EXERCISE 13

Water Quality Data and Pollution Sources

INTRODUCTION

Water quality in a stream, lake, well, or spring is a product of the quality of the precipitation and any changes that have occurred to the water at or below the surface of the earth. As water moves through the hydrologic cycle, it changes chemically, physically, and biologically (Hem, 1985). Some changes cause the quality to deteriorate and if the inputs are significant from human sources, the water is considered to be contaminated.

Major sources of contamination include industrial, municipal, agricultural, and mining activities. The contaminants may be physical, chemical, or biological. Some constituents affect taste, others may be corrosive, and a few are health hazards. All natural water, however, contains some impurities. These naturally occurring background concentrations reflect the soluble products in the soil and rocks through which the water moved.

Under the 1986 Amendments to the Safe Drinking Water Act, the U.S. Environmental Protection Agency (USEPA) established *National Primary Drinking Water Regulations* for specific contaminants that may have any adverse effect on human health and could be expected in public water systems (Table 13.1). These regulations indicate MCLGs and MCLs. MCLGs (Maximum Contaminant Level Goals) are recommended maximum limits of contaminants in drinking water. They are nonenforceable health goals of contaminant levels at which no known or anticipated adverse health effects occur and that allow an adequate margin of safety. MCLs (Maximum Contaminant Levels) are the maximum permissible levels. They are set as close to the MCLGs as is feasible using the best technology and techniques available. Additional organic chemicals and their potential health effects from exposure above the MCLs are available online from the USEPA.

In addition to health concerns addressed under the primary regulations, the USEPA has developed *National Secondary Drinking Water Regulations* that cover aesthetic qualities, such as taste and odor, of drinking water (Table 13.2). Under this section, Secondary Maximum Contaminant Levels (SMCLs) have been set for contaminants. The SMCLs are federally nonenforceable and establish limits for contaminants in drinking water that may affect aesthetic qualities and public acceptance of drinking water. Standards for drinking water in the United States continue to evolve.

The concentrations of substances dissolved in water are normally reported as milligrams per liter (mg/L), parts per million (ppm), parts per billion (ppb), or grains per gallon (gpg). Milligrams per liter and parts per million are practically the same for waters with less than 7,000 ppm total dissolved solids (TDS). The two terms are often used interchangeably. One mg/L means that a 1-liter sample of water contains 1 milligram of substance dissolved in it, or that in a million total units 1 unit consists of a dissolved substance. To correctly interpret the significance of water-quality data, it is necessary to understand something about the origin and reactions of certain compounds.

In this exercise we investigate the importance of selected inorganic chemicals in water and their potential sources. An estimate of the quantity of inorganic chemicals in water is provided by specific conductance. The capacity for water to conduct an electric current is determined by the temperature and the degree of ionization of the elements and compounds in the water. This capacity is known as *specific conductance,* and by measuring it we can determine the quantity of total dissolved solids (TDS) in the water. The concentration of dissolved solids (in ppm) is usually estimated by multiplying the specific conductance, which is given in μmhos/cm, or microsiemens, by 0.67. A mho, which is a unit for conductivity, is the reverse of an ohm, the unit for resistivity.

TABLE 13.1 National Primary Drinking Water Standards for Selected Contaminants (USEPA, 2007 http://www.epa.gov/safewater/contaminants/index.html#listmcl). See text for MCLG and MCL.

