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Design of Small Water Systems - Water Quality Requirements

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Chapter 3
Water Quality Requirements

3-1. Introduction

Water, even treated water, may be used economically for a multitude of purposes. However, water quality requirements are usually dictated by the highest level of intended use. In this manual, the highest use considered is human consumption; therefore, primary emphasis is placed on drinking water quality requirements. Water that is suitable for human consumption is of high enough quality to serve most commercial and many industrial activities. When higher quality water is required, point-of-use treatment is generally preferable to providing additional treatment of the entire water supply. Exceptions to this rule may occasionally arise, for example, when a small water system serves a relatively large commercial or industrial customer.

3-2. The National Safe Drinking Water Act

a. Purpose. The overall purpose of the SDWA is to assure that water supply systems serving the public meet certain minimum national standards. The act directs the USEPA to establish a regulatory program and to enforce it in such a way as to provide for uniform safety and quality of drinking water in the United States. Specifically the act requires USEPA to do the following:

(1) Set standards for drinking water specifying maximum permissible levels of contamination and minimum monitoring frequencies.

(2) Protect sole or principal sources of drinking water from contamination by federally assisted projects.

(3) Protect underground drinking water sources from contamination by underground injection.

(4) Establish regulatory programs for assuring compliance with the standards.

(5) Ensure proper implementation of the regulatory program through oversight and technical assistance to the states or, if necessary, through direct implementation.

(6) Provide financial assistance to the states in their implementation of programs.

(7) Gather pertinent information pertaining to drinking water sources and supplies.

The SDWA differs substantially from previous Federal legislation in that it is directly applicable to all public water systems, not just those serving common carriers engaged in interstate commerce (U.S. Congress 1974).

b. Regulation. In responding to the mandate of the SDWA, USEPA has established a Drinking Water Program (DWP) composed of two major elements: the Public Water System Supervision (PWS) and the Groundwater Protection (GWP) programs. The former is designed to ensure that utilities comply with appropriate water quality standards, and the latter seeks to protect present and future sources of drinking water from contamination via underground injection wells. The principal regulatory mechanism of the DWP is the National Primary Drinking Water Regulations (NPDWR). The SDWA makes it clear that the responsibility for enforcing the NPDWR should ideally lie with the states and that the principal roles of USEPA are standard setting, supervision, and coordination. In fact, the 1996 reauthorization of the SDWA requires USEPA to publish operator certification guidelines for community and nontransient noncommunity public water systems.

3-3. 1996 Reauthorization of SDWA

a. The reauthorization updates the standards setting process. Originally, USEPA was required to provide 25 new standards every 3 years. This has been replaced with a new process based on occurrence, relative risk, and cost-benefit considerations. The USEPA is required to select at least five new candidate contaminants to consider for regulation every 5 years, but the regulation must be geared toward contaminants posing the greatest health risks. Additionally, the reauthorization requires states to develop operator certification programs or risk losing a significant portion (20 percent) of their revolving fund grant.

b. The USEPA is also required to identify technologies that are more affordable for small systems to comply with drinking water regulations. Small System Technical Assistance Centers are to be authorized to meet training and technical needs of small systems. States are to be given specific authority to grant variances for compliance with drinking water regulations for systems serving 3,300 or fewer persons and, with the concurrence of the USEPA Administrator, for systems serving more than 3,300 persons but fewer than 10,000 persons. Generally, it is not recommended that waivers be applied for at Corps projects; but if a need should arise, opinion of the Office of Counsel should be obtained prior to submittal.

3-4. The National Primary Drinking Water Regulations

a. General. These regulations specify the maximum permissible levels of contaminants that may be present in drinking water. While their principal purpose is to protect the public health, these regulations authorize a maximum contaminant level (MCL) to be set for a given substance, or group of related substances, even though no direct linkage to public health has been conclusively shown. The USEPA Administrator is empowered by the SDWA to consider economic feasibility as well as public health in establishing MCLs. The SDWA allows the Administrator of USEPA to establish treatment methodology criteria in order to provide general protection against a contaminant or group of contaminants without specifying any MCL.

b. Nomenclature. Several terms used in the SDWA and the DWP are specifically defined therein. Those that are especially pertinent are defined below.

(1) Contaminant. A contaminant is any physical, chemical, biological, or radiological substance or matter in water.

(2) Maximum contaminant level (MCL). The MCL is the maximum permissible level of a contaminant in water delivered to the free-flowing outlet of the ultimate user of a public water system, except in the case of turbidity where the maximum permissible level is measured at the point of entry to the distribution system. Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition.

(3) Public water system. A public water system is a system for the provision to the public of piped water for human consumption, if such a system has at least 15 service connections or regularly serves an average of at least 25 individuals at least 60 days out of the year. Collection, pretreatment storage, treatment, storage, and distribution facilities are included in this definition. A public water system may be further classified as a “community” or “noncommunity” water system (Craun 1981).

(4) Community water system. A community water system is a public water system that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents (Craun 1981; USEPA 1979c) .

(5) Noncommunity water system. Any public water system that is not a community water system is defined as a noncommunity water system (Craun 1981).

