parameters

Parameter	Example	Source	Issue	Levels of Concern	Treatment Methods	Detection Methods
Salts	Salinity	Naturally occurring, & from laundry detergents	Affects crop water availability	EC >0.7ds/m TDS>450	TDS effectively removed by NF/RO, distillation, electro dialysis, or dilution with less salty water. Treatment options for salinity are limited and costly	Electrical conductivity measurement, ion analysis
	Calcium, magnesium chloride		Infrastructure damage (scaling and corrosion)			
	Sodium, chloride		Can be toxic to plants and cause soil permeability issues	Na>70 mg/L Cl>100 mg/L		
Nutrients	Nitrate	Runoff from fertilizer use, leaching from septic tanks, sewage, erosion of natural deposits	Infants below 6 months could become seriously ill and may die if untreated (shortness of breath, and blue-baby syndrome)	MCL= 10 mg/L nitrate	High efficiency for Nitrate: NF/RO, SAT, Riverbank filtration Low-no efficiency for Nitrate: Filtration, PAC/GAC, MF/UF, Chloramine, Chlorine, Ozone, UV, UV/H_2O_2, BAC, Direct inj. [141][142]	EPA Method: 352.1
	Nitrite			MCL= 1 mg/L		EPA Method: 353.1
	Ammonia (NH_3) Ammonia hydroxide (NH_4OH)	Metabolic, agricultural, and industrial processes [22]	Not of immediate health relevance, can compromise disinfection efficiency and cause failure of filters to remove manganese and cause taste/odor problems [22]	Natural level 0.2 mg/L No level of concern has been proposed [22]		EPA Method: 350.1 (ammonia nitrogen)
	Nitrogen and phosphorous	Human and animal waste products	Eutrophication (rapid growth of algae)-oxygen depletion, alteration of trophic state, biofilms [143]	Total-N >5 mg/L(irrigation)		EPA method (nitrogen): 351.1, 351.2 EPA method (phosphorus): 365.1, 365.3, 365.4
	Bicarbonate		Impacts susceptible crops	HCO_3 >90 mg/L		
Suspended Solids	Measure of suspended material		Contaminants and heavy metals etc. can be adsorbed on particulates, shield microorganisms from disinfectants, sludge deposits and anaerobic conditions in aquatic			Grab samples, not continuous monitoring

			environment, clog irrigation systems			
Turbidity	Measure of water cloudiness	Soil runoff	Can indicate effectiveness of water quality and filtration, and if disease-causing organisms are present	TT: When conventional or direct filtration used, turbidity cannot be greater than 1 NTU (nephelometric turbidity units)		EPA Method 180.1
pH	Hydrogen ion concentration		Impacts disinfection efficacy, coagulation, metal solubility, and alkalinity. (Important at all stages of the treatment process to ensure water clarification and disinfection)	Normal Range 6.5-8.4		pH meter/ strip EPA Method 150.2
Dissolved Oxygen	Biochemical oxygen demand (BOD)		Elevated BOD leads to reduced oxygen levels inadequate to support aquatic organisms	Target BOD, 20 mg/L (indicator of sewage treatment plant effectiveness)	Ultrafiltration or nanofiltration	BOD_5 measurement
Hardness	calcium carbonate and magnesium	Naturally occurring, dissolved in water [22]	Inverse relationship between hardness of water and cardiovascular disease [22], mineral balance			EPA method 130.1

The chemicals and properties in this table can also be related to water taste, odor, and smell and can impact the effectiveness of water treatment
General references for water quality table: [144]–[146]

