

Water Quality



WATER QUALITY

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Canyons

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CHAPTER 1: WATER RESOURCES AND THE ORIGIN OF CONTAMINANTS

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Understand and describe water sources
- Describe the water cycle
- Compare the term water contaminants with water pollutants

This chapter presents a brief introduction to the water sources that are available for potable supply; detailed information is presented in Water 132 (Water Supply). Understanding drinking water sources is important to assess the variety of contaminants that can be present in water.

WATER SOURCES

According to the United States Geological Survey (USGS), 71% of the Earth's surface is covered in water, and of that 97% are the oceans. The Earth's water can be broken into two different categories: freshwater and salt water. Fresh water is simply water that is not salty and can be found in the planet's surface water such as streams, lakes, and frozen as ice, but also underground in aquifers. Fresh water is stored on the surface as **surface water** or stored underground in aquifers as **groundwater**. Salt water can be found in the world's oceans.

Figure 1.1 shows that our planet's water sources are limited. Freshwater is much easier to use for potable (drinkable) applications because it requires more simple treatment. However, it represents only a small fraction of the Earth's water portfolio. A large proportion of the freshwater is locked in glaciers and is not accessible. As a result, less than 1% of the water present on the planet is groundwater and surface water that can be more easily used as potable water source. Although desalination plants have become more prevalent, they are very costly and their overall environmental impacts are unknown.

Distribution of Earth's Water

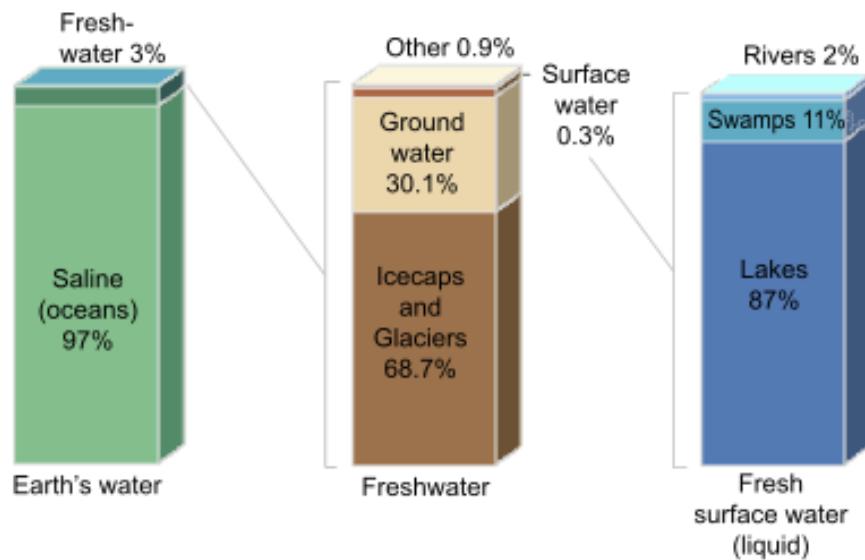


Figure 1.1¹

The origin of a water source determines its characteristics and the presence of specific contaminants. The concentration and composition of contaminants in water is also influenced by the movements of water, which is illustrated by the water hydrologic cycle (Figure 1.2). The Water Cycle is both driven by gravity (i.e., water flows downhill) and sunlight (i.e., water evaporates and condenses).

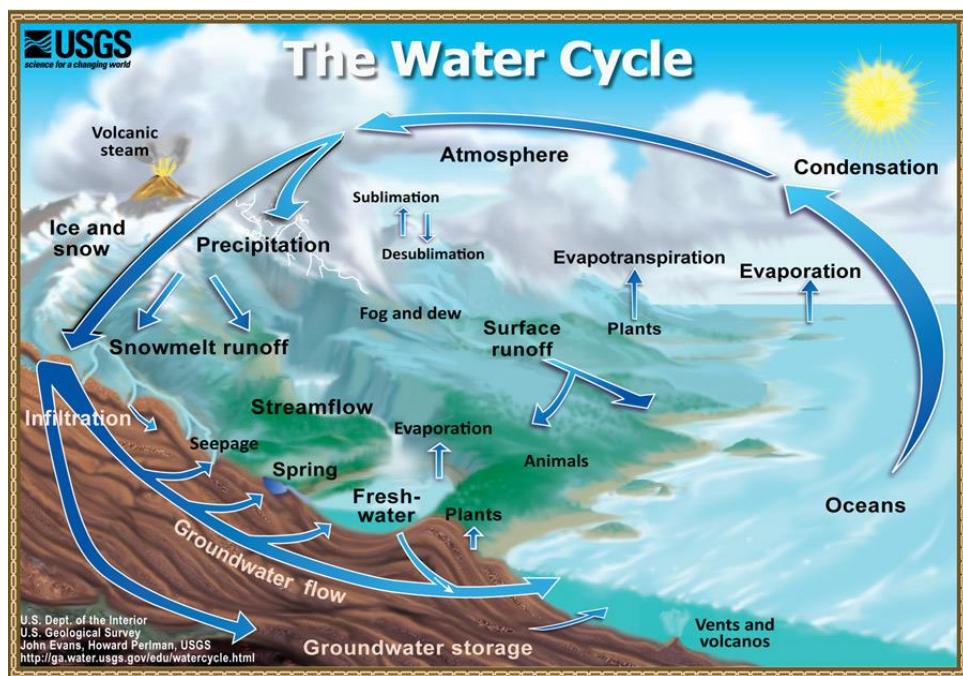


Figure 1.2: Water Hydrologic Cycle²

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² [The Water Cycle](#) by the [USGS](#) is in the public domain

CLASSIFICATIONS OF CONTAMINANTS

According to the Safe Drinking Water Act, a contaminant is any physical, chemical, biological, or radiological substance in water. While some contaminants are harmless, others are deadly. As water condenses, runs off as surface water or percolates into the ground, it accumulates contaminants. Contaminants can even mix with water molecules in the atmosphere.



Pin It! Misconception Alert

Many people think that all contaminants are manmade. They are not! Some have natural sources in the soil, such as arsenic and uranium. These can be expensive to remove because they occur naturally in the rocks around the water source.

Contaminants can be classified in several ways. One way to classify contaminants is by source:

- **Natural contaminants** come from soil geology, erosion of soils, etc. Examples of contaminants include fluoride and arsenic.
- **Anthropogenic (human caused) contaminants:**
 - Industrial contaminants vary widely and are specific to the industries that generate them. Examples of industries that generate contaminants often found in water include chemical, mining, metal, textile, food processing, petrochemical, and pulp and paper industries.
 - Agricultural contaminants can be separated into two broad groups:
 - Contaminants that originate from crops, such as pesticides, fertilizers, nutrients, and sediments.
 - Contaminants that are derived from animal production, which include a variety of organic contaminants, nitrogenous chemicals, microorganisms, salts
 - Domestic contaminants can be separated into two groups:
 - “Conventional” contaminants, which include microorganisms, organics, nitrogen, phosphorus, inorganics, metals, detergents, and pesticides.
 - Pharmaceuticals and personal care products, which have been gaining attention in the water industry.



Pin It! Misconception Alert

People use the words contaminants and pollutants interchangeably. What is the difference between a contaminant and a pollutant?

- A contaminant is a substance that is not normally expected;
- A pollutant is a substance found at a concentration that has reached a level that adversely affects the suitability of the water for its intended purpose.

Key Terms

- **anthropogenic contaminants** – human-caused (manmade) contaminants
- **contaminant** – a substance that is not normally expected
- **groundwater** – water stored in the ground
- **natural contaminants** – contaminants in soil geology, erosion of soils, etc. Examples of contaminants include fluoride and arsenic
- **pollutant** – a substance found at a concentration that has reached a level that adversely affects the suitability of the water for its intended purpose
- **surface water** – water on the surface of the earth

REVIEW QUESTIONS

1. Outline the water cycle highlighting water sources.
 2. List the major contaminants of water in the environment.

CHAPTER QUIZ

1. How much water on planet earth is easily treated for drinking water?
 - a. 96%
 - b. 20.9%
 - c. 32%
 - d. < 1.0%
2. Most of the water on earth is found in the _____.
 - a. atmosphere
 - b. ocean
 - c. ground
 - d. rivers
3. Which of the following is a natural contaminant?
 - a. Pesticides
 - b. Nitrates
 - c. Phosphates
 - d. Fluoride
4. Anthropogenic contaminants refers to _____.
 - a. turbidity
 - b. geological contaminants
 - c. inorganic contaminants
 - d. manmade contamination
5. The _____ is(are) essential for the maintenance of most life and ecosystems on the planet.
 - a. climate
 - b. water cycle
 - c. aesthetic characteristic of water
 - d. atmospheric circulation

6. The _____ drive(s) the water cycle.
- a. types of precipitation
 - b. oxygen concentration
 - c. nutrient levels
 - d. sun
7. What portion of surface water is found in the permafrost and ice?
- a. 69%
 - b. 68.7%
 - c. 96.5%
 - d. 30.1%

CHAPTER 2: INTRODUCTION TO CHEMISTRY AND MATTER

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Discuss matter, elements, molecules, and atoms
- Explain electronegativity
- Explain chemical bonding and compounds
- Explain chemical equations and reactions
- Discuss physical states of matter

This chapter presents the fundamentals of chemistry, starting with an introduction on matter and its elemental constituents. Molecular arrangements and chemical bonding are then introduced, followed by examples of chemical nomenclature.

COMPOSITION OF MATTER

Matter can be viewed as anything that has a mass and occupies a space, i.e., that has a specific volume. **Mass** is defined as a measurement of the quantity of matter present.



Pin It! Misconception Alert

Mass is different than weight though people commonly use them interchangeably. Mass is how much matter is present. Weight is a measure of the gravitational pull on the object. So your weight will change if you travel to the moon, but your mass will not!