Contaminant	MCLG[1]	MCL[1]	Potential Health Effects	Contaminant Sources
Microbiological				
Coliforms (total)	0	5.0%[2,3]	Gastrointestinal Illness (GII)	human/animal fecal waste
Cryptosporidium	0	TT[3]	GII (diarrhea, vomiting, cramps)	human/animal fecal waste
Giardia lamblia	0	TT[3]	GII (diarrhea, vomiting, cramps)	human/animal fecal waste
Legionella	0	TT[3]	Legionnaire's Disease	multiplies in heating sys.
Turbidity	—	TT[3]	assoc. with microorganisms	soil runoff
Viruses (enteric)	0	TT[3]	GII (diarrhea, vomiting, cramps)	human/animal fecal waste
Inorganics				
Antimony	0.006	0.006	incr. blood cholesterol, decr. sugar	oil ref.; fire retard.; ceramics; solder
Arsenic	—[4]	0.010	skin, circulatory, cancer	nde,[5] orchards, electronics
Asbestos	7 MFL	7MFL[6]	benign intestinal polyps	asbestos cement in water mains
Barium	2	2	incr. blood pressure	drilling wastes; metal refin.; nde
Beryllium	0.004	0.004	Intestinal lesions	metal refin., defense industries.
Cadmium	0.005	0.005	kidney	galvanize pipes, battery waste
Chromium	0.1	0.1	dermatitis	steel and pulp mills, nde
Copper	1.3	(1.3)TT[7]	GII, liver, kidney	plumbing, nde
Cyanide (free)	0.2	0.2	nerve, thyroid problems	steel/metal/plastic/fertilizer fact.
Fluoride	4.0	4.0	bone disease, mottled teeth	additive, nde, aluminum waste
Lead	0	(0.015) TT[7]	mental dev, kidney, blood pres.	plumbing, nde
Mercury (inorganic)	0.002	0.002	kidney	factories, landfills, farms, nde
Nitrate (as N)	10	10	<6 mos, illness/death, "blue-baby"	fertilizer, septic tanks, nde
Nitrite	1	1	<6 mos, illness/death, "blue-baby"	fertilizer, septic tanks, nde
Selenium	0.05	0.05	hair, fingernail loss, numbness, circ.	oil ref., mines, nde
Thallium	0.0005	0.002	hair loss; blood, kidney, liver	ore-proc., electron, glass and fact.
Radionuclides				
Alpha particles	—[4]	15 pCi/L	cancer risk	nde of radioactive mines
Beta particles	—[4]	4 mrem/yr	cancer risk	decay radioactive mins.
Radium 226 + 228	—[4]	5 pCi/L	cancer risk	nde
Uranium	0	30 ug/L	cancer risk; kidney toxicity	nde
Organic Chemicals				
Atrizine	0.003	0.003	cardiovasc., repro. problems	herbicide runoff
Carbofuran	0.04	0.04	blood, nervous syst., repro.	soil fumigant (rice, alfalfa)
Chlordane	0	0.002	liver, nervous syst., cancer	residue of banned termiticide
2,4-D	0.07	0.07	liver, kidney, adrenal glands	herbicide runoff
Diquat	0.02	0.02	cataracts	herbicide runoff

TABLE 13.1 National Primary Drinking Water Standards for Selected Contaminants (USEPA, 2007 http://www.epa.gov/safewater/contaminants/index.html#listmcl). See text for MCLG and MCL. (continued)

Contaminant	MCLG[1]	MCL[1]	Potential Health Effects	Contaminant Sources
Lindane	0.0002	0.0002	liver, kidney	insecticide, cattle, lumber, gardens
PCBs	0	0.0005	anemia, blood, cancer risk	factories, dry cleaners
Benezene	0	0.005	anemia, blood, cancer risk	factories, gas storage, landfills
Carbon tetrachloride	0	0.005	liver, cancer risk	chemical plants
1,2 Dichloroethane	0	0.005	cancer risk	industrial chemical factories
Ethlbenzene	0.7	0.7	liver, kidney	petroleum refineries
Styrene	0.1	0.1	liver, kidney, circ. syst.	rubber/plastic factories, landfills
Tetrachloroethylene	0	0.005	liver, cancer risk	factories, dry cleaners
Vinyl chloride	0	0.002	cancer risk	PVC pipes, plastic factories
Dioxin (2,3,7,8-TCDD)	0	0.00000003	reproduction, cancer risk	waste incin. chemical factories
Disinfectants and By-products				
Chlorine (Cl_2)	MRDLG[8]=4	MRDL[8]=4.0	eye/nose irritation; stomach	add to disinfect drinking water
Total trihalomethanes (TTHMs)	—[4]	0.080	liver, kidney, nervous, cancer	byproduct of water disinfection
Bromate	0	0.010	cancer risk	byproduct of water disinfection.