Metals

Example	Source	Issue	Long Term Use mg/L (irrigation)	Short Term Use mg/L (irrigation)	EPA Regulation/Suggestion (human)	Detection Methods
Aluminum	Most abundant metallic element, used in water treatment as a coagulant [22]	Non-productivity in acid soils Little indication that when ingested it is acutely toxic to humans [22]	5.0	20.0	50-200 ug/mL	EPA Method: 200.7
Arsenic	Runoff from orchards and glass and electronics waste	Variable plant toxicity, skin damage, circulatory issues, increased cancer risk (EPA), long term exposure dermal lesions after 5 years, cardiovascular effects in children after 7 years of consumption [22][147]	0.10	2.0	MCL:0.010 mg/L	EPA Method: 206.5, 200.7 ICP/MS; hydride generation AAS or FAAS
Beryllium	Discharge from metal refineries and coal burning factories, electrical, aerospace, and defense industries	Variable plant toxicity, intestinal lesions in humans	0.10	0.5	MCL:0.004 mg/L	EPA method: 200.7
Boron	Usually present in compounds, used as additive for fiberglass, fertilizers	Toxic to sensitive plants (citrus), compounds are toxic to arthropods and can be used as insecticides	0.75	2.0	600 ug/L	EPA method: 200.7
Cadmium	Corrosion of galvanized pipes, discharge from metal refineries, runoff from waste batteries and paints	Toxic to beans, beets, turnips, kidney damage in humans	0.01	0.05	MCL: 0.005 mg/L	EPA Method: 200.7 ICP/MS; FAAS [22] Coagulation or precipitation softening [22]
Chromium	Discharge from steel and pulp mills, chromium bioremediation of tannery effluent	Toxicity to plants unknown and humans at high doses, allergic dermatitis	0.1	1.0	MCL: 0.1 mg/L	EPA method: 200.7 (218.6 hexavalent chromium) AAS [22] [148]
Cobalt	Primary used in the preparation of magnetic, wear-resistant, and high strength alloys	Toxic to tomato plants	0.05	5.0	0.7 ug/L (AZ); 40 ug/L (WI)	EPA method: 200.7

Copper	Corrosion of household plumbing	Toxic to many plants, gastrointestinal distress, liver or kidney damage	0.2	5.0	TT: 10% of samples exceed 1.3 mg/L	EPA method: 200.7 ICP/MS; ICP/optical emission spectroscopy, FAAS [22]
Fluoride	Water additive, discharge from fertilizer and aluminum factories	Bone disease, skeletal fluorosis	1.0	15.0	MCL: 4.0 mg/L	EPA method: 9214 IC; ion-selective electrodes; SPADNS colorimetric method [22]
Iron	Most widely used metal, usually smelted with other alloys to become harder	Contributes to soil acidification, loss of phosphorous and molybdenum	5.0	20.0	300 ug/L	EPA method: 200.7
Lead	Corrosion of household plumbing	Inhibits plant cell growth at high concentrations, delays physical or mental development in children, kidney problems and high blood pressure in adults	5.0	10.0	TT: More than 10% of samples exceed 0.015 mg/L	EPA method: 200.7 AAS [22]
Lithium compounds	Ceramics and glass, batteries, lubricating greases, a wide range of uses	Toxic to citrus at low doses	2.5	2.5	No standards	EPA method: 200.7
Manganese		Toxic to many crops in acid soils	0.2	10.0	50 ug/L	EPA method: 200.7 AAS, ICP/MS, ICP/optical emission spectroscopy, EAAS, FAAS [22]
Mercury	Discharged from refineries and factories, runoff from landfills and croplands	Toxic to humans and plants at high levels, kidney damage			MCL: 0.002 mg/L	EPA methods: 245.1, 245.2, 245.7, 200.7, 1631 Cold vapor AAS, ICP, FAAS [22]
Molybdenum	High pressure and high temperature applications such as pigments, and used as catalysts	Nontoxic to plants at normal concentrations, toxic to livestock	0.01	0.05	40 ug/L	EPA method: 200.7 Graphite furnace AAS, ICP/AES [22]
Nickel	Nickel steels, nonferrous alloys and super alloys, electroplating, other uses	Toxic to many plants	0.2	2.0	100 ug/L	EPA method: 200.7 ICP-MS, FAAS, ICP-AES [22]
Selenium	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines	Toxic to plants and livestock Hair or fingernail loss; numbness in finger or toes; circulatory problems	0.02	0.02	0.05 mg/L	EPA method: 200.7 AAS with hydride generation [22]