(6) Nontransient Noncommunity Water System (NTNC). A public water system that is not a community water system and that regularly serves at least 25 of the same individuals at least 6 months per year is on NTNC. Many Corps facility water systems are regulated in this classification. Individuals might include park rangers, resource administrative personnel, lock and dam operators, powerhouse personnel, and contract maintenance personnel among others.

(7) Transient noncommunity water system. This is a public water supply serving a transient population of at least 25 people a day at least 60 days a year. This may include parks, campgrounds, marinas, restaurants, and rest areas.

(8) Best available technologies (BAT). BAT is the technology referenced when USEPA sets the MCLs. The SDWA requires that the MCL be set as close as possible to the maximum contaminated level goal (MCLG) “with the use of the best technology, treatment techniques, and other means the Administrator finds available (taking cost into consideration).” Therefore, the MCL is generally affected by the technology available to remove that contaminant, because the MCL is set with cost of removal taken into consideration.

(9) Maximum contaminant level goal. The MCLG for each contaminant is a nonenforceable, health-based goal, set at a level at which no known or anticipated adverse effect on human health occurs. It allows for an adequate margin of safey, without regard to the cost of reaching these goals.

c. Coverage. The Drinking Water Regulations (DWR) apply to all public water systems except those meeting all of the following conditions:

(1) The system consists only of distribution and storage facilities (i.e., has no collection and treatment facilities).

(2) The system obtains all its water from, but is not owned or operated by, a public water system to which the regulations do apply.

(3) The system does not sell water to any person (individual, corporation, company, association, partnership, state, municipality, or Federal agency).

(4) The system is not a carrier that conveys passengers in interstate commerce.

Therefore, it is obvious that almost all water systems serving the public may be classified as public water systems and, thus, are regulated by the DWR. Facilities at Corps recreation areas, campgrounds, resorts, highway rest areas, and similar locations may frequently, however, be defined as noncommunity water systems. This is an important distinction since not all MCLs apply to such systems.

d. Maximum contaminant levels (MCLs).

(1) General comments. The MCLs are based on an assumed daily intake of water, or water-based fluids, of 2ℓ and are designed to protect the public from potential health effects of long-term exposure. Since these levels are not generally necessary to protect transients or intermittent users, many of the MCLs are not applicable to noncommunity water systems. An exception is nitrate, which is known to have an adverse effect on susceptible infants in even a short period of time. MCLs have not been developed for contaminants about which little is known, or which are only very rarely found in water supplies. However, the National Academy of Sciences and USEPA have developed Suggested No Adverse Response Levels (SNARLs) for several potential contaminants. SNARLs (also known as Health Advisories) are neither legally enforceable standards, nor directly comparable to MCLs since they have been developed for short-term, rather than lifetime, exposures. However, as more information comes available, it is likely that additional MCLs will be issued. Therefore, current SNARLs may be of some interest to water system designers and operations personnel, especially with respect to systems that will serve only transient populations. The SNARLs are most useful to managers and operators who must deal with such emergency situations as chemical spills, or industrial and agricultural accidents. Because of their very nature, the SNARLs are being continuously reviewed and revised; thus, they are not presented herein. Up-to-date information concerning them may be obtained from the Office of Drinking Water, U.S. Environmental Protection Agency, Washington, DC 20460. The current Internet address for the Office of Drinking Water is www.epa.gov/ow/. This Web site contains current published USEPA drinking water MCL's.

(2) MCLs for inorganic chemicals. The MCLs for inorganic chemicals (shown in Table 3-1) apply to all community and NTNC water systems. However, only nitrate limits require direct adherence for NTNC systems. If other contaminants exceed MCLs for the NTNC systems, an investigation of the possible health risk will be made. If it is determined that a health risk does exist, the MCL for that particular contaminant will apply. Thus, most Corps recreational area water systems would be subject to only the nitrate MCL. Compliance should be based on the analysis and sampling method as approved by the USEPA and/or the host state or territory as appropriate.

(3) MCLs for organic chemicals. MCLs for organic chemicals are presented in Table 3-1. They are applicable to community and NTNC water systems. Generally these chemicals would not be of regulatory interest for Corps recreation area water systems. However, all of the organic standards apply to noncommunity water systems if after an MCL is determined to be exceeded an investigation determines a risk to the public health exists.

(4) MCLs for total trihalomethanes. The MCL for total trihalomethanes is applicable to community systems serving a population of 10,000 or more and which add a disinfectant (oxidant) to the water during any part of the treatment process and community and NTNC systems obtaining water in whole or in part from a surface supply source. Compliance is determined on the basis of the running average of quarterly samples.

(5) MCLs for turbidity. MCLs for turbidity are applicable to both community and noncommunity water systems using surface water sources in whole or in part. In general terms, compliance with the turbidity MCL is based upon the monthly average of samples taken and analyzed daily at "representative entry points to the distribution system." The MCL for turbidity is based on a performance standard and should be 0.5 turbidity unit (TU) or less, but not to exceed 1.0 turbidity unit any time for surface water. Groundwater sources can be 5.0 TU or less, but not to exceed 15 TU at any time.