Elements and Atoms

At the center of all matter are elements. **Elements** are basic substances that cannot be broken down without altering their basic identities; they cannot be further simplified (e.g., hydrogen, H; oxygen, O). An **atom** is the smallest amount of an element. The center of each atom contains a nucleus made of **protons** (very small particles with a positive electric charge) and **neutrons** (very small particles, without electrical charge), with **electrons** (very small, negatively charged particles) that gravitate around the nucleus. Electrons have an insignificant mass compared to protons and neutrons.

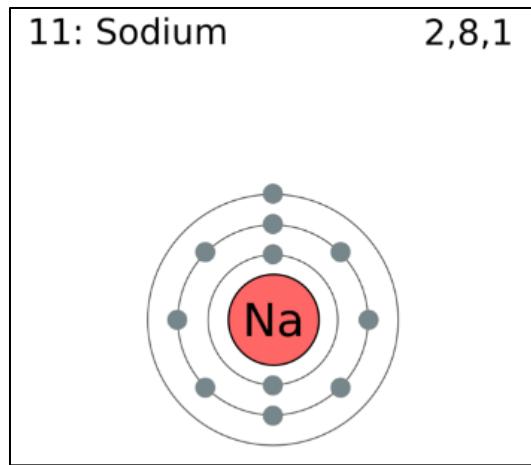


Figure 2.1: Electron Shells Gravitating Around Sodium Atom³

Electrons gravitate around the nucleus of protons and neutrons in layers or shells (Figure 2.1). There is only a limited number of electrons per shell, as shown in Figure 2.2.

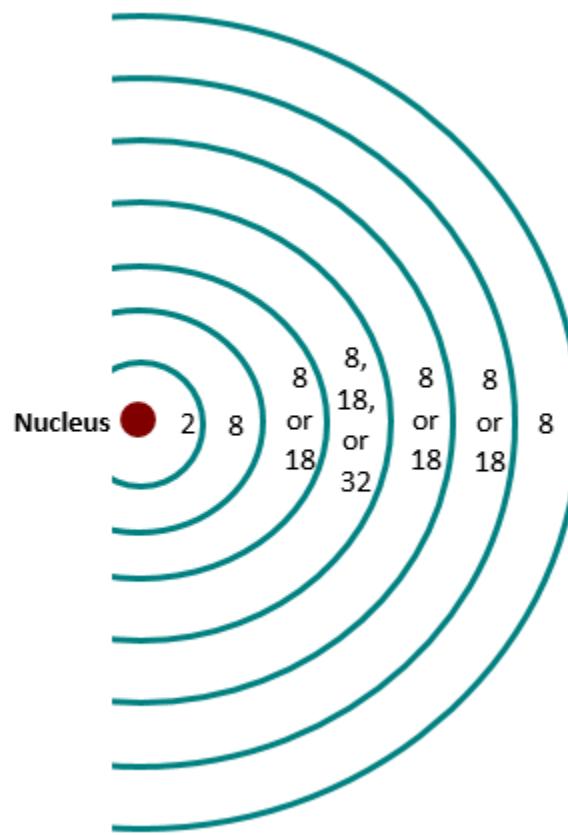


Figure 2.2: Maximum Number of Electrons per Shell⁴

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⁴ Image by [COC OER](#) is licensed under [CC BY 4.0](#)

Atoms have the same number of protons and electrons; thus, atoms have a neutral electrical charge. However, most atoms tend to gain or lose electrons to complete their last electron shell and obtain a stable electron configuration. Only the Noble Gasses (such as helium, neon, and argon) do not tend to gain or lose electrons because their electron configuration is naturally stable. An atom with an unequal number of protons and electrons is called an **ion**. Atoms that lose electron(s) become positively charged and are called **cation** (e.g., sodium, Na^+). Atoms that gain electron(s) become negatively charged and are called **anion** (e.g., chloride, Cl^-). Note that only electrons are gained, lost, or shared because they are readily available; only radioactive compounds can release protons and neutrons.



Pin It! Misconception Alert

Be careful distinguishing between cations and anions. An atom with an unequal number of protons and electrons is an ion. Cations are positively charged ions and anions are negatively charged ions.

The **Periodic Table** illustrates all elements that have been found or were synthesized to date (Figure 2.3). In this table, elements are ordered in increasing number of protons (from left to right in each row; rows are called periods) and are grouped in columns (called groups) by electron configuration. For example, chlorine appears as number 17 in the Periodic Table (i.e., its atomic number is 17), which means that it has 17 protons. Chlorine is part of the Halogen Family, which all tend to gain an electron to stabilize their last electron shell. While gaining this electron, they become negative charged (e.g., chlorine becomes chloride, Cl^-). Each column represents a family, e.g., Alkali Metals (Column 1), Alkali Earth Metals (Column 2), Halogens (Column 17), and Noble Gases (Column 18). Some families are named after their first element, e.g., Boron Family (Column 13), Nitrogen Family (Column 15), and Oxygen Family (Column 16). Additional characteristics are presented later.

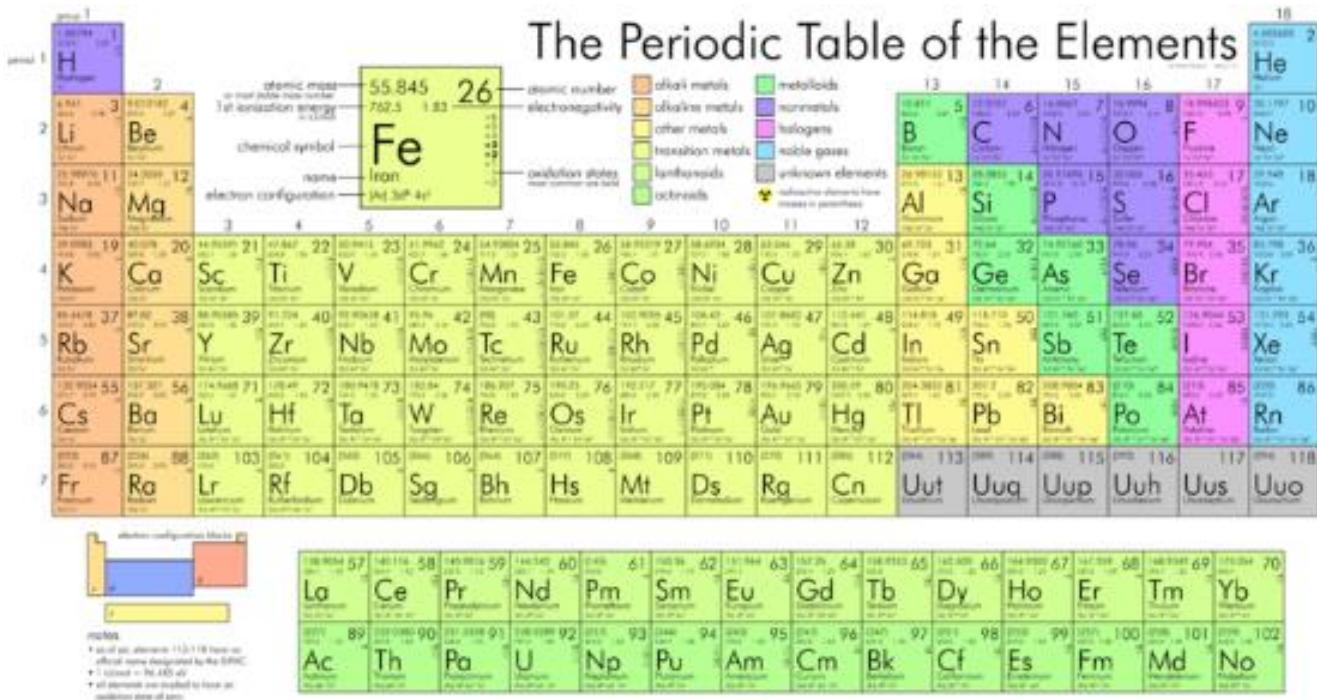


Figure 2.3: Period Table of the Elements⁵

The **valence** (also called the ionic state or oxidation state) is the number of electrons gained, lost, or shared between atoms. Because all elements of a family share similar electron configuration, they all tend to have the same valence, as follows:

- Noble Gases are stable, thus their valence is 0.
- Alkali Metals tend to lose one electron, thus their valence is +1.
- Alkali Earth Metals tend to lose two electrons, thus their valence is +2.
- Elements of the Boron Family tend to lose three electrons, thus their valence is +3.
- Halogens tend to gain one electron, thus their valence is -1.
- Elements of the Oxygen Family tend to gain two electrons, thus their valence is -2.
- Elements of the Nitrogen Family tend to gain three electrons, thus their valence is -3.

Certain elements have multiple valences with different characteristics based on their valence. For example, ferrous iron, Fe^{2+} , has lost two electrons (it has a valence of +2) and is highly soluble in water. On the other hand, ferric iron, Fe^{3+} (valence of +3), has lost three electrons and is insoluble in water, i.e., it forms a solid and precipitates. Trivalent chromium (i.e., chromite, also called chromium 3, Cr (III), or Cr^{3+}) has lost three electrons and has a valence of +3. It is an essential element that helps regulate the body's use of sugar, proteins, and fats. However hexavalent chromium (i.e., chromate, also called chromium 6, Cr (VI), or Cr^{6+}) has lost six electrons (valence of +6) and is toxic to humans.