Vanadium	Mostly used as an alloy called ferrovanadium as an additive to improve steels	Toxic to many plants at low concentrations	0.1	1.0	7 ug/L (AZ), 49 ug/L (FL), 50 ug/L (MN), 30 ug./L (WI), 30 ug/L (CA)	EPA method: 3050B
Zinc	Galvanizing, alloys, brass and bronze, miscellaneous	Toxic to many plants, reduced at high pH and in fine-textured soils	2.0	10.0	Max level: 5 mg/L (CWAR), 5000 ug/L (EPA secondary MCL), 2000 ug/L (EPA Lifetime health advisory), 5000 ug/L (AZ), 2000 ug/L (MN)	EPA Method: 245.1, 245.1, 245.7, 289.2

Many metals are regulated by the clean water act requirement (CWAR)
General Treatment Methods:
High efficiency: NF/RO, SAT, riverbank filtration, direct inj., ASR, wetlands, reservoirs, electro-dialysis
Low efficiency: Chlorine, ozone, UV, UV/H_2O_2, filtration, PAC/GAC, MF/UF, chloramine, BAC
General Detection Methods: Mass spectrometry
End Use Concerns: Some metals are toxic to humans, but many pose a greater threat to agriculture, reused water with concentrated metals can cause damage to plants
General references for metals table: [149]–[151]

Water Treatment Chemicals (DBP: Disinfection Byproducts)

Example	Source	Issue	EPA Regulation/Suggestion (human)	Treatment	Detection Methods
Acrylamide	Sewage treatment, concentrations of a few micrograms per liter have been detected in drinking water [22]	Nervous system and blood issues, carcinogen	TT: 0.05% dosed at 1 mg/L	Residual monomer occurs in polyacrylamide coagulants used in water treatment [22]	EPA method: 8316, 8032A GC, HPLC, HPCL with UV detection [22]
Chloramines	Water additive used to control microbes	Eye/nose irritation, stomach discomfort	MRDL= 4.0	Limit use	HPCL/MS [152]
Chlorine	Water additive used to control microbes, used as an disinfectant and bleach	Eye/nose irritation, stomach discomfort	MRDL= 4.0	Limit use	EP method: 334.0 HPLC, Calorimetry, ion chromatography [22]
		Leaf tip burn, damaging to plants	Concentrations > 0.05 mg/L		
Chlorine dioxide	Water additive used to control microbes	Anemia in young children, and nervous system effects	MRDL= 0.8	Limit use	EPA method: 327.0 DPD colorimetric test kits if the state approves
Chlorite	Byproduct of drinking water disinfection	Anemia in young children, and nervous system effects	MCL= 1.0 mg/L		EPA method: 300.1, 327.0

Haloacetic acids (HAA5) Dichloroacetonitrile, dibromoacetonitrile, bromochloroacetonitrile, trichloroacetonitrile	Byproduct of drinking water disinfection, dichloroacetonitrile is most predominate	Increased cancer risk	MCL= 0.060 mg/L	Reduce organic precursors will reduce their formation [22]	EPA method: 552.3 GC with an ECD [22]
Total Trihalomethanes (TTHMs)	Byproduct of drinking water disinfection	Liver, kidney, central nervous system problems, increased cancer risk	MCL= 0.080 mg/L	Concentrations can be reduced by changes to disinfection practice or air stripping [22]	EPA method: 501.2 Purge and trap and liquid-liquid extraction and direct aqueous injection in combination with a chromatographic system, GC with ECD, GC/MS [22]

General references for water treatment chemicals table: [153]–[155][156][157], [158]

Industrial and Production Chemicals

Example	Source	Issue	EPA Regulation/Suggestion (human)	Treatment	Detection Methods
Acrylamide	Sewage treatment	Nervous system and blood issues, carcinogen	TT: 0.05% dosed at 1 mg/L	Conventional treatment processes do not remove. Controlled by limiting either the acrylamide content of polyacrylamide flocculent or the dose used or both [22]	EPA method: 8316 HPLC, HPLC with UV detection [22]
Antimony	Petroleum refineries, fire retardants, ceramics, electronics, metal plumbing and fittings [22]	Increase in blood cholesterol, decrease in blood sugar	MCL: 0.006 mg/L	Conventional treatment methods do not remove, not a raw water contaminant [22]	EPA method: 7062 EEAS, ICP/MS, graphite furnace AAS, hydride generation AAS [22]
Barium	Discharge of drilling waste, from metal refineries, and erosion of natural deposits	Increased blood pressure	MCL: 2 mg/L	Ion exchange, reverse osmosis, lime softening, and electro dialysis	ICP/MS; AAS; ICP/optical emission spectroscopy [22]