(6) MCLs for microbiological contaminants. MCLs for microbiological contaminants are applicable to both community and noncommunity water systems. Compliance is determined based on the analysis of samples taken at regular time intervals, and in numbers proportionate to the population served by the system. As of the August 1996 reauthorization of the SDWA, regulated standards for microbial contaminants included requirements from three regulations: Surface Water Treatment Rule (SWTR); Enhanced Surface Water Treatment Rule (ESWTR); and the Total Coliform Rule (TCR). Specifically, SWTR provides BAT requirements for *Giardia lamblia*, heterotrophic bacteria, and viruses. At the time of publication for this manual, the ESWTR proposed criteria guidelines for *Cryptosporidium*. Once the TCR was finalized, January 1991, criteria were in place to establish treatment techniques to achieve acceptable bacterial removal of fecal coliforms, total coliforms, and *E. coli*.

(7) MCLs for radioactivity. MCLs for radioactivity are rather complex and are generally based on limiting the annual dose to the whole body, or to any single organ. Basic requirements are presented in Table 3-1. The USEPA's proposed rule for radionuclides was published in July 1991.

Table 3-1
EPA Drinking Water Standards (USEPA)

Contaminant	Regulation	Status	MCLG, mg/L	MCL, mg/L
		Microbials		
Cryptosporidium	ESWTR	Proposed	0	TT
E. coli	TCR	Final	0	[1]
Fecal coliforms	TCR	Final	0	TT
Giardia lamblia	SWTR	Final	0	TT
Heterotrophic bacteria	SWTR	Final[2]	-	TT
Legionella	SWTR	Final[2]	0	TT
Total coliforms	TCR	Final	0	[1]
Turbidity	SWTR	Final	-	PS
Viruses	SWTR	Final[2]	0	TT
		Inorganics		
Antimony	Phase V	Final	0.006	0.006
Arsenic	Interim	Final	NA	0.05
Asbestos (fibers/1>10 µm)	Phase II	Final	7 million fibers per liter	7 MFL
Barium	Phase II	Final	2.00	2.00
Beryllium	Phase V	Final	0.004	0.004
Bromate	D/DBP (Disinfectants/ Disinfection-By-Product Rule)	Proposed	0	0.01
Cadmium	Phase II	Final	0.005	0.005
Chlorite	D/DBP	Proposed	0.08	1.0
Chromium (total)	Phase II	Final	0.10	0.10
Copper	LCR (Lead and Copper Rule)	Final	1.30	TT
Cyanide	Phase V	Final	0.20	0.20
Fluoride	Fluoride	Final	4.00	4.00
Lead	LCR	Final	0	TT
Mercury	Phase II	Final	0.002	0.002
Nickel	Phase V	Final	0.10	0.10
Nitrate (as N)	Phase II	Final	10.0	10.0
Nitrite (as N)	Phase II	Final	1.0	1.0

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Note: Standards are subject to change and the USEPA and host state should be contacted for up-to-date information. Abbreviations used in this table: NA - not applicable; PS - performance standard 0.5-1.0 ntu; TT - treatment technique.

[1] No more than 5 percent of the samples per month may be positive. (For systems collecting fewer than 40 samples per month, no more than 1 sample per month may be positive.)

[2] Final for systems using surface water; also being considered for groundwater systems.

Table 3-1. (Continued)

Contaminant	Regulation	Status	MCLG, mg/L	MCL, mg/L
		Inorganics (continued)		
Nitrite & Nitrate (as N)	Phase II	Final	10.0	10.0
Selenium	Phase II	Final	0.05	0.05
Thallium	Phase V	Final	0.0005	0.002
		Organics		
Acrylamide	Phase II	Final	0	TT
Alachlor	Phase II	Final	0	0.002
Aldicarb	Phase II	Final	0.001	0.003
Aldicarb sulfone	Phase II	Final	0.001	0.002
Aldicarb sulfoxide	Phase II	Final	0.001	0.004
Atrazine	Phase II	Final	0.003	0.003
Benzene	Phase I	Final	0	0.005
Benzo(a)pyrene	Phase V	Final	0	0.0002
Bromodichloromethane	D/DBP	Proposed	0	NA
Bromoform	D/DBP	Proposed	0	NA
Carbofuran	Phase II	Final	0.04	0.04
Carbon tetrachloride	Phase I	Final	0	0.005
Chloral hydrate	D/DBP	Proposed	0.04	TT
Chlordane	Phase II	Final	0	0.002
Chloroform	D/DBP	Proposed	0	NA
2,4-D	Phase II	Final	0.07	0.07
Dalapon	Phase V	Final	0.2	0.2
Di(2-ethylhexyl) adipate	Phase V	Final	0.4	0.4
Di(2-ethylhexyl) phthalate	Phase V	Final	0	0.006
Dibromochloromethane	D/DBP	Proposed	0.06	NA
Dibromochloropropane (DBCP)	Phase II	Final	0	0.0002
Dichloroacetic acid	D/DBP	Proposed	0	NA
p-Dichlorobenzene	Phase I	Final	0.075	0.075
o-Dichlorobenzene	Phase II	Final	0.6	0.6
1,2-Dichloroethane	Phase I	Final	0	0.005
1,1-Dichloroethylane	Phase I	Final	0.007	0.007
cis-1,2-Dichloroethylene	Phase II	Final	0.07	0.07