⁵ [Image](#) is in the public domain

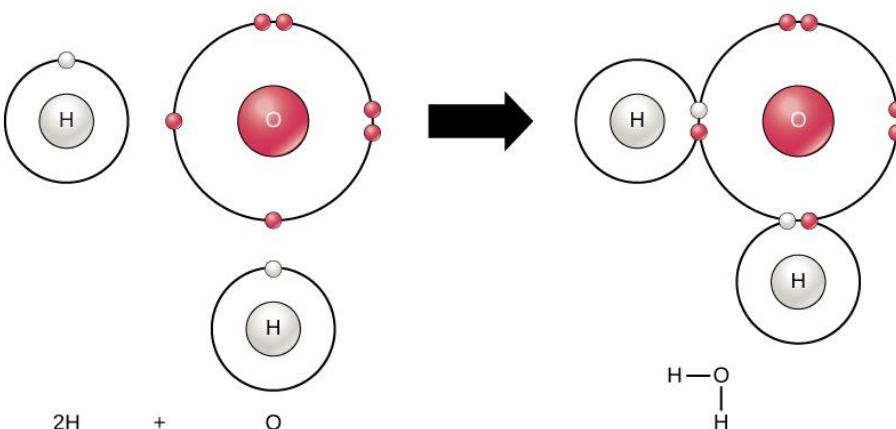
Electronegativity is the degree of attraction of an element for electrons; it defines an element's affinity for electrons. Electronegativity determines whether an atom will gain, lose, or share electrons.

Molecules and Compounds

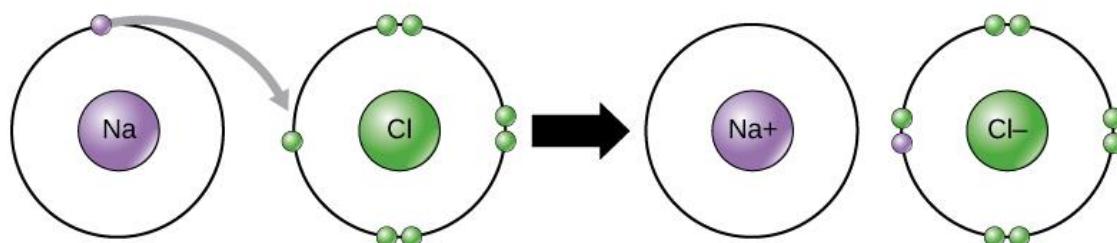
Molecules or compounds result from the combination of two or more atoms that are chemically joined (or bonded); e.g., oxygen in the air, O₂; water, H₂O. Atoms will tend to combine in such ways to increase their stability and complete their electron configuration. For some molecules, this means that they will obtain a zero net electrical charge.

Chemical bonds can be grouped in two broad categories, as illustrated in Figure 2.4.

Figure 2.4: Covalent and Ionic Bonds



Example of a covalent bond⁶



Example of an ionic bond⁷

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1. In an **ionic bond**, electrons are transferred from one atom to another. The atom that loses electron(s) becomes positively charged and is called a cation. Conversely, the atom that gains electron(s) becomes negatively charged and is called an anion. Examples of ionic bonds are shown in Table 2.5.
2. In a **covalent bond**, electrons are shared between atoms. The electronegativity of each atom will determine the polarity of the resulting molecule.

Table 2.1: Examples of Ionic Bonds

Sodium chloride, NaCl	<ol style="list-style-type: none"> 1. Sodium tends to lose 1 electron to become Na^+ 2. Chloride tends to gain 1 electron to become Cl^- 3. Net zero charge: $\text{Na}^{+1} + \text{Cl}^{-1} = \text{NaCl}^0$
Sodium oxide, Na_2O	<ol style="list-style-type: none"> 1. Sodium tends to lose 1 electron to become Na^+ 2. Oxygen tends to gain 2 electrons to become O^{2-} 3. Net zero charge: $(2 \times \text{Na}^{+1}) + (1 \times \text{O}^{2-}) = \text{Na}_2\text{O}$

Table 2.2: Examples of Covalent Bonds

Homonuclear molecules: Equal attraction for the shared electron(s)	Hydrogen, H_2: Single covalent bond: $\text{H}-\text{H}$ Chlorine, Cl_2: Single covalent bond: $\text{Cl}-\text{Cl}$ Oxygen, O_2: Double covalent bond: $\text{O}=\text{O}$ Nitrogen, N_2: Triple covalent bond: $\text{N}\equiv\text{N}$
Heteronuclear molecule: Unequal attraction for the shared electron(s) Example: Water, H_2O	<ol style="list-style-type: none"> 1. Hydrogen, H^+ Valence of +1: Need 1 bond 2. Oxygen, O^{2-} Valence of -2: Need 2 bonds 3. Net zero charge: $(2 \times \text{H}^{+1}) + (1 \times \text{O}^{2-}) = \text{H}_2\text{O}$

The key differences between ionic and covalent bonds are summarized in Table 2.3 on the following page.

Table 2.3: Comparison of Ionic Bonds and Covalent Bonds

Ionic Bonds	Covalent Bonds
<ul style="list-style-type: none"> Transfer of electron(s) from one atom to another Tend to be inorganic High melting point Often solid at room temperature Good conductor Resulting substance is called a <u>compound</u> 	<ul style="list-style-type: none"> Electrons are shared between atoms Organic compounds Low melting point Solid, liquid or gas at room temperature Poor conductor Resulting substance is called a <u>molecule</u> or <u>molecular compound</u>

Dissociation

Molecules that result from polar covalent bond (i.e., atoms of different types that share electrons) may breakdown or dissociate. This is the case for water, H₂O, which dissociates into hydrogen ion, H⁺, and hydroxide, OH⁻. The dissociation of water is measured as pH.

Chemical Names

The Period Table (Figure 2.3) presents all the elements that are known to mankind to this day.

When naming chemical molecules and compounds, the cation name is the same as the element name, as listed in the Periodic Table. The anion name, however, is not the same: the end of the element name ends in –ide. For example, chloride is the anion of the element chlorine.

Binary compounds (i.e., compounds that contain only two elements) are typically made of a metal and a non-metal. If these compounds have predictable valences, they also end in –ide, even if one element has multiple atoms: for example, magnesium chloride, MgCl₂.

Metals with variable valences, such as the Transition Metals (Columns 3 through 12 of the Periodic Table, Figure 2-3), are more complex because they are followed by a symbol that reflects the valence. This was introduced earlier in Section 2.1.1. For example, trivalent chromium (i.e., chromite) has a valence of +3, and is referred to as Cr(III), or Cr³⁺; hexavalent chromium (i.e., chromate) has a valence of +6 and is referred to as Cr(VI), or Cr⁶⁺.

Naming acids and their derivatives is more complex and may depend on the acid's oxidation state. Generally, the acids with the highest oxidation state end in –ic; e.g., sulfuric acid (H₂SO₄), nitric acid (HNO₃), or phosphoric acid (H₃PO₄). Their salts end in –ate; e.g., sulfate (SO₄²⁻), nitrate (NO₃⁻), or phosphate (PO₄²⁻). Acids with the next lowest oxidation state end in –ous; e.g., sulfurous acid, H₂SO₃. Their salts end in –ite; e.g., sulfite, SO₃²⁻. Acids with the lowest oxidation state begin in hypo– and end in –ous; e.g., hypochlorous acid, HOCl. Their salts begin in hypo– and end in –ite; e.g., hypochlorite ion, OCl⁻.

PHYSICAL STATES OF MATTER

States of matter are distinct forms that matter can take. They are based on how elements are arranged in matter. Matter can take four different states (Figure 2.9):

1. Solid: Volume and shape are fixed;
2. Liquid: Fixed volume, but variable shape that adapts to its container;
3. Gas: Volume and shape are variable;
4. Plasma: Variable volume and shape, with electrical charges.

The physical states of matter reflect different energy levels: solids have the lowest energy level, followed by liquids. Gases have higher energy level, and plasma have the highest energy level. In water, the first three states (i.e., solid, liquid and gas) are important.

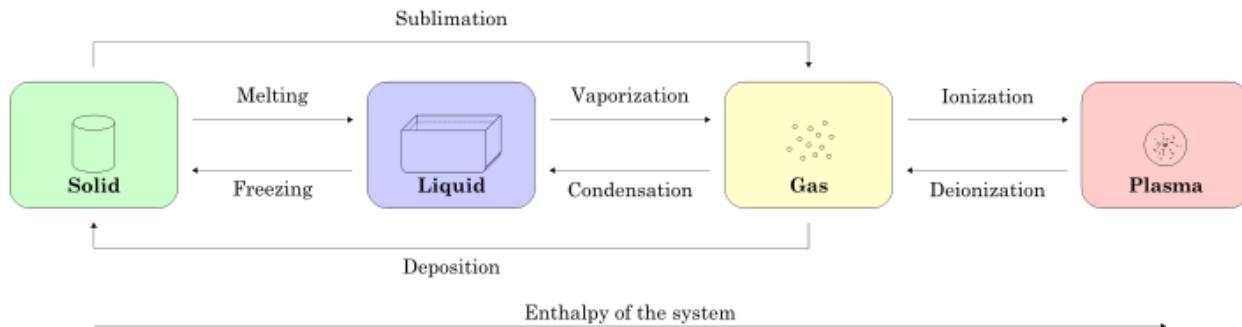


Figure 2.9: Physical States of Matter⁸

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Key Terms

- **anion** – an atom that gains electrons and becomes negatively charged
- **cation** – an atom that loses one or more electrons and becomes positively charged
- **covalent bond** – A type of bond in which electrons are shared between atoms; organic compounds; low melting point; solid, liquid or gas at room temperature; poor conductor; resulting substance is called a molecule or molecular compound
- **electronegativity** – the degree of attraction of an element for electrons; it defines an element's affinity for electrons. Electronegativity determines whether an atom will gain, lose, or share electrons.
- **ionic bond** – Transfer of electron(s) from one atom to another; tend to be inorganic; High melting point; often solid at room temperature; good conductor; resulting substance is called a compound
- **mass** – a measurement of the quantity of matter present
- **matter** – anything that has a mass and occupies a space; can take on four states (solid, liquid, gas, and plasma)
- **periodic table** – an organization of all elements that have been found or synthesized in order from increasing number of protons (from left to right in each row); rows are called periods and columns are called groups
- **valence** - also called the ionic state or oxidation state; the number of electrons gained, lost, or shared between atoms. Because all elements of a family share similar electron configuration, they all tend to have the same valence