Benzene	Discharge from factories, landfills, storage tanks, used in production of other organic chemicals, petrol, and vehicular emissions	Anemia, reduced blood platelets, cancer risk	MCL: 0.005 mg/L	0.01 mg/L should be achievable using GAC or air stripping [22]	EPA method: 8260B, 8021B, 8260, 524.2 GC with photoionization detection [22]
Benzo(a)pyrene (PHAs)	Leach from linings of water storage tanks and distribution lines	Anemia, reduced blood platelets, cancer risk	MCL: 0.0002 mg/L		EPA method 8310[159]
Carbon tetrachloride	Discharge from chemical plants and industrial activities	Liver problems, increased cancer risk hepatic tumors [22]	MCL: 0.005 mg/L	Air stripping [22]	GC with ECD or MS [22]
Chlorobenzene	Discharge from chemical and agricultural chemical factories	Liver or kidney problems	MCL: 0.1 mg/L		IMS [160]
Cyanide	Discharge from steel/metal, plastic, and fertilizer factories	Nerve damage or thyroid problems	MCL: 0.2 mg/L	Removed by high doses of chlorine [22]	EPA methods: 335.4, OIA1677 titrimetric and photometric techniques [22]
1,4 Dioxane	Industrial solvent	Probable carcinogen	3 ug/L (CA), 5 ug/L (FL), 0.3 ug/L (MA), 32 ug/L (ME), 3 ug/L (NH), no federal	Breaks through reverse osmosis membranes Not removed using conventional treatments; effectively removed by biological activated carbon treatment [22]	GC/MS [22]

o-Dichlorobenzene	Discharge from industrial chemical factories	Liver, kidney, or circulatory problems	MCL: 0.6 mg/L		
p-Dichlorobenzene	Discharge from industrial chemical factories	Anemia, liver, kidney or spleen damage, changes in blood	MCL: 0.075 mg/L		
1,2-Dichloroethane	Discharge from industrial chemical factories	Increased risk of cancer	MCL: 0.005 mg/L	GC/MS, GC with electrolytic conductivity detector, GC with FID, GC with photoionization detection [22]	0.0001 mg/L should be achievable using GAC [22]
1,1-Dichloroethylene	Discharge from industrial chemical factories	Liver problems	MCL: 0.007 mg/L		
cis-1,2-Dichloroethylene	Discharge from industrial chemical factories	Liver problems	MCL: 0.07 mg/L	GC with MS [22]	0.01 mg/L should be achievable using GAC or air stripping [22]
trans-1,2-Dichloroethylene	Discharge from industrial chemical factories	Liver problems	MCL: 0.01 mg/L	GC with MS [22]	0.01 mg/L should be achievable using GAC or air stripping [22]
Dichloromethane	Discharge from drug and chemical factories	Liver problems, increased cancer risk	MCL: 0.005 mg/L	Purge and trap GC with MS detection [22]	20 ug/L should be achievable using air stripping [22]
1,2-Dichloropropane	Discharge from industrial chemical	Increased risk of cancer	MCL: 0.005 mg/L	0.02 ug/L by a purge and trap GC method with	1 ug/L should be achievable using GAC [22]