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Table 3-1. (Continued)

Contaminant	Regulation	Status	MCLG, mg/L	MCL, mg/L
		Organics (continued)		
trans-1,2-Dichloroethylene	Phase II	Final	0.1	0.1
Dichloromethane (methylene chloride)	Phase V	Final	0	0.005
1,2-Dichloropropane	Phase II	Final	0	0.005
Dinoseb	Phase V	Final	0.007	0.007
Diquat	Phase V	Final	0.02	0.02
Endothall	Phase V	Final	0.1	0.1
Endrin	Phase V	Final	0.002	0.002
Epichlorohydrin	Phase II	Final	0	TT
Ethylbenzene	Phase II	Final	0.7	0.7
Ethylene dibromide (EDB)	Phase II	Final	0	0.00005
Glyphosate	Phase V	Final	0.7	0.7
Haloacetic acids[3]	D/DBP	-	-	-
(Sum of 5; HAA5)	Stage 1	Proposed	-	0.06
-	Stage 2	Proposed	-	0.03
Heptachlor	Phase II	Final	0	0.0004
Heptachlor epoxide	Phase II	Final	0	0.0002
Hexachlorobenzene	Phase V	Final	0	0.001
Hexachlorocyclopentadiene	Phase V	Final	0.05	0.05
Lindane	Phase II	Final	0.0002	0.0002
Methoxychlor	Phase II	Final	0.04	0.04
Monochlorobenzene	Phase II	Final	0.1	0.1
Oxamyl (vydate)	Phase V	Final	0.2	0.2
Pentachlorophenol	Phase II	Final	0	0.001
Picloram	Phase V	Final	0.5	0.5
Polychlorinated byphenyls (PCBs)	Phase II	Final	0	0.0005
Simazine	Phase V	Final	0.004	0.004
Styrene	Phase II	Final	0.1	0.1
2,3,7,8-TCDD (dioxin)	Phase V	Final	0	0.00000003
Tetrachloroethylene	Phase II	Final	0	0.005
Toluene	Phase II	Final	1.0	1.0
Toxaphene	Phase II	Final	0	0.003

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[3] The sum of the concentrations of mono-, di-, and trichloracetic acids and mono- and dibromoacetic acids.

Table 3-1. (Concluded)

Contaminant	Regulation	Status	MCLG, mg/L	MCL, mg/L
		Organics (continued)		
2,4,5-TP (silvex)	Phase II	Final	0.05	0.05
Trichloroacetic acid	D/DBP	Proposed	0.3	NA
1,2,4-Trichlorobenzene	Phase V	Final	0.07	0.07
1,1,1-Trichloroethane	Phase I	Final	0.2	0.2
1,1,2-Trichloroethane	Phase V	Final	0.003	0.005
Trichloroethylene	Phase I	Final	0	0.005
Trihalomethanes[4]	Interim	Final	NA	0.1
(sum of 4)	D/DBP	-	-	-
-	Stage 1	Proposed	NA	0.08
-	Stage 2	Proposed	NA	0.04
Vinyl chloride	Phase I	Final	0	0.002
Xylenes (total)	Phase II	Final	10.0	10.0
		Radionuclides		
Beta-particle and	Interim	Final	-	4 mrem
photon emitters	R (Radionuclide Rule)	Proposed	0	4 mrem
Alpha emitters	Interim	Final	-	15 pCi/L
-	R	Proposed	0	15 pCi/L
Radium 226+228	Interim	Final	-	5 pCi/L
Radium 226	R	Proposed	0	20 pCi/L
Radium 228	R	Proposed	0	20 pCi/L
Radon	R	Proposed	0	300 pCi/L
Uranium	R	Proposed	0	20 µg/L

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[4] The sum of the concentrations of bromodichloromethane, dibromochloromethane, tribromomethane, and trichloromethane.

Subsequently, there was much controversy over the proposed radon standard. As of 1996, USEPA has chosen to delay promulgation of any radionuclides rule package since the development of a radon standard was an interrelated part of that package.

3-5. The National Secondary Drinking Water Regulations

a. General. USEPA has promulgated secondary as well as primary drinking water regulations (USEPA 1979b). The major difference between the two is that the secondary regulations are not enforceable at the Federal level. The regulations are intended to serve as guidelines for the states, but may be adopted as part of the drinking water program of any given state and, hence, become enforceable at that level. The purpose of the regulation is to guide the states in controlling contaminants that affect primarily the aesthetic qualities relating to public acceptance of drinking water. However, some of the contaminants may have health implications at higher concentration levels.

b. Secondary maximum contaminant levels (SMCLs). SMCLs for public water systems are presented in Table 3-2. Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded. The SMCLs are designed to represent reasonable goals for

Table 3-2
Secondary Maximum Contaminant Levels (USEPA)

Contaminant	SMCL
Aluminum	0.05 + 0.2 mg/L
Chloride	250 mg/L
Color	15 color units
Copper	1.0 mg/L
Corrosivity	Noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 TON[1]
pH	6.5 - 8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

[1] Threshold odor number.

drinking water quality. They are important, though not federally enforceable, since undesirable aesthetic qualities may encourage users to rely on some alternative source (spring, cistern, etc.) that may be unsafe. Thus, every effort should be made, within the constraints of technological and economic feasibility, to produce water that meets the requirements of the secondary regulations.