[1] In milligrams per liter (mg/L) unless otherwise noted

[2] More than 5.0% samples total coliform-positive in month, then tests for fecal coliforms or E. coli. Fecal coliform and E. coli are bacteria that indicate water may be contaminated with human/animal wastes. Disease-causing microbes (pathogens) in these wastes can cause diarrhea, cramps, nausea, headaches, etc., and may pose risk of severe illness for infants, the young, and those with weak immune systems.

[3] For Giardia and viruses, the TT is a combination of (1) inactivation by disinfection and (2) filtration. Filtration (or boiling at home) is the technique for Cryptosporidium, which has cysts very resistant to chlorine-based disinfect. Legionella is also controlled through inactivation/filtration. Turbidity a measure of filtration effectiveness and must be <0.3 NTU in 95% samples/month. (Treatment Technique is a required process intended to reduce level of a contaminant in drinking water.)

[4] None established.

[5] Nde or nde, natural deposit erosion

[6] Million fibers per liter (<10 um in size)

[7] Lead and copper TT controls the corrosiveness of water. When $>10\%$ of tap water samples exceed "action level" (in parens.) then additional steps needed.

[8] MRDLG, Maximum Residual Disinfectant Level Goal (residual from water treatment), MRDL, Maximum Residual Disinfectant Level.

PART A. SIGNIFICANCE OF SELECTED MAJOR INORGANIC CONSTITUENTS

Hardness

Hard water usually has significant amounts of calcium and magnesium. Hardness is usually associated with the effects that take place when using soap. Hard water requires the use of large amounts of soap and leaves insoluble residues in bathtubs and sinks. In addition, hard water causes scale to form in water heaters, boilers, and pipes.

Hardness depends mainly on the concentration of calcium (Ca) and magnesium (Mg), but other substances such as sulfate (SO_4) also form insoluble residues from soap. Water having a hardness of less than 60 ppm is considered soft, 61 to 120 ppm is moderately hard, 121 to 180 ppm is hard, and more than 180 ppm is very hard.

CALCIUM (Ca). Calcium may be leached from most rocks, but limestone and dolomite provide the largest amount. Calcium is a major cause of hardness and forms scale on utensils, boilers, and pipes. Calcium is not considered detrimental to health.

SODIUM (Na). Sodium is readily leached from rocks and tends to remain in solution. Any salt, clay or silt-rich deposits may provide high sodium concentrations to circulating water. In addition, sodium may be taken into solution if the transporting water comes in contact with sewage or industrial wastes. The concentration of sodium is not especially important in water for domestic uses. Persons having an abnormal sodium metabolism should consult their physicians concerning the planning of a sodium-free diet if the supply of drinking or culinary water has a high sodium content. A concentration of sodium in excess of 500 mg/L, when combined with chloride, results in a salty taste. Concentrations in excess of 1,000 mg/L are unsuitable for many purposes. On the other hand, some communities use water containing more than 4,000 mg/L of dissolved solids because other supplies are not available. Generally the more highly mineralized the water, the more distinctive its taste.

Hydrogen-Ion Concentration (pH)

The pH of water is a measure of alkalinity or acidity. A pH of 7 indicates a neutral solution; a pH greater than 7 indicates an alkaline solution and a pH less than 7 indicates an acidic solution. The pH is related to the corrosive properties of water. Low pH water is most corrosive. Acidic water may have a sour taste. Most water has a pH between 5.5 and 8. The recommended range is 6.5–8.5. A low pH may be related to the discharge of acid water from coal mining regions or disposal of spent acids by certain industries.