REVIEW QUESTIONS

1. Define matter.

2. Define element.

3. Define atom.

4. Define electronegativity.

5. List the types of chemical bonding and define each one.

6. What is a chemical reaction?

7. List the physical states of matter and describe each one.

CHAPTER QUIZ

1. _____ determines whether an atom will gain, lose, or share electrons.
 - a. Covalent bonding
 - b. Ionic bonding
 - c. Physical states of matter
 - d. Electronegativity

2. The physical states of matter reflect different energy levels; _____ have the lowest energy level.
 - a. solids
 - b. liquids
 - c. gas
 - d. plasma

3. _____ are basic substances that cannot be broken down without altering their basic identities; they cannot be further simplified.
 - a. Atoms
 - b. Molecules
 - c. Electrons
 - d. Protons

4. The center of each atom contains a nucleus made of protons (very small particles with a positive electric charge) and neutrons (very small particles, without electrical charge), with electrons (very small, negatively charged particles) that gravitate around the nucleus.
 - a. protons and neutrons
 - b. electrons
 - c. neutrons
 - d. protons

5. _____ are very small particles with a positive electric charge.
 - a. protons and neutrons
 - b. electrons
 - c. neutrons
 - d. protons

6. _____ are very small, negatively charged particles.
- a. protons and neutrons
 - b. electrons
 - c. neutrons
 - d. protons
7. _____ cannot be created or destroyed over the course of chemical reactions. Thus, the number of _____ must be the same for each element and on each side of the equation.
- a. Molecules, molecules
 - b. Reactants, products
 - c. Atoms, atoms
 - d. Products, reactants

CHAPTER 3: CHEMICAL EQUATIONS

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Describe ionic, covalent, and hydrogen bonding
- Explain synthesis, decomposition, exchange, and combustion reactions
- Describe the energy flow through chemical reactions

BONDING

When the outermost energy level of an atom is not filled by electrons, the unfilled spaces or extra electrons in the outer energy level are critical as to whether it is easier for the atom to gain or lose electrons. The most chemically stable configuration for any atom is to have its outermost shell of electrons filled. For example, an atom of sodium, Na, has one electron in its outermost energy level. This level is filled when eight electrons occupy this space. For this reason, sodium atoms find it easier to give up the one electron to have a full outermost shell. An atom of chlorine, Cl, has seven electrons in its outer most energy level. This level is filled when eight electrons occupy this space. Chlorine finds it easier to accept an electron to fill the level with electrons. Sodium and chloride combine to form salt. Sodium gives up one electron to chlorine; therefore, sodium loses an electron to acquire a completed outermost energy level and chlorine accepts the electron to have a completed outermost shell.

The valence, or combining capacity, of an atom is the number of extra or missing electrons in its outermost electron shell. Hydrogen has a valence of 1 (one unfilled space, or one extra electron), oxygen has a valence of 2 (two extra electrons), chlorine has a valence of 1 (one extra electron), and magnesium has a valence of 2 (two extra electrons).

Atoms achieve the full complement of electrons in their outermost energy shells by combining to form molecules, which are made up of atoms of one or more elements. A molecule that contains at least two different kinds of atoms, such as sodium chloride (salt), is called a compound. In sodium chloride, the omission of a subscript indicates that there are one atom of sodium and one atom of chloride. In the compound, water (H_2O) the subscript 2 indicates that there are two atoms of hydrogen and the absence of a subscript for oxygen indicates that there is one atom of oxygen. Molecules hold together because the valence electrons of the combining atoms form attractive forces, called chemical bonds, between the atomic nuclei. For this reason, valence may also be viewed as the bonding capacity of an element. Because energy is required for chemical bond formation, each chemical bond possesses a certain amount of potential chemical energy.

Atoms form bonds in one of two ways. They either gain or lose electrons from their outer electron shell, or they share outer electrons. When atoms have gained or lost outer electrons,

the chemical bond is called an ionic bond. When outer electrons are shared, the bond is called a covalent bond. The types of bonds that are found in molecules range from highly ionic to highly covalent.

Ionic Bonds

Atoms are electrically neutral when the number of positive charges (protons) equals the number of negative charges (electrons). When an isolated atom gains or loses electrons, the balance is upset. If the atom gains electrons, it acquires a negative charge because electrons are negatively charged. Such a negatively or positively charged atom is called an ion.

For example, sodium (Na) has 11 protons and 11 electrons, with one electron in its outer electron shell. Sodium tends to lose the single outer electron. It is considered an electron donor. When sodium donates an electron to another atom, it is left with 11 protons and 10 electrons. Sodium is positively charged, and it is called a sodium ion. It is written as Na^+ . Chlorine (Cl) has a total of 17 electrons, 7 of them are in the outer electron shell. This outer shell can hold 8 electrons. For this reason, chlorine tends to pick up an electron that has been lost by another atom. It is considered to be an electron acceptor. By accepting an electron, chlorine totals 18 electrons. But it has only 17 protons in its nucleus. The chloride ion for this reason has a charge of -1, and it is written as Cl^- .

The opposite charges of the sodium ion (Na^+) and chloride ion (Cl^-) attract each other. The attraction, an ionic bond, holds the atoms together, and a molecule of table salt is formed. An ionic bond is an attraction between ions of opposite charge that holds them together to form a stable molecule. An ionic bond is an attraction between atoms in which one atom loses electrons and another atom gains electrons. Strong ionic bonds have limited importance in living cells. Weaker ionic bonds formed in aqueous (water) solutions are important in biochemical reactions in living organisms.

An atom whose outer electron shell is less than half-filled will lose electrons and form positively charged ions, called cations, such as potassium (K^+), calcium (Ca^{+2}), and sodium (Na^+). When an atom's outer shell is more than half-filled, the atom will gain electron and form negatively charged ions, called anions, such as iodide ion (I^-), sulfide (S^{-2}), chloride (Cl^-).

Covalent Bonds

A covalent bond is a chemical bond formed by two atoms sharing one or more pairs of electrons. Covalent bonds are stronger and more common in living organisms than true ionic bonds. In the hydrogen molecules, H_2 , two hydrogen atoms share a pair of electrons. Each hydrogen atom has one electron in the outer orbit. In order to have a full shell, one additional electron is needed. In the hydrogen molecule, the one hydrogen atom with one electron shares an electron with the other hydrogen atom so that a shared pair of electrons orbits the nuclei of each atom. The outer electron shells of both atoms are filled. Atoms that share one pair of electrons form a single covalent bond. Atoms that share two pairs of electrons form a double

covalent bond, expressed as two single lines (=). A triple covalent bond is expressed as three single lines, and it occurs when atoms share three pairs of electrons.

Methane (CH_4) has covalent bonding between atoms of hydrogen and carbon. The outer electron shell of the carbon atom can hold eight electrons but has only four electrons. Each hydrogen atom can hold two electrons but has only one electron in the outer orbit. In the methane molecule, the carbon atom gains four hydrogen electrons to complete its outer shell, and each hydrogen atom completes its outer shell by sharing one electron from the carbon atom. Each outer electron of the carbon atom orbits the carbon nucleus and a hydrogen nucleus. Each hydrogen electron orbits its nucleus and the carbon nucleus.

Elements like hydrogen and carbon, whose outer electron shells are half-filled, form covalent bonds easily. In living organisms, carbon almost always forms covalent bonds. Covalent bonds are formed by the sharing of electrons between atoms. Ionic bonds are formed by attrition between atoms that have lost or gained electrons and are positively or negatively charged.

Hydrogen Bonds

Another type of bond is the hydrogen bond where a hydrogen atom that is covalently bonded to one oxygen or nitrogen atom is attracted to another oxygen or nitrogen atom. These bonds are weak and do not bind atoms into molecules. They serve as bridges between different molecules or between various portions of the same molecule.

When hydrogen combines with atoms of oxygen or nitrogen, the relatively large nucleus of the larger oxygen or nitrogen atoms has more protons and attracts the hydrogen electron more strongly than does the small hydrogen nucleus. In a molecule of water (H_2O), the electrons tend to be closer to the oxygen nucleus than to the hydrogen nuclei. As a result, the oxygen portion of the molecule has a slightly negative charge, and the hydrogen portion of the molecule has a slightly positive charge. When the positively charged end of one molecule is attracted to the negatively charged end of another molecule, a hydrogen bond is formed. This attraction can also occur between hydrogen and other atoms of the same molecule, especially in large molecules. Oxygen and nitrogen are the elements most frequently involved in hydrogen bonding.

Hydrogen bonds are weaker than ionic or covalent bonds. Hydrogen bonds are formed and broken relatively easily. This property accounts for the temporary bonding that occurs between certain atoms of large and complex molecules, like proteins and nucleic acids.

MOLECULAR WEIGHT AND MOLES

Bond formation results in the creation of molecules. Molecules are discussed in terms of units of measure called molecular weight and moles. The molecular weight of a molecule is the sum of the atomic weights of the atoms that make up the molecule. To relate the molecular level to the laboratory level, a unit called a **mole** is used.

One mole of a substance is its molecular weight expressed in grams so that one mole of water (H_2O) weighs 18 grams because the molecular weight of water is 18, or

H_2O : The atomic number of Hydrogen (2) is 1 and Oxygen (16) is 16 $[(2 \times 1, \text{H}) + 16, \text{O}] = 18$

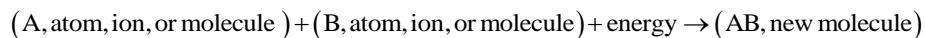
CHEMICAL REACTIONS

Chemical energy occurs whenever chemical bonds between atoms are formed or broken during chemical reactions.

Synthesis Reactions

When two or more atoms, ions, or molecules combine to form new and larger molecules, the reaction is called a **synthesis reaction**. To synthesize means to put together, and a synthesis reaction forms new bonds. This process most often requires energy be added to the system.