3-6. Other Regulatory Requirements

a. Federal. A complete discussion of all Federal regulations that may impact on water system design and operation is beyond the scope of this manual. However, it is important for the planner/designer to understand that the SDWA is not the only Federal law that affects water systems. Other Federal legislation with provisions that may affect water systems would include the following (among others):

(1) Clean Water Act.

(2) Resources Conservation and Recovery Act.

(3) Hazardous Materials Transportation Act.

(4) Occupational Safety and Health Act.

(5) National Energy Conservation Policy Act.

(6) River and Harbor Act of 1899.

The effects of these, and other, Federal acts on water system design are minimal. In the vast majority of cases, compliance with the applicable state regulations will ensure compliance with pertinent Federal regulations as well.

b. State and local. All the states and many localities have legislation and regulations that affect the design of water supply systems either directly or indirectly. A review of all such requirements is clearly beyond the scope of this work. Fortunately, following the requirements of the state public health agency usually ensures that any local water quality problems will be minimal. To avoid possible conflicts, it is well worthwhile to contact state and local public health officials very early in the planning stage of project development. This is good practice even though Federal facilities may, in many cases, technically be exempt from state and local regulation. State and local problems often develop simply because the affected agencies are not consulted regularly and kept informed, and not because of any real conflict over technical issues.

3-7. Water Quality and Public Health

a. Introduction. Although ancient people did have some appreciation for the relationship between sanitation and public health, widespread treatment of public water supplies has developed only since the 1850's. Most historians point to the British cholera epidemics of 1845-1849 and 1853 as landmark events. In the latter case at least 69 of a total of nearly 11,000 deaths were attributed to a single well (in the Saint James Parish district of London), which was found to be polluted via a pipe draining a nearby cesspool. From that point, water treatment for the control and prevention of waterborne disease became more and more important. Today the emphasis in water treatment is changing somewhat, and while the control and prevention of the traditional diseases is still a concern, the possibly deleterious effects of literally thousands of chemical contaminants that may be present in drinking water supplies must be considered. A brief discussion of these problems is presented below.

b. Waterborne disease.

(1) General. Absolutely no natural water should be assumed to be free of microbial life. Some of these organisms (the pathogens) cause disease, some cause nuisance problems such as tastes and/or odors, and the vast majority are really of no particular consequence unless present in very great

numbers. Modern water treatment practice calls for the removal or inactivation of all organisms that may cause disease (this process is often called disinfection), but not necessarily the removal or inactivation of all life forms (sterilization). Organisms of special interest include bacteria, algae, fungi, molds, and viruses.

(2) Bacteria. Some waterborne diseases that may be traced to bacterial origin are noted in Table 3-3. Other bacteria, although not pathogenic themselves, can lead indirectly to disease by rendering water so aesthetically unpleasing that users turn to alternative, but unsafe, supplies such as polluted springs. Examples would include the iron bacteria frequently responsible for "red water" problems, and bacteria producing unpleasant tastes and odors. As a general rule, disinfection practices will control waterborne bacterial diseases. Therefore, special attention should be given to the design of disinfection facilities.

(3) Other organisms.

(a) Algae. Algae are nuisance organisms that may occasionally "bloom" (a bloom is defined as more than 1,000,000 cells/mL) and cause operational problems such as filter clogging as well as undesirable tastes and odors. Some algae produce toxic metabolites, but freshwater algae are not known to cause any waterborne diseases.

(b) Viruses. Viruses are the smallest of all the infectious agents that may be found in drinking water. They are probably not consistently removed to any great extent during conventional water treatment, but the methods used to detect and quantify them are so difficult and unreliable that the matter is open to debate. It is theoretically possible for virtually any enteric virus to be transmitted via drinking water and produce disease. However, only polio and hepatitis have been shown to do so. As a rule of thumb, outbreaks of waterborne diseases that cannot be traced to other causes are generally blamed on viruses.

(c) Protozoans. Protozoans are microscopic animals that may frequently be found in water. While many species have been identified, only three, *Entamoeba histolytica*, *Giardia lamblia*, and *Cryptosporidium* are of really major pathogenic significance. The first is the cause of amoebic dysentery (which can be a very serious condition) and is infectious only during the cyst stage. The cysts are quite resistant to chlorination, but fortunately are so large (8-12 micrometers) that they are readily removed by coagulation, flocculation, and sedimentation followed by granular media filtration. *Giardia* cause a recurring form of diarrhea frequently called giardiasis. *Giardia* cysts are also relatively large and are adequately removed in the manner described above. *Cryptosporidium* cysts are more difficult to remove than *Giardia* cysts. But when operated properly, a treatment plant producing finished water turbidity with less than 0.1-0.2 nephelometric turbidity units (NTU) through conventional treatment or direct filtration can usually achieve adequate treatment. Waterborne disease outbreaks in Milwaukee, WI (March 1993), Racine, WI (March 1994), and Washington, DC (December 1993) were all attributed to *Cryptosporidium*, contributing to the generation of additional treatment regulations. Other animals, such as the parasitic worms (nematodes, trematodes, and cestodes), may be found in water but are likewise adequately removed via conventional practices.