Other Inorganic Chemicals

Other inorganic chemicals, often present in trace quantities, are also important water quality factors and some have implications for human health. Limits on several inorganic chemicals are given in Table 13.1

SULFATE (SO_4). Sulfate is dissolved from rocks containing sulfur compounds, such as gypsum and pyrite (Hem, 1985). Sulfate, when combined with other elements, may produce a bitter taste. Large amounts of sulfate may produce a laxative effect in some people; therefore the U.S. Public Health Service (1962) recommended that the sulfate concentration in public supplies should not exceed 250 mg/L. Although high sulfate concentrations may reflect natural background conditions, various industrial activities may cause severe contamination. In the extensive coal-mining region of Appalachia, much of the surface water contains high levels of sulfate. This is the result of weathering of abundant iron sulfides associated with the coal deposits and the leaching of the water-soluble products into streams. This activity is largely responsible not only for the high sulfate, but the acid condition of the streams as well, since it forms sulfuric acid. Several industries, particularly steel mills, use large amounts of sulfuric acid, which in the past in North America was dumped into streams after it was used. High sulfate content may also indicate sewage pollution.

CHLORIDE (Cl). Although chloride is dissolved from rocks and soil, its presence may indicate contamination by human and animal sewage as well as industrial effluents. Chloride may combine with sodium to produce a salty taste; the chloride content of public water supplies should not exceed 250 mg/L (Table 13.2). This recommended limit is based solely on taste. Throughout nearly all the land masses, fresh water is underlain by salt water. The depth to the freshwater-salt-water interface may range from a few to several hundred feet. Highly mineralized water from a deep well could reflect the underlying salt water. In addition to sewage, major sources of contamination by wastes of high chloride content include disposal of hydrochloric acid, leaching of oilfield brines, and road salting.

FLUORIDE (F). Most fluoride compounds have a low solubility; hence, fluoride occurs only in small amounts in natural water. Fluoride in drinking water has been shown to reduce the formation of dental caries if the water is consumed during the period of enamel calcification; it may also cause mottling of the teeth under certain conditions. Former recommended fluoride concentrations for public water supplies

TABLE 13.2 Secondary Maximum Contaminant Levels[1]

Contaminant	Level[2]
Aluminum	0.05–0.2 mg/L
Chloride	250 mg/L
Copper	1.0 mg/L
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids (TDS)	500 mg/L
Zinc	5.0 mg/L
Color	15 color units
Corrosivity	noncorrosive
Odor	3 threshold odor number
pH	6.5–8.5

[1] Secondary Maximum Contaminant Levels (SMCLs) are federally nonenforceable and establish limits for contaminants in drinking water that may affect the aesthetic qualities (e.g., taste and odor) and the public's acceptance of drinking water.

[2] These levels represent reasonable goals for drinking water quality. The states may establish higher or lower levels, which may be appropriate dependent upon adverse effect on public health and welfare and upon local conditions such as unavailability of alternate source waters or other compelling factors. Some contaminants appear in both primary and secondary standards.

varied with the annual average temperature (Table 13.3). An excess of fluoride is associated with excessive bone formation and calcification of ligaments. Fluoride is now included in both the primary and secondary drinking water standards (Tables 13.1 and 13.2).

NITRATE (NO_3). Nitrate may be leached from some rocks by water, but certain plants, plant debris, animal excrement, sewage wastes, and inorganic nitrate fertilizers are probably the major contributors of nitrate. Nitrate concentration (measured as N) in water in excess of 10 mg/L, the maximum limit set by the USEPA (Table 13.1), causes infantile methemoglobinemia (blue babies).

IRON (Fe). Iron compounds are very common in rocks and they are easily leached by water, particularly water with a low pH. Concentrations of iron in excess of 0.3 mg/L will cause staining of laundry and utensils; it is usually objectionable for food processing, beverages, ice manufacturing, and many other processes. It may cause a metallic taste. Streams draining coal or other mining areas commonly contain excessive iron concentrations. Various other industrial processes, such as steel production, may also contribute to excessive iron concentrations.

Minor and trace inorganic substances are included in Tables 13.1 and 13.2 and microbiological and organic chemical data are in Table 13.1. Consult the footnotes for these tables for additional information on the nature, occurrence, and health effects of these substances in drinking water.