	factories			an electrolytic conductivity detector, GC/MS [22]	
Di(2-ethylhexyl) adipate	Discharge from chemical factories, plasticizer for synthetic resins	Weight loss, liver problems (tumors), reproductive difficulties	MCL: 0.4 mg/L		
Di(2-ethylhexyl) phthalate	Discharge from rubber and chemical factories	Liver problems, reproductive difficulties, increased risk of cancer	MCL: 0.006 mg/L	GC/MS [22]	No data available [22]
Dioxin (2, 3, 7, 8-TCDD)	Emissions from waste incineration and other combustion	Reproductive difficulties, increased risk of cancer	MCL: 0.00000003 mg/L	Biodegradation of dioxin by a newly isolated *Rhodococcus sp*. [161]	
Epichlorohydrin	Discharge from industrial chemical factories, impurity of some water treatment chemicals	Increased cancer risk, stomach problems	TT: 0.01% dosed at 20 mg/L	Conventional treatments do not remove. Controlled by either limiting the epichlorohydrin content or polyamine flocculants or the dose used, or both [22]	GC with ECD, GC/MS, GC with FID [22]
Ethylbenzene	Discharge from petroleum refineries	Liver or kidney problems	MCL: 0.07 mg/L	Air stripping	GC with photoionization detector, GC/MS [22]
Ethylene dibromide	Discharge from petroleum refineries, fumigant for soils, grains, and fruits	Liver, stomach, kidney, reproductive system problems, increased cancer risk	MCL: 0.00005 mg/L	0.1 ug/L should be achievable using GAC [22]	GC/MS, purge and trap GC with halogen-specific detector, purge and trap capillary column GC with photoionization and electrolytic conductivity detectors in series [22]

Hexachlorobenzene	Discharge from metal refineries and agricultural chemical factories	Liver, kidney, and reproductive problems, increased risk of cancer	MCL: 0.001 mg/L		
Hexachlorocyclopentadiene	Discharge from chemical factories	Kidney or stomach problems	MCL: 0.05 mg/L		
Methyl tertiary butyl ether	Gasoline additive	Inconclusive data on health effects	20-40 ug/L (EPA)		
Pentachlorophenol	Discharge from wood preserving factories	Liver or kidney problems, increased cancer risk	MCL: 0.001 mg/L	0.4 ug/L should be achievable using GAC [22]	GC with ECD [22]
Perfluorooctanoic acid			0.3 ug/L (MN), 0.04 ug/L (NJ), no federal		
Polychlorinated biphenyls (PCBs)	Runoff from landfills, discharge of waste chemicals	Skin changes, thymus gland, immune, reproductive, nervous system problems, increased cancer risk	MCL: 0.0005 mg/L		
Sryrene	Discharge from rubber and plastic factories, landfills	Liver, kidney, circulatory problems	MCL: 0.1 mg/L		
Selenium	Discharge from petroleum and metal refineries, erosion of natural deposits, discharge from mines	Hair or fingernail loss, numbness in fingers or toes, circulatory problems	MCL: 0.05 mg/L	EPA method: 7742 AAS with hydride generation [22]	0.01 mg/L achievable using coagulation for selenium(IV) removal; selenium(V) is not removed by conventional treatment processes [22]
Tetrachloroethane 1,1,2,2,-tetrachloroethane	No longer used much do to concerns about toxicity	Chronic inhalation results in jaundice, enlarged liver, headaches, tremors, dizziness, numbness, and drowsiness, possible carcinogen	Subject to effluent limitations (Clean Water Act Requirement) [162]		
Tetrachloroethylene	Discharge from factories and dry	Liver problems, increased risk of	MCL: 0.005 mg/L		

	cleaners	cancer			
Thallium	Leaching from ore-processing sites, discharge from electronics, glass, and drug factories	Hair loss, changes in blood, kidney, intestine, or liver problems	MCL: 0.002 mg/L		
Toluene	Discharge from petroleum factories	Nervous system, kidney, or liver problems	MCL: 1 mg/L	GC with FID, GC/MS [22]	0.001 mg/L should be achievable using air stripping [22]
1,2,4-Trichlorobenzene	Discharge from textile finishing companies	Changes in adrenal glands	MCL: 0.07 mg/L		
1,1,1-Trichloroethane	Discharge from metal degreasing sites and factories	Liver, nervous system or circulatory problems	MCL: 0.2 mg/L		
1,1,2-Trichloroethane	Discharge from industrial chemical factories	Liver, kidney or immune system problems	MCL: 0.005 mg/L		
Trichloroethylene	Discharge from metal degreasing sites and factories	Liver problems, increased risk of cancer	MCL: 0.005 mg/L		
Vinyl chloride	Leaching from PVC pipes, discharge from plastic factories	Increased cancer risk	MCL: 0.002 mg/L	GC with ECD or FID with MS for confirmation [22]	0.001 mg should be achievable using air stripping
Xylenes	Discharge from petroleum and chemical factories	Nervous system damage	MCL: 10 mg/L	GC/MS, GC with FID [22]	0.005 mg/L should be achievable using GAC or air stripping [22]