(4) Indicator organisms. The direct examination of drinking water for all possible pathogenic organisms is impractical for a number of reasons, for example:

(a) There are a wide variety of pathogens.

(b) Many pathogenic organisms may be present in very small numbers (e.g., viruses) and thus may escape detection; and analytical procedures for the isolation, identification, and enumeration of many pathogens are difficult, unreliable, time-consuming, and/or very expensive.

Thus, public health officials have long sought the elusive "ideal indicator" organism. Such an organism would have the following characteristics:

(a) Indicate the presence of pathogens in both raw and treated water.

(b) Be somewhat more hearty than pathogens.

(c) Be present in biologically contaminated waters in great numbers (certainly in greater numbers than the pathogens).

(d) Be readily identifiable via simple, quick, inexpensive, straightforward analytical procedures.

(e) Be such that the population density of the indicator is directly related to the degree of contamination.

Needless to say, no such organism has been found. However, over many years public health professionals in the United States have come to depend on the coliform bacteria to serve this purpose. They are not a perfect indicator, but their presence in treated water is ample reason to suspect the microbiological safety of the water. Unfortunately, the mere absence of coliforms does not ensure that water is free from pathogens. For many years the "coliform" count was the specific tool used to evaluate quality. Now, however, discoveries indicate that high levels of heterotrophic bacteria may result in false negative samples for total coliform. Problems with such indicators and the lack of ability to readily

Table 3-3
Some Bacterial Waterborne Diseases

Disease	Responsible Organism	Comment
Cholera	*Vibrio cholera*	Very serious. Organism can survive in clean or turbid water.
Salmonellosis	Several species of *Salmonella*	Range from typhoid fever (*S. Typhosa*) to "ptomaine poisoning."
Shigellosis	Several species of *Shigella*	Common cause of acute diarrhea. *S. Dysenteriae* causes bacillary dysentery.
Leptospirosis	Several species of *Leptospira*	Comparatively uncommon, but worldwide.
Tularemia	*Francisella tularensis*	Extremely virulent organism. Can survive in water for long periods.
Tuberculosis	*Mycobacterium tuberculosis*	Very resistant to chlorination.
Montezuma's Revenge	Variants of *Esherichia coli*	Generally harmless to natives, but not visitors.
Gastroenteritis	Many bacteria, e.g., *Yersina enterocolitica*	Survives in very cold waters. Also caused by other types of organisms.

measure and detect these and other organisms have led EPA to establish accepted treatment techniques.

c. Chemical hazards.

(1) Current situation. In recent years, the water supply industry, regulatory agencies, consumer advocates, lawmakers, and the general public have become increasingly aware of, and concerned about, the presence of various chemicals, some of them quite exotic, in public water supplies. During this period, analytical capabilities have advanced at an almost incredible pace while the knowledge needed to interpret the resulting data has developed comparatively slowly. Thus, the industry is in the unfortunate position of being able to detect the presence of contaminants, especially metals and organic compounds, to the ppb or mg/L level or lower, but has virtually no rational basis on which to assess the public health consequences of the vast majority of the substances so identified. This is especially true with regard to long-term effects of low-level exposures.

(2) Outlook. It seems highly likely that at least some of the compounds now being detected in water will prove to be deleterious to health, even in very low concentrations, and that such compounds will continue to be discovered. The reauthorized SDWA (August 1996) requires USEPA to select at least five new candidate contaminants to consider for regulation every 5 years based on the contaminants posing the greatest health risk. Resulting regulation is to be developed from a balance of occurrence, relative risk, and cost-benefit considerations. Since treatment techniques for the removal of low levels of contaminants often tend to be rather complicated and expensive, it behooves planners and designers of small water supply systems to consider alternate sources of water very carefully. The expenses associated with investigatory items such as test wells and complete laboratory analyses may seem almost prohibitive; but they must be compared to those associated with major renovations, process additions, more sophisticated operation, or shifting to a new water source after collection, treatment, and distribution facilities are in place. If there is any reason to believe that a potential water source may be contaminated, great caution should be used in developing that source. Planners and designers must certainly look beyond current water quality regulations, although to do so admittedly involves as much art as science. Cost consideration for monitoring and compliance must always be included in economic comparisons.