QUESTIONS 13, PART A

1. Which of the major inorganic substances might indicate contamination by sewage?

2. What are the major inorganic substances discussed in Part A that may be detrimental to human health?

TABLE 13.3 Former Recommended Fluoride Limits (USPHS, 1962)

Annual Average Of Maximum Daily Air Temperatures (°F)	Recommended Fluoride Limit (mg/L)
50.0–53.7	1.7
53.8–58.3	1.5
58.4–63.8	1.3
63.9–70.6	1.2
70.7–79.2	1.0
79.3–90.5	0.8

3. Iron and chloride are major inorganic substances that adversely affect drinking water. Are they health hazards according to the USEPA tables in this exercise?

4. a. What are the health hazards of excessive fluoride?

b. Why is fluoride listed in Tables 13.1 and 13.2?

5. For each of the following contaminants in drinking water, list the potential health effects and their sources.

Arsenic

Asbestos

Atrizine

Bromate

Carbofuran

Chlordane

Chlorine (as Cl_2)

Chromium

Cryptosporidium

Dioxin

Diquat

Lead

Nitrate

PCBs

Selenium

Tetrachloroethylene

Vinyl chloride

6. Use the information in Table 13.1 to help answer the following.

a. What is the purpose or role of adding disinfectants to drinking water?

b. What are the potential health effects (if any) of the disinfectant byproducts (listed in Table 13.1) that are produced during disinfection of drinking water?

c. For control of *Giardia lamblia* (and most other biologicals in the water), what two techniques are employed?

d. A treatment technique that controls the corrosiveness of water is used to limit copper and lead contaminants in drinking water. Why is corrosion a factor in copper and lead contamination?

Use information in Tables 13.4 and 13.5 to answer the questions below.

7. a. What water quality factors suggest that the North Dakota farm well is contaminated?

b. What are the most likely sources of contamination in this well?

8. a. What is the most likely cause of contamination of the domestic well in Ohio?

b. Could the water be used for cooking? Explain.

TABLE 13.4 Dissolved Solids (mg/L), Inorganic Chemicals (mg/L), and pH of Four Surface-Water Samples in the United States

Water Quality Factor	Source			
	Public Supply Buffalo, NY (Lake Erie)	Public Supply Seattle, WA (Cedar River)	Mahoning River Northeastern Ohio	Big Four Hollow Creek East Central Ohio
Dissolved solids	177	40	890	1620
Sulfate	23	2.4	470	1100
Chloride	23	0.5	100	15
Nitrate	0.2	0.2	4.6	2.1
Iron	0.01	0.05	52	52
pH	8.0	7.4	5.5	2.9

TABLE 13.5 Dissolved Solids (mg/L), Inorganic Chemicals (mg/L), and pH of Four Groundwater Samples in the United States

Water Quality Factor	Source			
	Public Supply Wichita, KS (well field)	Public Supply Shreveport, LA (well field)	North Dakota farm well (30 ft deep)	Ohio domestic well (47 ft deep)
Dissolved solids	844	142	2,400	15,390
Sulfate	128	12	1,750	24
Chloride	221	40	893	7,730
Nitrate	0.4	0.3	222	1.0
Iron	0.05	0.02	5.1	4.1
pH	7.3	6.6	7.3	7.4

9. a. What is the most likely source of contamination of Big Four Hollow Creek?

b. Could this water be detrimental to health if consumed? Explain.

c. What taste should it have?

10. Why do you think that the well water in Wichita is more highly mineralized than the well water in Shreveport? (Consider climate as well as possible differences in geology.)

11. Why does the public water supply in Seattle contain fewer dissolved solids than the supply in Buffalo? (Consider geology, climate, and topography.)

12. Lake Erie was once considered to be strongly contaminated and even "dead" by some environmentalists. Do the data in Table 13.4 support this idea or are other data needed (e.g., water quality factors for fish? Explain.

13. Recall the relationship between dissolved solids (TDS) and specific conductance (see Introduction to Exercise 13) and determine the probable specific conductance for water from the

a. Mahoning River?

b. Big Four Hollow Creek?

14. From the data in these tables, would you expect most water supplies to be acidic or alkaline?

15. What is the source of water where you are now living? If possible, check with your local water treatment facility by phone or online, determine its dissolved solids content and record it here.