Synthesis reaction:



The combining substances, A and B are called the reactants, and the substance formed by the combination, AB, is the product. The arrow indicates the direction in which the reaction proceeds.

Pathways of synthesis reactions in living organisms are collectively called anabolic reactions, or simply anabolism. The combining of sugar molecules to form starch and of amino acids to form proteins are examples of anabolism. Anabolic reactions, in general, require an input of energy. The energy is stored in the newly formed chemical bond as potential energy (chemical energy).

Decomposition Reactions

The reverse of a synthesis reaction is a decomposition reaction. To decompose means to break down into smaller parts, and in a decomposition reaction chemical bonds are broken.

Decomposition reactions split large molecules into smaller molecules, ions, or atoms. A decomposition reaction occurs:

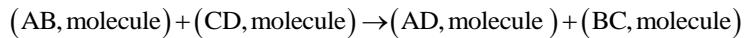


Decomposition reaction that occur in living organisms are collectively called catabolic reactions, or catabolism. Catabolism occurs when sucrose is broken down into simpler sugars like glucose

during digestion. Bacterial decomposition of petroleum is another example of decomposition reactions. Energy is released when the chemical bonds are broken down.

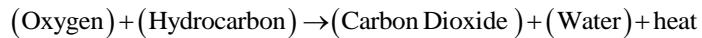
Exchange Reactions

Chemical reactions are based on synthesis and decomposition. Many reactions, such as exchange reactions, are actually part of synthesis and part decomposition. An exchange reaction works

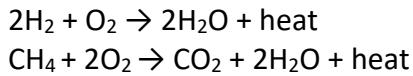


Combustion Reactions

Combustion reactions are types of chemical reactions where compounds and oxidants react to produce heat and new products. A common combustion reaction is the reaction between oxygen and hydrocarbons to yield water and carbon dioxide:

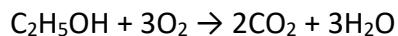


For example:



It is also common for a combustion reaction to release light and produce a flame. However, it is not necessary. For a combustion reaction to be initiated, the activation energy for the reaction must be overcome. Often combustion reactions are started with a flame, which provides the heat to initiate the reaction. Once combustion begins, the heat that is produced sustains the reaction until the reactants are used.

In order to recognize combustion reactions, oxygen will be on the reactant side of the equation and the release of heat will be on the product side of the equation. Sometimes the fuel molecule contains oxygen. For example, the combustion of ethanol:



Combustion is an exothermic reaction so that it releases heat. However, sometimes the reaction proceeds so slowly that a temperature change is not noticeable. The signs that a combustion reaction occurs is the presence of oxygen as a reactant and carbon dioxide, water, and heat as products. Inorganic combustion reaction may not form the same types of products;

however, they are recognizable by the reaction of oxygen. The surest method of recognizing a combustion reaction is that the products contain carbon dioxide and water.

Combustion does not always proceed to completion or 100-percent efficiency. The reactions are prone to limiting reactants. Two types of combustion reactions exist:

1. **Complete Combustion:** known as clean combustion where oxidation of the reactants (hydrocarbons) produces only carbon dioxide and water. The burning of candle wax, where the heat from the wick vaporizes the wax (hydrocarbon), is an example. The reaction results from the oxygen in the air so that carbon dioxide and water are the products. All of the wax burns so that nothing remains once the candle is consumed. The water vapor and carbon dioxide dissipate into the atmosphere.
2. **Incomplete Combustion:** incomplete combustion is the oxidation of a hydrocarbon that is incomplete or dirty. The products are carbon monoxide and carbon (soot) in addition to carbon dioxide. An example would be the combustion of coal, where soot and carbon monoxide are the products. Fossil fuels oxidize incompletely, and they release waste products.

ENERGY FLOW IN CHEMICAL REACTIONS

Chemical bonds represent stored chemical energy, and chemical reactions ultimately result in net absorption or release of energy. Reactions that release energy are called exergonic reactions. These reactions yield products with less energy than the initial reactants, along with energy that can be harvested for use. Catabolic and oxidative reactions are exergonic for the most part.

The products of energy absorbing, endergonic, reactions contain potential energy in their chemical bonds which is more than the energy that the reactants contained. Anabolic reactions are energy absorbing reactions. For example, the energy released when fuel molecules are broken down (oxidized) is captured in ATP molecules and used to synthesize complex biological molecules the body needs to sustain life.

FACTORS THAT INFLUENCE THE RATE OF CHEMICAL REACTIONS

For atoms and molecules to react, they must collide with enough force to overcome the repulsion between their electrons. Interaction between valence shell electrons cannot occur long distance. The force of collisions depends on the speed of the particles. Solid, forceful collisions between rapidly moving particles in which valence shells overlap are much more likely to cause a reaction than are collisions in which the particles graze each other.

Increasing the temperature of a substance increases the kinetic energy of its particles and the force of their collisions. Chemical reactions proceed more quickly at higher temperatures.

Chemical reactions progress more rapidly when the reacting particles are present in high numbers, concentrations, because the chance of collisions are greater. As the concentrations of the reactants declines, the reaction slows. Chemical equilibrium eventually occurs unless additional reactants are added or products are removed from the reaction site.

Smaller particles move faster than large particles and tend to collide more frequently and more forcefully. The smaller the reacting particles, the faster a chemical reaction proceeds at a given temperature and concentration.

Chemical reactions in nonliving systems can be speeded up by heating. However drastic increases in body temperature are life threatening because important biological molecules are destroyed. At normal body temperature, most chemical reactions would proceed at too slow of a pace to maintain life, if catalysts were not present. **Catalysts** are substances that increase the rate of chemical reactions without becoming chemically changed or part of the product. Biological catalysts are called enzymes.

Key Terms

- **catalysts** – substances that increase the rate of chemical reactions without becoming chemically charged or part of the product; biological catalysts are called enzymes
- **combustion reactions** – types of chemical reactions where compounds and oxidants react to produce heat and new products
- **decomposition reactions** – a reaction in which larger molecules are split into smaller molecules, ions, or atoms
- **mole** – one mole of a substance is its molecular weight expressed in grams
- **synthesis reactions** – a reaction in which two or more atoms, ions, or molecules combine to form new and larger molecules

REVIEW QUESTIONS

- 1. Describe hydrogen bonding.**

- 2. Describe synthesis reactions.**

- 3. Describe decomposition reactions.**

- 4. Describe exchange reactions.**

- 5. Describe combustion reactions**

CHAPTER QUIZ

1. The _____ or combining capacity of an atom is the number of extra or missing electrons in its outermost electron shell.
 - a. valence
 - b. atomic number
 - c. exchange rate
 - d. nucleus

2. _____ is the oxidation of a hydrocarbon that is incomplete or dirty. The products are carbon monoxide and carbon (soot) in addition to carbon dioxide.
 - a. Complete combustion
 - b. Incomplete combustion
 - c. Reduction
 - d. Decomposition

3. _____ is where a hydrogen atom that is covalently bonded to one oxygen or nitrogen atom is attracted to another oxygen or nitrogen atom. These bonds are weak and do not bind atoms into molecules.
 - a. Ionic bonding
 - b. Covalent bonding
 - c. Hydrogen bonding
 - d. Temporary bonding

4. _____ is an attraction between ions of opposite charge that holds them together to form a stable molecule.
 - a. Ionic bonding
 - b. Covalent bonding
 - c. Hydrogen bonding
 - d. Temporary bonding

5. _____ are stronger and more common in living organisms than are true ionic bonds. In the hydrogen molecules, H₂, two hydrogen atoms share a pair of electrons.
 - a. Ionic bonds
 - b. Covalent bonds
 - c. Hydrogen bonds
 - d. Temporary bonds

6. _____ represent stored energy.
- a. Chemical bonds
 - b. Hydrogen bonds
 - c. Covalent bonds
 - d. Ionic bonds
7. When two or more atoms, ions, or molecules combine to form new and larger molecules, the reaction is called a _____.
- a. decomposition reaction
 - b. exchange reaction
 - c. combustion reaction
 - d. synthesis reaction
8. _____ are substances that increase the rate of chemical reactions without becoming chemically changed or part of the product.
- a. Products
 - b. Reactants
 - c. Catalysts
 - d. Chemical bonds
9. For a combustion reaction to be initiated, the _____ energy for the reaction must be overcome.
- a. kinetic
 - b. potential
 - c. activation
 - d. decomposition

CHAPTER 4: ORGANIC CHEMISTRY

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Explain carbon-based compounds
- Describe molecular structure
- Describe organic matter
- Describe methane, trihalomethanes, acetic acid, haloacetic acid

Organic compounds contain carbon. All organic compounds are covalently bonded molecules, and most organic compounds are large molecules. All other chemicals are considered **inorganic compounds**, which do not contain carbon. Inorganic compounds include water, salts, and many acids and bases. Organic and inorganic compounds are equally essential for life.

Organic materials are derived from plant fibers and animal tissues, which are produced by synthesis reactions that produce materials like rubber, plastics, and other compounds; and fermentation reactions that produce alcohols, acids, antibodies, and other compounds.



Pin It! Misconception Alert

In chemistry, the word “organic” refers to compounds containing carbon. It does not refer to organic food (e.g., grown without chemical fertilizers or pesticides).

Inorganic compounds, in contrast to organic compounds, are combustible, high in molecular weight, and sparingly soluble in water and a source of food for animal consumers and microbial decomposers.

Carbohydrates, lipids, proteins, and nucleic acids are molecules unique to living systems. Each of these molecules contain carbon and they are referred to as organic compounds. Organic compounds are distinguished by the fact that they contain carbon, and inorganic compounds are defined as compounds that lack carbon. However, carbon dioxide and carbon monoxide are carbon containing compounds but are considered inorganic compounds.

Organic molecules are large molecules. Only small, reactive parts of their structure interact with other compounds. These areas are referred to as active sites and are functional groups, such as acid groups, amines, and others.