3-8. Contaminants Found in Water Supplies

a. Definition. The word contaminant is subject to varying usage. In this manual the term is applied to any physical, chemical, biological, or radiological substance found in water. Thus, a contaminant is not necessarily good or bad. The term pollutant is sometimes applied to identify a contaminant that has a deleterious effect.

b. Occurrence. The number of contaminants that may be present in a water supply is virtually unlimited. Whenever substances listed in Table 3-1 are found in concentrations greater than those shown, the water should be viewed with caution and possible alternative sources should be investigated. However, it should be understood that only a few of the contaminants shown warrant outright rejection of the supply. It is important to understand that, where the principal concern is aesthetics, regional factors are very important. For example, hardness levels that are perfectly acceptable in one geographical area might be grounds for rejection of the supply in some other location. Fortunately, only a few contaminants are of general interest. A brief discussion of some of the more common contaminants and important properties of water is presented below. For more information the reader is directed to the references listed in Appendix A.

c. Turbidity.

(1) Definition. Turbidity results from optical properties that cause light to be scattered and/or absorbed rather than transmitted directly through the medium of interest. Turbidity in water is caused by the presence of suspended matter such as clay, silt, algae, or bacteria (i.e., any finely divided organic or inorganic matter). The suspended materials that cause turbidity are considered undesirable since they may represent a direct or indirect hazard to public health and certainly render water aesthetically unpleasing. As a general rule, turbidity is measured by nephelometry (i.e., measurement of the portion of a light beam that is scattered in some selected direction-usually 1.57 radians (rad) (90 degrees (deg)) to the direction of the light path) and reported in NTUs. Occasionally other methods and reporting units may be used.

(2) Occurrence and removal. Provisions must almost always be made to remove turbidity when surface waters are to be used for public water supply. While plain sedimentation is of some value for pretreatment, it is generally ineffective as a sole means of treatment. This is true because the particles that usually contribute most of the turbidity are of colloidal size (1 to 200 nm in diameter). These particles are so small that their behavior is controlled by their state of hydration (interaction with water molecules) and surface electrical charges (similar particles develop similar charges and thus repel each other electrically) rather than by gravitational effects. In the typical surface water treatment plant, coagulants or flocculants are added to interact with the colloidal particles to coalesce into larger particles under the influence of gentle mixing. Filter alum, a hydrated form of aluminum sulfate, is by far the most commonly used coagulant in the United States. These larger particles are then typically removed by sedimentation and granular media filtration. By these means, water that is sparkling clear (0.1 NTU) can consistently be produced. The diversity of materials makes it impractical to define any meaningful maximum recommended turbidity level for raw surface waters. In fact, the difficulty encountered in turbidity removal is often inversely proportional to the initial turbidity. For the most part, turbidity requirements are regulated under the SWTR and the TCR.

d. Color. "True" color is caused by the presence of any of a number of dissolved materials and, unlike turbidity, is more likely to occur in ground waters than surface waters. "Apparent" color includes true color plus the effects of any suspended substances that may be present. This latter component is easily removed along with turbidity. Color in water supplies usually results from the presence of such factors as metallic ions, humic substances, industrial wastes, or algae, and is usually more pronounced at higher pH. Color, per se, is not a public health problem, although some substances that can impart color to water are hazardous. Therefore, when color is encountered in a water supply, it is important to determine the cause. It is best to avoid potential water sources that exhibit significant color. However, if a suitable alternative is not available, color removal should be seriously considered. The specific process selected will vary with the source of the color, but chemical oxidation and adsorption have both been effective in some cases whereas ordinary water treatment is generally ineffective against true color. Even a slight bit of color is so aesthetically displeasing to some people that they will prefer to use colorless water from a source of questionable sanitary quality (e.g., a spring).

e. Tastes and odors. Tastes and odors in water generally result from the presence of algal, bacterial, or actinomycete metabolites; decomposing organic matter; or dissolved gases, although industrial wastes are occasionally implicated. As is the case with color, difficulties with tastes and odors are usually more related to aesthetics than to public health. Taste and odor problems are especially difficult to deal with since they tend to be intermittent (e.g., they may follow the growth cycles of the responsible organisms). This is compounded by the fact that even very minute (ppb level) concentrations of some substances can be detected by many people. Thus, for example, it might be possible to remove 90 percent or more of some given odorant without significantly reducing complaints from customers. Therefore, when a choice is available, water sources known to be free of tastes and odors are much to be preferred. Taste and odor problems vary considerably, and when removal is to be practiced, some care should be exercised in the selection of a method. Aeration, chemical oxidation (e.g., with potassium permanganate), and activated carbon adsorption have been effective in a number of installations.

f. Hardness.

(1) General. Hardness in water is caused by the presence of divalent metal ions. While a number of these can occur, solubility constraints are such that only calcium (Ca^{++}) and magnesium (Mg^{++}) are generally present to a significant extent in natural waters. Hardness may be a problem for both surface and ground waters, but is more likely in the latter case. No definitive relationship (either positive or negative) has been established between hardness in drinking water and public health; however, it may be very deleterious from an economic

and aesthetic point of view. Excessive hardness creates a high soap demand and thus makes bathing difficult, interferes with laundry and other washing activities, contributes to deterioration of fabrics, and promotes excessive deposition of calcium carbonate ($CaCO_3$) and magnesium hydroxide ($Mg(OH)_2$) on pipes, especially hot water pipes and boiler tubes. On the other hand, insufficient hardness interferes with rinsing operations and promotes rapid corrosion of metallic waterlines and appurtenances. The optimal total hardness of a given water supply is a function of many factors, but is generally between 50 and 80 mg/L as $CaCO_3$. Magnesium hardness greater than 40 mg/L as $CaCO_3$ is very undesirable in hot water applications.