The chemicals in this table are used in industrial and production settings.
General References for Table: [163]

Pharmaceuticals and Metabolites

Example	Source	Issue	EPA Suggestion (human)	Treatment	Detection Methods
Acetaminophen (ibuprofen)	Analgesics		No federal or state standards	microbial [164]	
Atenol	Beta-blockers		No federal or state standards		
Azithromycin	Antibiotics		No federal or state standards		
Ethinyl estradiol, synthetic estrogen	Oral contraceptives	Fish feminization [165] [166]	No effect concentration 0.35 ng/L [167]		EPA method: 539
Natural estrogen	Animal hormones		No federal or state standards	Reverse osmosis removes more than 95%, free chlorine and ozone disinfection are effective	EPA method: 539
Phenytoin, carbamazepine	Antiepileptic		No federal or state standards		
Sulfamethoxazole	Antibacterial		No federal or state standards		
Antibiotics					[168][169]

Treatment methods:
High efficiency: Reverse osmosis, free chlorine and ozone disinfection
Low efficiency:
General References for pharmaceutical and metabolites table: [170]–[173]

<u>**Personal Care Products**</u>

Example	Source	Issue	EPA Suggestion (human)	Treatment	Detection Methods
Fragrances		Bioaccumulation in fish [174]		Incompletely removed by conventional waste water treatment [175]	
4-Nonylphenol	Detergents	Potential endocrine disruptor and xenoestrogen	Should not exceed 6.6 ug/l in freshwater and 1.7 ug/l in saltwater		
Triclosan	Antimicrobials	Associated with a higher risk of food allergy. Can react with free chlorine in tap water produce other compounds that can convert to dioxins with exposure to UV light.	Must be indicated on labels. FDA issued a draft rule revoking the “generally regarded as safe” status as an ingredient in hand wash products citing the need for additional studies of its potential endocrine and developmental effects; impact on bacterial resistance, and carcinogenic potential. [176]		

<u>General References for Personal Care Products Table: </u>[170][172]

Food Additives

Example	Source	Issue	EPA Suggestion	Treatment	Detection Methods
Bisphenol A (BPA)		Estrogenic [177] [178]	350 ug/L (FL)	Rapid oxidation by chlorine and ozone disinfectants	
Dibutyl phthalate			34 mg/L (CWAR, ambient water), 154 mg/L (CWAR, aquatic organisms), 700 ug/l (ME, FL, MN), 800 ug/l (NH), 100 ug/l (WI)		EPA method: 8061B
Sucralose	Artificial sweetener		No federal or state standards	Difficult to remove through biological treatment, resistant to oxidation	

Pesticides, Biocides, and Herbicides

Example	Source	Issue	EPA Regulation	Treatment	Detection Methods
Alachlor	Herbicide used in row crops, degrades in the soil by volatilization, photodegration and biodegradation [22]	Eye, liver, kidney, spleen issues, anemia, cancer Metabolite, 2,6-diethylaniline shown to be mutagenic [22]	MCL: 0.002 mg/L	0.001 mg/L should be achievable using GAC [22]	Gas chromatography with electrolytic conductivity detection [22]
Atrazine	Herbicide used on soybean and corn crops	Cardiovascular or reproductive issues	MCL: 0.003 mg/L	0.1 ug/L should be achievable using GAC	GC/MS [22]
Carbofuran	Fumigant used on rice and alfalfa	Blood, nervous system, or reproductive issues	MCL: 0.04 mg/L	Granular activated carbon [22]	GC with a nitrogen-phosphorus detector, reverse phase HPCL with a fluorescence detector [22]
Chlordane	Residue of banned termiticide, broad spectrum insecticide	Liver or nervous system problems, increased risk of cancer	MCL: 0.002 mg/L	Granular activated carbon [22]	GC with an ECD [22]
2, 4-D	Herbicide used in row crops	Kidney, liver, or adrenal gland issues	MCL: 0.07 mg/L		
Dalapon	Herbicide	Minor kidney changes	MCL: 0.2 mg/L		
1,2- Dibromo-3-chloropropane (DBCP)	Soil fumigant used on soybeans, cotton, pineapples, & orchards	Reproductive difficulties, increased cancer risk	MCL: 0.0002 mg/L		
Dinoseb	Herbicide used on soybeans and vegetables	Reproductive difficulties	MCL: 0.007 mg/L		
Diquat	Herbicide	Cataracts Does not appear to be carcinogenic or genotoxic [22]	MCL: 0.02 mg/L	Rarely found in drinking water because it rapidly degrades [22]	
Diuron	Herbicide		10 ug/L (EPA)		
Endothall	Herbicide	Stomach, intestinal issues	MCL: 0.1 mg/L		