Carbon is a special atom. No other small atom is so electroneutral. The consequence of its electroneutrality is that carbon does not lose or gain electrons. It shares them. With four valence shell electrons, carbon forms four covalent bonds with other elements, as well as with

other carbon atoms. As a result, carbon helps to form long, chainlike molecules, ring structures, and other structures that are uniquely suited for specific roles in living systems.

Many biologic molecules are polymers like carbohydrates and proteins. Polymers are chainlike molecules made of many similar or repeating units, monomers, which are joined together by dehydration synthesis. During dehydration syntheses, a hydrogen atom is removed from one monomer and a hydroxyl group is removed from another monomer. The resultant products are joined together with a covalent bond, and in the process, a water molecule is released. The removal of a water molecule at the bond site occurs each time a monomer is added to the growing polymer chain.

HYDROCARBONS

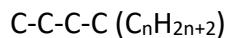
In organic chemistry, any chemical compound that consists of the elements of carbon and hydrogen is a **hydrocarbon**. Carbon and hydrogen atoms share an electron pair forming covalent bonds in hydrocarbons. One of the special properties of carbon is its ability to form double and triple bonds.

Saturated hydrocarbons contain only the elements of carbon and hydrogen with single bonds between carbon atoms. Methane is the simplest hydrocarbon, and it is a gas produced in the anaerobic decomposition of organic compounds.

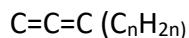
When hydrocarbon molecules include one or more double or triple bonds between some of the carbon atoms it is not possible for as many hydrogen atoms to be included in the molecule as when the bonds are single bonds. The term used to describe the presence of one or more double or triple bonds in a molecule of an organic compound is **unsaturated**. If the organic compound contains all single bonds, it is called **saturated**.

Alkanes, Alkenes, and Alkynes

Hydrocarbons are classified as unsaturated or saturated. Alkanes are a group of saturated hydrocarbons meaning that the hydrocarbon contains only single bonded carbon atoms represented as:



Alkenes are a group of unsaturated hydrocarbons meaning that the hydrocarbon contains double carbon-carbon bonds represented as:



Alkynes are hydrocarbons that include triple carbon-carbon bonds ($\text{C}_n\text{H}_{2n-2}$).

A bromine solution is used to test for unsaturation of hydrocarbon molecules. Bromine solution is orange in color. When an alkene is added to a bromine solution, the orange color disappears resulting in a colorless solution. Bromine reacts with alkenes forming a new colorless compound. This test is useful in distinguishing alkenes from alkanes because alkanes do not react with bromine solution.

Unsaturated hydrocarbons are distinguished from paraffins by the presence of multiple bonds between some carbon atoms. The multiple bonds between carbon atoms displace hydrogen atoms, creating molecules containing fewer hydrogen atoms.

Vegetable shortenings available as solid fats are produced from oils through the process of hydrogenation which adds hydrogen atoms through the addition of hydrogen gas under controlled conditions. Reducing the number of unsaturated bonds increases the melting point, converting an oil to a solid fat.



Figure 4.1⁹

CHEMICAL STRUCTURE

The parent compound of aromatic hydrocarbons is benzene. **Benzene** is a 6-carbon ring with double bonds between alternate atoms. Benzene is used in the manufacture of a variety of commercial products including insecticides, plastics, solvents, explosives, and dyes.

⁹ Image by [doornekamph](#) on [Pixabay](#)

Alcohols

Alcohols are formed from hydrocarbons by replacing one or more hydrogen atoms by hydroxyl groups (-OH). **Methanol** is manufactured synthetically by a catalytic process from carbon monoxide and hydrogen. It is used extensively in manufacturing organic compounds, like solvents, fuel additives, and formaldehyde. **Ethyl alcohol** for beverage purposes is produced through the fermentation of a variety of natural organic materials, like corn, wheat, rice, and potatoes. Industrial ethanol is produced from fermentation of waste solutions containing sugars, like blackstrap molasses and residues resulting from the purification of cane sugar.



Figure 4.2¹⁰

Propanol has two isomers, the more common is **isopropyl alcohol**, which is widely used by industry and sold as a medicinal rubbing alcohol. The three primary alcohols have boiling points less than 100°C, and they are miscible with water.

- Methanol or methyl alcohol (CH_3OH)
- Ethanol or ethyl alcohol ($\text{CH}_3\text{CH}_2\text{OH}$)
- Isopropyl alcohol or 2-Propano ($\text{CH}_3\text{CH}_2\text{CHOH}$)

Miscible liquids are homogenous when mixed together.

The derivative of benzene containing one hydroxyl group, known as phenol, has a molecular formula of $\text{C}_6\text{H}_5\text{OH}$. The formula and -ol in the name indicate the characteristics of an alcohol; however, phenol, known as carbolic acid, ionizes in water yielding hydrogen ions, and exhibits features of an acid. It occurs as natural component of wastes from coal, gas, petroleum, and a variety of industrial wastes where phenol is used as a raw material. Phenol is a strong toxin that

¹⁰ [Image](#) by [Fritzs](#) is licensed under [CC BY-SA 3.0](#)

makes the waste materials particularly difficult to treat in biological systems. Phenols impart undesirable tastes to water at low concentrations.

Aldehydes and Ketones

Aldehydes and ketones are compounds containing a carbonyl group. **Formaldehyde** is used to produce plastics and resins. **Acetone** (dimethyl ketone) is a good solvent of fats and is a common cleaning agent for laboratory glassware.

- Formaldehyde (CH_2OH)
- Acetone (CH_3CHCOH)



Figure 4.3¹¹

Carboxylic Acids

Organic acids contain the carboxyl group, -COOH. **Carboxylic acid** is the highest state of oxidation that an organic radical can achieve. Further oxidation results in the formation of carbon dioxide and water. Acids through 9-carbons are liquids, and those acids with more carbons are greasy solids, fatty acids. Organic acids are weak and ionize poorly.

Formic, acetic, and propionic acids have sharp penetrating odors, and butyric and valeric acids have extremely disagreeable odors associated with rancid fats and oils. Anaerobic decomposition of long chain fatty acids result in the production of 2 and 3-carbon acids, which are converted to methane and carbon dioxide gas in decomposition reactions.

- Formic acid (HCOOH)
- Acetic acid (CH_3COOH)
- Propionic acid ($\text{CH}_3\text{CH}_2\text{COOH}$)

¹¹ [Image](#) by [Chris](#) is licensed under [CC BY-NC-SA 2.0](#)

- Butyric acid ($\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$)
- Valeric acid ($\text{C}_4\text{H}_9\text{COOH}$)
- Caproic acid ($\text{C}_5\text{H}_{11}\text{COOH}$)

Basic compounds react with acids to produce salts. NaOH, sodium hydroxide, reacts with acetic acid to produce sodium acetate. Soaps are salts of long chain fatty acids. Other derivatives of carboxylic acids include esters, such as ethyl acetate and amides.

- Methylamine (CH_3NH_2)

ORGANIC MATTER

Biodegradable organic matter in water is classified into three categories: fats, carbohydrates, and proteins. **Carbohydrates** consist of sugar units containing the elements of carbon, hydrogen, and oxygen. A single sugar is known as a monosaccharide. Disaccharides are composed of two monosaccharide units. Sucrose, table sugar, is glucose plus fructose. The most prevalent sugar in milk is lactose, consisting of glucose plus galactose. Polysaccharides, long chains of sugar units, are divided into two groups: readily degradable starches, like potatoes, rice, corn, and other edible plants; and cellulose which is found in wood, cotton, paper, and similar plant tissues. Cellulose compounds degrade biologically at a slower rate than starches.

Proteins are long strings of amino acids containing carbon, hydrogen, oxygen, nitrogen, and phosphorus. They form an essential part of living tissue and constitute a diet necessary for higher life forms.

Fats refer to a variety of biochemical substances that have the property of being soluble to varying degrees in organic solvents, like ether, ethanol, acetone, and hexane, while being sparingly soluble in water. Because of their limited solubility, degradation by microorganisms is very slow. A simple fat is a triglyceride composed of a glycerol unit with short or long chain fatty acids attached.

The majority of carbohydrates, fats, and proteins in nature are in the form of large molecules that cannot penetrate the cell membrane of microorganisms. Bacteria, in order to metabolize high-molecular weight substances, must be capable of breaking down the large molecules into diffusible fractions for assimilation into the cell. The first step in bacterial decomposition of organic compounds is hydrolysis of carbohydrates into soluble sugars, proteins into amino acids, and fats into short fatty acids. Aerobic biodegradation results in the formation of carbon dioxide and water. Anaerobic digestion, decomposition in the absence of oxygen, results in the formation of organic acids, alcohols, and other liquid intermediates as well as gaseous entities of carbon dioxide, methane, and hydrogen sulfide.

Several organic compounds, like cellulose, long chain saturated hydrocarbons, and complex compounds, although available as a bacterial substrate, are considered non-biodegradable because of the time and environmental limitations of biological treatment systems. Petroleum

derivatives, detergents, pesticides, and synthetic organic compounds are also resistant to biodegradation, and some of these compounds are toxic and inhibit the activity of microorganisms in biological processes.

Some waste odors are inorganic compounds, like hydrogen sulfide gas; however many odors are caused by volatile organic compounds, such as mercaptans and butyric acid. Industries may produce a variety of medicinal odors in the processing of raw materials. Surface water supplies plagued with blooms of blue green algae have fishy or pigpen odors. The cause of odors can be anaerobic decomposition, industrial chemicals, or growths of obnoxious microorganisms.



Figure 4.4¹²

METHANE AND TRIHALOMETHANE

Chlorine is used to inhibit or destroy harmful organisms. This method of disinfection alters cell chemistry causing microorganisms to die. Chlorine is the most widely used disinfectant chemical. Chlorine is relatively inexpensive, and leaves a residual chlorine that can be measured. An increased interest in disinfection other than chlorine has developed because of the carcinogenic compounds that chlorine may form, trihalomethanes, THMs.