(2) Classification and removal. There are no hard and fast rules as to exactly what constitutes hard water, but the values shown in Table 3-4 are widely accepted in the United States. As a general rule, water with a total hardness greater than about 125 mg/L as $CaCO_3$ (or magnesium hardness greater than about 40 mg/L as $CaCO_3$) should be softened prior to use if it is operationally and economically feasible to do so. Chemical precipitation and ion exchange are both effective. The former is often less costly, but the latter is far simpler and is, therefore, usually preferred for small installations.

Table 3-4
Classification of Hardness in Water (from Dufor and Becker 1968)

Hardness, mg/L as $CaCO_3$	Classification
0-20	Soft
20-60	Slightly Hard
60-120	Moderately Hard
120-180	Hard
Above 180	Very Hard

g. Iron.

(1) Occurrence. Iron may be found in both surface and ground waters, but is more commonly a problem in the latter. In water exposed to the atmosphere, ferrous iron (Fe++) is readily oxidized to ferric iron (Fe+++) by oxygen, and various relatively insoluble precipitates are formed. Thus, surface waters containing sufficient soluble iron to cause significant problems are fairly rare. An exception is water in the hypolimnion of a stratified reservoir. In such an environment molecular oxygen is not readily available and insoluble ferric iron may be reduced to the soluble ferrous form. The acceptable limit for drinking water is 0.3 mg/L.

(2) Problems. Iron problems usually occur when the soluble ferrous form present in the raw water is oxidized to the insoluble form in the distribution system or after delivery to the user. Since the precipitates are colored (yellowish, reddish, or brownish), they are immediately obvious to customers and, therefore, constitute a color problem. In addition they can produce a metallic taste, stain plumbing fixtures, and interfere with laundry and cleaning operations. Similar problems result when corrosive water is supplied through iron or steel pipes. A related phenomenon involves certain attached autotrophic bacteria, such as *Crenothrix* and *Gallionella*, that may establish residence in distribution systems. These organisms derive energy from the oxidation of iron and store the resultant precipitates in cellular material. Occasionally "clumps" of the bacteria break away from pipe walls or pumps and cause periodic problems. Iron can be sequestered by various "corrosion inhibitors" such as polyphosphates, or may be removed from water by ion exchange/adsorption or by a combination of oxidation, sedimentation, and filtration. The latter process is widely used, with oxygen, chlorine, and potassium permanganate all finding substantial usage as the oxidant.

h. Manganese. Manganese is less common than iron, but causes similar problems (the characteristic color is dark brown or black). Manganese chemistry is complex, but removal methods are similar to those previously described for iron. One significant difference is that manganese oxidizes in air at a very slow rate and hence may be somewhat more likely to be present to a significant extent in surface waters. The acceptable limit for manganese in drinking water is 0.05 mg/L.

i. Alkalinity. Alkalinity may be defined as the ability of water to neutralize an acid, and is determined by titration against a known standard acid (usually 0.02 N sulfuric acid). Alkalinity has traditionally been reported in terms of mg/L as $CaCO_3$. This is somewhat confusing nomenclature since the chemical species responsible for virtually all the alkalinity of natural waters is the bicarbonate ion (HCO_3^-). The optimal amount of alkalinity for a given water is a function of several factors including pH, hardness, and the concentrations of dissolved oxygen and carbon dioxide that may be present. As a general rule, 30 to 100 mg/L as $CaCO_3$ is desirable although up to 500 mg/L may be acceptable. Alkalinity is apparently unrelated to public health (at least directly), but is very important in pH control. Alum, gaseous chlorine, and other chemicals occasionally used in water treatment act as acids and, therefore, tend to depress pH. Alkalinity resists this change and thereby provides buffer capacity. Many waters are deficient in natural alkalinity and must be supplemented with lime (CaO or $Ca(OH)_2$) or some other chemical to maintain the pH in the desirable range (usually 6.5 to 8.5). Alkalinity values can change significantly for groundwater between samples taken at the wellhead and samples taken from a storage reservoir that are a few hours old.

j. pH. pH is especially important with respect to body chemistry, the effectiveness and efficiency of certain water treatment processes, and corrosion control. Most natural waters have a pH in the range of 6.5 to 8.5. Since this range is generally acceptable, pH control usually requires making only relatively minor adjustments rather than wholesale changes. Exceptions arise when low-alkalinity waters must be treated with acidic chemicals such as alum or chlorine gas, with waters that have been softened by the lime-soda process, or with well waters that are supersaturated with carbon dioxide and hence may have a very low pH (down to about 4.5). The occurrence of pH lower than about 4 to 4.5 is indicative of the presence of mineral acids and, hence, possible contamination by industrial wastes.