PART B. SOURCES AND AMOUNTS OF CONTAMINATION

Contamination of surface-water sources, such as lakes and water courses, commonly results from (1) point-source discharge of effluent (wastewater) directly into the water, (2) non-point-source discharge such as runoff from fields, and (3) inflow of contaminated groundwater. Although it may be relatively easy to determine the location of a surface outfall and to measure both the rate of the effluent discharge and its composition, it is much more difficult to evaluate non-point-source pollution and to detect areas where contaminated groundwater affects the quality of surface water.

The principle that "dilution is the solution to pollution" has been used for centuries. During the 1970s in an effort to clean up the streams and rivers of North America, reduction and/or pretreatment of industrial effluent was implemented.

However, dilution is still an important concept. The reasoning behind this is that generally effluent discharge is many times smaller than the discharge of the receiving stream, and consequently the waste ultimately will be diluted to an acceptable concentration for most uses by humans and for aquatic life. For example, contaminated groundwater is constantly being diluted as it slowly moves through the ground.

The quantity of contaminated groundwater seeping into a stream is generally quite small relative to the flow of the stream, and the contaminant may be so diluted that it is undetectable in stream waters even in areas of discharge.

The concentration of a contaminant in a stream is also directly related to the physical properties of the stream. Many organic and inorganic chemicals may become attached to silt or clay particles. These chemicals can be released later and contaminate ground or surface water that otherwise might not be contaminated. Suspended sediment in water (turbidity) is also a contaminant (Table 13.1).

As indicated in the Introduction to Water Resources and Contamination and this exercise, major sources of water pollution come from industrial, municipal (domestic and industrial sources), and agricultural activities (Table 13.6). Physical, chemical, or biological contaminants may adversely affect water quality. Some constituents affect taste (chloride, sulfate, phenols, iron), others may be corrosive (high in dissolved solids, low pH) and a few may be health hazards (heavy metals, nitrate, pathogenic bacteria, and viruses). Increased temperature or increased biological oxygen demand (BOD) from organic wastes causes a reduction in the amount of dissolved oxygen (DO) in water. DO is important for fish survival.

TABLE 13.6 Summary of Sources and Their Contaminants in Ground- and Surface-Water Pollution

Source	Principal Contaminants (groundwater contaminants in italics)
Domestic	Undecomposed organic matter (garbage, grease) that increases BOD (Biochemical Oxygen Demand) Partially degraded organics (raw wastes and nitrates from humans) from combined sewers Combination of above after limited sewage treatment in municipal sewage plants Parasites, bacteria, and viruses (pathogens) Grit from washings, eggshells, ground bone Miscellaneous organics (paper, rags, plastics, synthetics) *Detergents* *Inorganics from organic decay (nitrate, sulfate)* from septic tank systems *Salts and ions in public water supply* *Soluble organic compounds*
Industrial	Biodegradable organics Inorganic solids, mineral residues Chemical residues (acids, alkalies, complex molecules) Metal ions *Soluble salts from industrial waste ponds and spills*
Agriculture	Increased concentration of salts and ions from animal feedlots Fertilizer residues including sewage sludge on land. Pesticide residues Silt and soil particles *Concentrated salts in water applied to land* from irrigation and sewage sludge
Landfill	*Hardness-producing leachate* *Soluble chemical and gaseous products*

(Modified from McGauhey, 1968)

The pollution load that a stream carries can be calculated if the stream discharge and the concentration of the specific contaminants are known.

$$\text{Load (tons/day)} = Q \times C \times 0.0027$$

where Q = stream discharge (cfs),
C = concentration of specific contaminant (mg/L), 0.0027 = constant to convert seconds and mg/L to days and tons

To determine if a stream is being contaminated, it is necessary to acquire data that were collected before the apparent contamination or to determine the concentrations of selected constituents in uncontaminated reaches of the stream. Commonly, water-quality data reflecting natural conditions prior to contamination, sometimes called background data, are not available. Background information may be obtained, however, by sampling the water course and its tributaries in reaches upstream from the suspected source of pollution. The quality at any sampling station represents all of the upstream input.