The exact mechanism of chlorine disinfection action is not fully understood. It is felt that chlorine exerts a direct action against bacterial cell, destroying them. Another theory is that the toxic character of chlorine inactivates the enzymes, which enable living microorganisms to use their food supply. As a result, the organisms die. However, the exact mechanism of chlorine disinfection is less important than its demonstrated effects as a disinfectant.

¹² [Image](#) by Tom Archer is in the public domain

When chlorine is added to water, several chemical reactions take place. Some of the reactions involve the molecules of the water, and some reactions involve organic and inorganic substances suspended in the water.

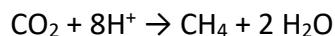
Chlorine combines with organic and inorganic materials to form chlorine compounds. If chlorine is added continuously, eventually all of the materials in the water that will react with chlorine are used and the chlorine reactions stop. At this point, the chlorine demand is satisfied.

The chemical reactions between chlorine and organic and inorganic substances produce chlorine compounds. Some chlorine compounds have disinfecting properties, and some compounds do not. Chlorine also reacts with the water and produces substances with disinfecting properties. The total of all of the compounds with disinfection properties plus any remaining free, uncombined, chlorine is known as the chlorine residual. The presence of this measurable chlorine residual indicates that all possible chemical reactions with chlorine have taken place and that a sufficient available residual of chlorine is available to kill microorganisms present in the water.

When organic materials are present in water being disinfected with chlorine, the chemical reactions that take place can produce suspected carcinogenic compounds, THMs. The formation of these compounds can be prevented by limiting the amount of chlorination and by removing the organic materials before chlorination of the water.

Methane

Methane is a colorless, odorless, flammable gas, and it is the primary constituent of marsh gas and the firedamp of coal mines. It is obtained commercially from natural gas, and it is the first member of the alkane series of hydrocarbons. The formation of methane can occur through organic matter decomposition or through organic synthesis which involve microorganisms, methanogenesis. The synthesis involves anaerobic and aerobic processes. Naturally occurring methane is produced by microbial methanogenesis. This multistep process is used by microorganisms as an energy source. The net reaction is:



The final step in the process is catalyzed by the enzyme coenzyme-B sulfoethylthiotransf erase. Methanogenesis is a form of anaerobic respiration used by organisms that occupy landfills, ruminants, and the guts of termites.

Trihalomethanes

Trihalomethanes are harmful by-products arising from a process of water disinfection with chlorine. Trihalomethanes are formed when organic materials react with chlorine to form chlorinated by-products. Trihalomethanes are chemical compounds where 3 of the 4-hydrogen atoms of methane are replaced by halogen atoms. Trihalomethanes (THMs) are used in

industry as solvents or refrigerants. THMs are environmental pollutants, and many of them are considered carcinogenic. Trihalomethanes with all the same halogen atoms are called haloform, and they are considered to be volatile organics. Some examples of trihalomethanes are:

- Chloroform
- Bromodichloromethane
- Bromoform
- Carbon tetrachloride
- Tetrachloroethylene

Trihalomethanes are formed as a by-product when chlorine is used to disinfect drinking water. They represent a group of chemicals referred to as disinfection by-products. They result from the reaction of chlorine or bromine with organic matter present in the water being treated. THMs have been associated through epidemiological studies with adverse health effects. Governmental agencies have set limits on the amount permissible in drinking water. The EPA limits the total concentration of the four chief constituents, chloroform, bromoform, bromodichloromethane, and dibromochloromethane, referred to as total TTHMs to 80 parts per billion in drinking water.

In drinking water, THM levels tend to increase with pH, temperature, contact time with chlorine, and the level of the organic precursors. The precursors, organic material, reacts with chlorine to form THMs. One method that is used to decrease THMs is to eliminate or reduce chlorination before the filters and to reduce precursors. Since more precursors are present before filtration, the treatment process is directed toward reducing or eliminating the time chlorine is in contact with the water. If some oxidation before filtration is required, an alternative disinfectant like potassium permanganate or peroxide should be considered. This strategy is not an option if pre-chlorination is necessary to achieve the required CT, contact time, values.

The EPA has advocated that the best available technology for THM control at treatment facilities is to remove precursors through enhanced coagulation. Enhanced coagulation refers to a process of optimizing the filtration process to maximize removal of precursors. Removal is improved by decreasing pH levels to 4 or 5, increasing the feed rate of coagulants, and using ferric coagulants in place of alum.

Acetic Acid and Haloacetic Acid

Haloacetic acids (HAA) are carboxylic acids where a halogen atom takes the place of hydrogen atoms in acetic acid. In monohaloacetic acid, a single halogen replaces a hydrogen atom. Chloroacetic acid has the structural formula of $\text{CH}_2\text{ClCO}_2\text{H}$. In this manner, two chlorine atoms are present in dichloroacetic acid where two hydrogen atoms are replaced with chlorine atoms. Dichloroacetic acid has a structural formula of $\text{CHCl}_2\text{CO}_2\text{H}$.

Haloacetic acids (HAA) are a common undesirable by-product of drinking water chlorination. Exposure to such disinfection by-products in drinking water, at high levels has been associated

with undesirable health outcomes through epidemiological studies. The five most common HAAs in water are:

- Monochloroacetic acid (ClCH_2COOH)
- Dichloroacetic acid (Cl_2CHCOOH)
- Trichloroacetic acid (Cl_3CCOOH)
- Monobromoacetic acid (BrCH_2COOH)
- Dibromoacetic acid (Br_2CHCOOH)

Collectively, these chemicals are called HAA₅.

HAAs can be formed by chlorination, ozonation, or chloramination of water with the formation of HAAs promoted by slightly acidic water, high organic matter content, and elevated temperature. Chlorine from the water disinfection process reacts with organic matter and small amounts of bromide present in the water to produce various HAAs.

Key Terms

- **acetone** – a good solvent of fats and is a common cleaning agent for laboratory glassware
- **carbohydrates** – sugar units containing the elements of carbon, hydrogen, and oxygen
- **carboxylic acid** – the highest state of oxidation that an organic radical can achieve
- **ethyl alcohol** – alcohol for beverage purposes that is produced through the fermentation of a variety of natural organic materials, like corn, wheat, rice, and potatoes
- **fats** – a variety of biochemical substances that have the property of being soluble to varying degrees in organic solvents, like ether, ethanol, acetone, and hexane, while being sparingly soluble in water
- **formaldehyde** – used to produce plastics and resins
- **haloacetic acids (HAA)** – carboxylic acids where a halogen atom takes the place of hydrogen atoms in acetic acid, a common undesirable by-product of drinking water chlorination
- **inorganic compounds** – molecules that do not contain carbon
- **isopropyl alcohol** – a type of alcohol, which is widely used by industry and sold as a medicinal rubbing alcohol.
- **methanol** – a type of alcohol manufactured synthetically by a catalytic process from carbon monoxide and hydrogen; used extensively in manufacturing organic compounds, like solvents, fuel additives, and formaldehyde
- **methane** – a colorless, odorless, flammable gas, and it is the primary constituent of marsh gas and the firedamp of coal mines
- **organic compounds** – molecules that contain carbon
- **proteins** – long strings of amino acids containing carbon, hydrogen, oxygen, nitrogen, and phosphorus.
- **trihalomethanes (THMs)** – harmful by-products arising from a process of water disinfection with chlorine; formed when organic materials react with chlorine to form chlorinated by-product

REVIEW QUESTIONS

1. What is an organic compound?

2. List some types of organic compounds.

3. Define an inorganic compound.

CHAPTER QUIZ

1. _____ are covalently bonded molecules, and most are large molecules.
 - a. Inorganic compounds
 - b. Hydrocarbons
 - c. Aldehydes
 - d. Organic compounds

2. _____ are harmful by-products arising from a process of water disinfection with chlorine. They are formed when organic materials react with chlorine to form chlorinated by-products.
 - a. Ketones
 - b. Trihalomethanes
 - c. Organic compounds
 - d. Aldehydes

3. _____ can be formed by chlorination, ozonation, or chloramination of water. They are promoted in slightly acidic water, high organic matter content, and elevated temperature. These compounds are precursors to Trihalomethanes.
 - a. Haloacetic acids
 - b. Organic compounds
 - c. Inorganic compounds
 - d. Carboxylic acids

4. _____ is(are) a colorless, odorless, flammable gas, and it is the primary constituent of marsh gas and the firedamp of coal mines.
 - a. Bromides
 - b. Chlorates
 - c. Methane
 - d. Chloroform

5. _____ is the highest state of oxidation that an organic radical can achieve. Further oxidation results in the formation of carbon dioxide and water.
 - a. Haloacetic acids
 - b. Organic compounds
 - c. Inorganic compounds
 - d. Carboxylic acids

6. Biodegradable organic matter in water is classified into three categories _____.
- a. THMs, HAA5s, carboxylic acids
 - b. fats, carbohydrates, and proteins
 - c. alkanes, alkenes, alkynes
 - d. chloroform, bromodichloromethane, bromoform
7. The parent compound of aromatic hydrocarbons is _____.
- a. benzene
 - b. alcohol
 - c. chloroform
 - d. acetic acid
8. Hydrocarbons are classified as unsaturated or saturated. _____ are a group of saturated hydrocarbons meaning that the hydrocarbon contains only single bonded carbon atoms.
- a. Alkanes
 - b. Alkenes
 - c. Alkynes
 - d. Acetic acids
9. _____ are derived from plant fibers and animal tissues, which are produced by synthesis reactions that produce materials like rubber, plastics, and other compounds; and fermentation reactions that produce alcohols, acids, antibodies, and other compounds.
- a. Inorganic materials
 - b. Biologic acids
 - c. Hydrocarbons
 - d. Organic materials

CHAPTER 5: ACIDS, BASES, AND SALTS

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Explain the properties of water
- Describe inorganic and organic acids
- Describe inorganic bases
- Explain pH, acids, and bases
- Describe buffers

Water is the most abundant and important inorganic compound on earth. It makes up 60 to 89-percent of the volume of most living cells, and it possesses several properties that make it vital to life. Water has a high heat capacity. Water absorbs and releases large amounts of heat before changing appreciably in temperature. This property prevents sudden changes in temperature caused by external factors, such as sun or wind exposure, or by internal conditions that release heat rapidly, such as vigorous muscle activity. As part of blood system or the environment, water redistributes heat among adjacent structures ensuing the temperature remains homeostatic.