Endrin	Residue of banned insecticide	Liver problems	MCL: 0.002 mg/L Traces found in the drinking water supplies of several countries [22]	GAC [22]	GC with ECD [22]
Fipronil	Insecticide	One of the main chemicals blamed for colony collapse disorder among bees. Possible carcinogen	No federal or state requirements for water		
Glyphosate	Herbicide	Kidney and reproductive problems	MCL: 0.7 mg/L Low toxicity [22]		
Heptachlor	Residue of banned termiticide, diet main source of exposure [22]	Liver damage, increased risk of cancer	MCL: 0.0004 mg/L		
Heptachlor epoxide	Breakdown of heptachlor, transformed product [22]	Liver damage, increased risk of cancer	MCL: 0.0002 mg/L		
Lindane	Insecticide used on cattle, lumber, gardens	Liver or kidney problems	MCL: 0.0002 mg/L	GC [22]	0.1 ug/l should be achievable using GAC [22]
Methoxychlor	Insecticide used on fruits, vegetables, alfalfa, livestock	Reproductive difficulties	MCL: 0.04 mg/L	GC [22]	0.1 ug/L should be achievable using GAC [22]
Oxamyl	Insecticide used on apples, potatoes and tomatoes	Nervous system effects	MCL: 0.2 mg/L		
Picloram	Herbicide	Liver problems	MCL: 0.5 mg/L		
Simazine	Herbicide	Blood problems	MCL: 0.004 mg/L	GC/MS, GC with flame thermionic detection [22]	0.1 ug/L should be achievable using GAC
Toxaphene	Insecticide used on cotton and cattle	Kidney, liver, thyroid problems, increased cancer risk	MCL: 0.003 mg/L		
2,4,5-TP (Silvex)	Banned herbicide	Liver problems	MCL: 0.05 mg/L	Packed or capillary column GC with ECD [22]	No data found; 0,001 mg/l should be achievable using GAC

Additional information can be found at the National Pesticide Information Center (**npic@ace.orst.edu)**

Household Chemicals

Example	Source	Issue	EPA Regulation	Treatment	Detection Methods
Alkylphenol polyethoxylates (APEOs)	Cleaning products (surfactants)	Estrogenic potency of degradation products. Toxic to aquatic life, feminization of fish	6.6 µg/L EPA water quality criterion for freshwater aquatic life	Anaerobic biotransformation during denitrification	
Boron (metalloid) Boric acid or borax	Household detergents, used in the manufacture of glass, soaps, and detergents, flame retardants, found in edible plants [22]	Toxic to humans and ornamental plants at high concentrations	7mg/L: adults 3mg/L: children 0.5-1mg/L:plants	Not removed by conventional biological and advanced treatment, moderate removal by NF/RO	ICP/MS; ICP/AES [22]
Bromate	Bleach (oxyhalides), byproduct of drinking water disinfection	Increased risk of cancer	MCL: 0.010 mg/L	Removal by NF/RO, Oxidation and disinfection can create oxyhalides	Ion chromatography with suppressed conductivity, ion conductivity with UV/visible absorbance, ion chromatography with detection by ICP/MS [22][179]
Chlorate	Decomposed bleach	Inhibition of iodide uptake and decreased production of thyroid hormones	Not regulated by EPA, CA: notification level 800 µg/L	No viable option for removal, instead must prevent its addition from sodium hypochlorite) or formation (from chlorine dioxide)[22]	Ion chromatography with suppressed conductivity detection [22]
Perchlorate		Inhibition of iodide uptake and decreased production of thyroid	Not regulated by EPA, CA:MCL 6 µg/L, MA: 2 µg/L	Ozonation can cause bromate formation	