QUESTIONS 13, PART B

1. Determine the daily load of iron (tons/day) going over Niagara's Horseshoe Falls (approximate discharge = 200,000 cfs) if the iron concentration is 0.1 mg/L.

2. Biodegradable organic matter promotes oxygen demand in streams. What water quality parameter would be expected to change with increased oxygen demand?

3. Why are silt and clay particles considered to be contaminants?

4. From Table 13.6, what differences in stream-water quality upstream and downstream from a sewage treatment plant should be expected? Explain.

5. a. What is meant by "background" concentrations of chemicals in a watershed?

b. What steps are required to determine the background concentration of chromium in a watershed with a chrome-plating factory?

6. List three microrganisms that indicate contamination by animal wastes (In addition to Tables 13.1 and Table 13.6, see the Introduction to water Resources and Contamination.)

PART C. BOTTLED WATER AND WATER PURIFICATION

Introduction

Bottled water has become a popular drink choice in the United States because it might be better tasting, safer, or more readily available than some tap water or because some people seek an alternative to soft drinks and other beverages (USEPA, 2005). Most bottled water comes from ground water, either from wells or springs; the remainder comes from surface water such as lakes and rivers—in some cases from public water systems. The taste of both bottled and tap water depends on *the source* (e.g., calcium and magnesium minerals add flavor and body) and the *treatment*(s), particularly the disinfection process, which inactivates disease-causing organisms but might leave a taste.

Bottled water from a ground water aquifer is obtained from a well or spring (possibly tapped by a well) and may be labeled as artesian if it comes from a confined aquifer. Distilled water from a surface or groundwater source is condensed after boiling to steam. The process kills microbes (including *Cryptosporidium*) and removes natural minerals (and much of the taste) and some organics.

Tap water is usually disinfected by chlorine or chloramine, because of the effectiveness, cost, and the continuing protection provided while in pipes of municipal water systems and in the home. Some tap water also uses ultraviolent (UV) light or ozone. Ozone is the preferred disinfectant for bottled water because it does not leave a taste and the sealed bottle does not need continuing disinfection. Other bottled water is disinfected using UV light or chlorine dioxide. Ozone (and UV light) kills most microbes depending on the dosage.

Sterilized water or **sterile water** is water that is free from all microbes. **Purified water** is essentially free of chemicals (TDS < 10 ppm) and might be produced by distillation, deionization, or by reverse osmosis (RO). In the latter process, water is forced through a membrane leaving behind all contaminants (minerals, organic and inorganic chemicals, color, turbidity, and microbes). Purified water may also be referred to as demineralized water; or distilled water if purified by distillation, deionized water if purified by deionization, or reverse osmosis water if purified by RO. For bottled water, micron filtration (screens with microscopic holes) remove most chemicals and microbes. To remove *Cryptosporidium* cysts, the largest hole in the filter must be one micron.

Although the EPA sets the standards for public drinking water supplies, the FDA (Food and Drug Administration) sets those for bottled water (based on EPA standards). The FDA regulates bottled water as a packaged food and sets the quality and identity standards and requirements for processing and bottling. *Carbonated water, soda water, seltzer water, sparkling water, and tonic water are not regulated as bottled water but as* ***soft drinks.*** Bottled water sold in the United States, including those from overseas, must meet the FDA standards for physical, chemical, microbial, and radiological contaminants.

There are many types of bottled water according to the Code of Federal Regulations (21 CFR 165.110 (a)(2)). See also **sterilized** and **purified** waters above.

Bottled water or drinking water is water intended for human consumption, sealed in bottles, with no added ingredients (except safe antimicrobial agents and fluoride).

Other types of bottled water are:

artesian water or artesian well water—water from a well tapping a confined aquifer in which water stands above the height of the top of the aquifer,

mineral water—water containing not less than 250 ppm TDS that originates from a geologically and physically protected underground water source, with no added minerals, and constant levels and proportions of minerals and trace elements. Mineral water is labeled as *"low mineral content"* if it is < 500 ppm TDS or as *"high mineral content"* if TDS $> 1{,}500$ ppm.

sparkling bottled water—water that after treatment and possible replacement of CO_2 contains the same CO_2 as it had when it emerged from the source (compare with *sparkling water,* above, that is regulated as a soft drink).

spring water—water derived from underground formation from which water flows naturally to surface (may also be collected through a borehole).

well water—name of water derived from a well (dug or drilled).