		hormones, accumulates in plants			
Perfluorooctanoic acid, perfluorooctane sulfonate	Flame retardants		0.3 ug/L (MN), 0.04 ug/L (NJ)		

General references for household chemicals table: [180]

Transformation Products

Example	Source	Issue	EPA Regulation	Treatment	Detection Methods
Nitrogenous, iodinated, and brominated products	Chlorination of nitrogen, iodine, and bromine	genotoxic		Granulated activated carbon	
Chloroform	Triclosan (antimicrobial) reacts with chlorine				
N-Nitrosodimethylamine (NDMA)	Chloramination of polymers, and unknown	carcinogen	EPA 1 in 1 million cancer risk at 0.7 ng/L	Not rejected by reverse osmosis membranes, removed by photolysis	Taguchi et al. 1994
Trihalomethanes	Bromodichloromethane		80 ug/l (EPA)		

Radionuclides

Example	Source	Issue	EPA Regulation	Treatment	Detection Methods
Alpha/ photon emitters	Erosion of natural deposits of certain minerals that are radioactive	Increased risk of cancer	15 picocuries (pCi)/ L		EPA methods: 900.0, 903.0
Beta photon emitters	Decay of natural and man-made deposits of certain minerals that are radioactive	Increased risk of cancer	4 millirems per year		EPA methods: 900.0
Radium 226 and 228 (combined)	Erosion of natural deposits	Increased risk of cancer	5 picocuries (pCi)/ L		EPA methods: 903.0 and 903.1
Uranium	Erosion of natural deposits	Increased risk of cancer, kidney toxicity	30µg/L WHO guideline: 0.015 mg/L [22]		

Radionuclides are the result of the natural decay of certain elements, and are used in medicine.
General References for radionuclides table: [181][182]

Other Concerns

Parameter	Example	Source	Issue	Levels of Concern	Treatment Methods	Detection Methods
Asbestos, Fibers	Asbestos	Decay of asbestos cement in water mains, erosion of natural deposits	Increased risk of benign intestinal polyps, no consistent evidence that ingested is a hazard to health	7 million fibers per L (MFL), (Fibers >10 micrometers)		
Algae, Cyanobacteria	Blue-green algae	Naturally occurring, especially in nutrient-rich waters (recycled water sources)	Block irrigation, can produce toxins harmful to animals if contacted, ingested or inhaled	Blooms Toxin levels of concern depend on species	[183]	Microscopy, molecular methods
Engineered nanomaterials	Have one or more dimensions ranging from 1 to 100 nm. Nanofilms (one dimension), nanotubes (two dimensions) and nanoparticles (three dimensions)	Manufactured	Nano-sorbents, nanocatalysts, bioactive nanoparticles, nanostructured catalytic membranes, and nanoparticle-enhanced filtration are categories that could change water treatment and monitoring. Questions about their fate and potential environmental and health effects. Studies have had inconsistent results [3]	To date, no link has been made between trace levels and adverse human health impact [184]ranking initial environmental and human health risk resulting from environmentally relevant nanomaterials) -potential ecotoxicological risk		
Geosmin and 2-methylisoborneol (MIB), Borneol	Organic chemical	Produced by algae and used in wine making	Not toxic, but cause unpleasant smell			
Prions	Chronic wasting disease, scrapie		Unknown in water sources		Unknown	[185]
Antibiotic	tetracycline,	Bactria that have	Transport of these antibiotic	Spread of antibiotic		Polymerase

resistance genes	sulfonamide genes	these genes	resistance genes can move the resistance to additional bacteria	resistance		chain reaction [186]–[190]
Endotoxins	Toxic inflammatory agents	Present inside bacteria cells				[191]

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