Also, if bottled water comes from a community water system, it will be labeled *"from a community water system"* or *"from a municipal source."*

Note that bottled water meets the EPA's Secondary Drinking Water Standards (e.g., chloride—250 mg/L and TDS 500 mg/L) *except for* mineral water. Bottled water that is certified by NSF International indicates that the bottler complies with all FDA requirements. Members of the International Bottled Water Association (IBWA) meet their trade association's "model code." To learn more about a bottled water and specific contaminants, contact the bottler through the contact information provided on the bottle.

To determine its quality, compare that information with the FDA standards (www.cfsan.fda.gov) and/or the EPA Groundwater and Drinking Water page (www.epa.gov/safewater) and EPA standards for drinking water (http://www.epa.gov/safewater/standards.html). See also EPA's Drinking Water and Health http://www.epa.gov/safewater/dwh/index.html. Additional information is available through the Code of Federal Regulations and NSF International (www.nsf.org) and the International Bottled Water Association (www.bottledwater.org).

Small public water systems are allowed to meet the National Primary Drinking Water Regulations by installing point-of-use (POU), for direct consumption, and point-of-entry (POE) treatment devices. Some consumers on municipal systems install at-the-tap filters or purchase "pitcher filters" for small amounts of drinking water. Filters are designed for removing one or more contaminants.

For information on ground water resources for the home, see the USGS publication on *Ground Water and the Rural Homeowner* (Waller, 2005).

QUESTIONS 13, PART C

With the aid of information in the Introduction to Part C (and possibly other sources) answer the questions below.

1. a. What are the sources of bottled water?

b. What factors control the taste of bottled water?

c. *Cryptosporidium* is a microscopic parasite that lives in human/animal intestines. Cysts of the organism in the public water supply of Milwaukee, Wisconsin, were eventually responsible for 400,000 cases of illness and several deaths. Why did the standard chemical disinfectant used in public water systems not kill this microorganism?

d. Since that time what changes in treatment for public water supplies now remove *Cryptosporidium?*

e. Who sets the standards and regulates bottled water?

f. Explain by defining each, the difference between purified and sterilized water.

2. What is the difference between sparkling water and sparkling bottled water?

3. Define what is meant by artesian water.

4. a. List all the requirements for bottled water to be labeled mineral water.

b. Does mineral water meet the national Secondary Drinking Water Regulations? Explain.

5. Examine a bottled water label, your own or one available in class or online, and record the following information on this water. You might need to use an online source, often listed on the bottle, for more information.

Name of the bottled water: Company:

Size of bottle: mL _____ oz _____ Type of water: __________

Listed geologic source of water (check one or more):

Groundwater aquifer _____ Spring_____ River _____
Lake _____

Public water system _____ Other ______________

Geographic source of water:

Methods of treatment (if any):

None: _____ None listed: _____

Distillation _____

Micron filtration: yes _____ no _____

Hole size: Nominal (average) = _______ or

Absolute (maximum) = _______

Reverse osmosis _______

Disinfection

Ozone _____ Chlorine dioxide _____

UV light ________

Chloramine _____ Chlorine _____

Other Treatments

Other Label Information:

6. Check the definitions in the Introduction to this part of the exercise to help answer the following.

a. What is the definition for purified water?

Is the bottle of water described in the question above purified?

What process was used in the purification?

What is the limit for total dissolved solids (TDS) for purified water?

Has anything been added to the water after purification?

b. What is the definition for sterilized water?

Has the bottle of water described above been sterilized _____

What was the process used for sterilization?

7. a. What is the cost per liter for bottled water (give the brand, size, and where purchased (vending machine, grocery, etc.)? Convert if the bottle is not liter-sized)?

b. How does this compare in price (per liter) with tap water in your city?

(Check with the city or the instructor for tap water cost; 1 U.S. gallon = 3.78 liters)

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