When water evaporates, or vaporizes, water changes from a liquid to a gas, water vapor. The transformation requires that large amounts of heat be absorbed to break hydrogen bonds that hold water molecules together. This property is beneficial because as water evaporates from an object or organism large amounts of heat are removed providing efficient cooling. This property is referred to as high heat of vaporization.

Water is the best solvent in nature. It is called the universal solvent. Biological molecules do not react chemically unless they are in solution, and virtually all chemical reactions that occur in the living cells depend on water's solvent properties. Water molecules are referred to as being polar. They orient with their slightly negative ends toward the positive ends of the solutes.. . This characteristic is called polarity, and it explains the reason that ionic compounds and other small reactive molecules, such as acids and bases, dissociate in water, where their ions separating from each other and become evenly scattered in the water forming a true solution.

Water also forms layers of water molecules, called hydration layers, around large charged molecules such as protein, shielding them from the effects of other charged substances in the areas and preventing them from settling out of solution. Such protein water mixtures are biological colloids. Water is also the major transport medium because it is an excellent polar solvent. Nutrients, gases, and metabolic wastes are carried dissolved in water based fluids. Wastes are excreted form living organisms in watery fluids. Specialized molecules that lubricate organisms also use water as the dissolving medium.

Water is an important reactant in many chemical reactions. Nutrients are decomposed by adding a water molecule to each chemical bond that is broken. Decomposition reactions are more specifically referred to as hydrolysis reactions. When large carbohydrates or protein molecules are synthesized from smaller molecules, a water molecule is removed for every bond formed, a reaction that is called dehydration synthesis.

Water forms resilient cushions, cushioning around certain biological structures providing protection from physical trauma.

When inorganic salts such as sodium chloride (NaCl) are dissolved in water, they undergo ionization or dissociation. They break apart into ions. Substances labeled acids and bases demonstrate similar behavior.

An **acid** can be defined as a substance that dissociates into one or more hydrogen ions (H^+) and one or more negative ions (anions) an acid is also called a proton donor (H^+). A **base** dissociates into one or more positive ions (cations) that can accept or combine with protons. Sodium hydroxide (NaOH) is a base because it dissociates to release OH^- , has a strong attraction for protons. Bases are among the most important proton acceptors in chemistry. A salt is a substance that dissociates in water into cations and anions, neither of which is H^+ or OH^- .

ACIDS

Salts, acids, and bases are electrolytes. They ionize and dissociate in water and can conduct an electrical current.

Acids have a sour taste, and they can react with or dissolve metals. The definition of an acid is a substance that releases hydrogen ions (H^+) in measurable amounts. Acids are also characterized as being proton donors because a hydrogen ion is a hydrogen nucleus, or a single proton.

When acids dissolve in water, they release hydrogen ions (protons) and anions, negative charged particles. The concentration of the protons determines the acidity of the solution. The anions have little or no effect on the acidity of the solution. Hydrochloric acid (HCl) dissociates into a proton and a chloride ion:



Living organisms maintain a constant balance of acids and bases. If a particular acid or base concentration is too high or too low, enzymes change in shape and are no longer effective. In aqueous environments, acids dissociate into hydrogen ions and anions. Bases dissociate into hydroxide ions and cations. The more hydrogen ions that are free in a solution, the more acidic the solution. The more hydroxide ions that are free in a solution the more basic or alkaline is the solution.

Biochemical reactions are sensitive to small changes in the acidity or alkalinity of the environment in which they occur. H^+ and OH^- are involved in almost all biochemical processes, and any deviation from a narrow band of the normal H^+ and OH^- concentration dramatically modifies the systems' functioning. Acids and bases that are formed in living systems must be kept in balance.

It is convenient to express the amount of H^+ in a solution by a logarithmic pH scale that ranges from 0 to 14. The term **pH** means potential of hydrogen ion concentration. On a log scale, a change of one whole number has 100 times more hydrogen ions than a solution of pH 2, and a pH of 2 has 100 times more hydrogen ions than a solution of pH 3.

Acidic solutions contain more H^+ than OH^- and have a pH lower than 7. If a solution has more OH^- than H^+ , it is a basic or alkaline solution. In pure water, a small percentage of molecules are dissociated into H^+ and OH^- ions so that it has a pH of 7. When the ion concentrations of a solution are equal, the solution has a pH of 7 and is considered to be neutral.

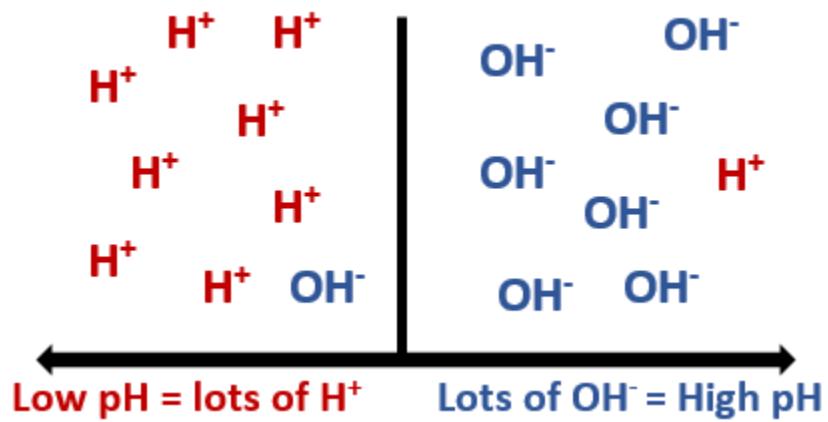


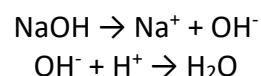
Figure 5.1: Depiction demonstrating the concentrations of H^+ and OH^- at differing pH levels¹³

The pH of a solution can be changed. When substances that will increase the concentration of hydrogen ions are added to a solution, then the pH will decrease. **Buffers** prevent the pH of a solution from changing drastically. The pH in the environment can be altered by waste products from organisms, pollutants from industry, and fertilizers used in agricultural fields or gardens. When bacteria are grown in a laboratory, they excrete waste products such as acids that can alter the pH. If acid production were to continue, the medium where the bacteria are growing will become acidic enough to inhibit bacterial enzymes and kill the bacteria. To prevent this problem, pH buffers are added to solutions or to the natural environment to prevent changes in pH. Buffers resist a change in pH.

¹³ Image by [COC OER](#) is licensed under [CC BY 4.0](#)

BASES

Bases have a bitter taste, feel slippery, and are proton acceptors. They take up hydrogen ions in measurable amounts. Common inorganic bases include the hydroxides like magnesium hydroxide and sodium hydroxide. Lye acids, hydroxides dissociate when dissolved in water. In this case, hydroxyl ions (OH^-) and cations are released. Ionization of sodium hydroxide produces a hydroxyl ion and a sodium ion. The hydroxyl ion binds to a proton present in the solution. This reaction produces water and simultaneously reduces the acidity of the solution by taking up free H^+ ions:



The term pH is used to express the intensity of an acid or alkaline solution.

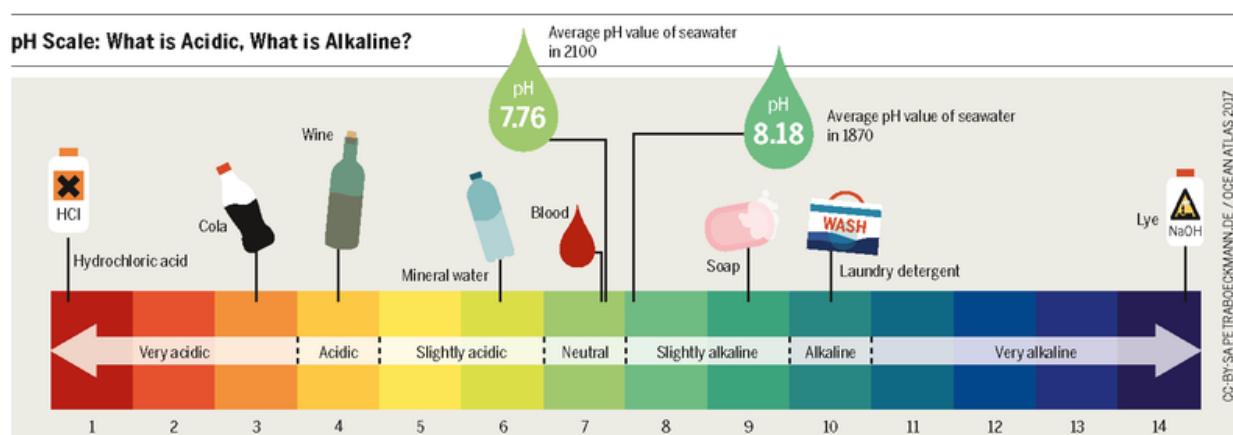
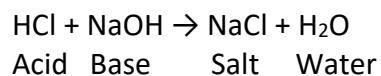


Figure 5.2: pH scale from 0 to 14 demonstrating acid, neutral, and base¹⁴

SALTS AND NEUTRALIZATION

The more hydrogen ions in a solution, the more acidic the solution. The greater the concentration of hydroxyl ions, the more basic, or alkaline, the solution.

When acids and bases are mixed, they react with each other in displacement reactions to form water and a salt. For example, when hydrochloric acid and sodium hydroxide interact, sodium chloride (salt) and water are formed.



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This type of reaction is called a neutralization reaction because the joining of H⁺ and OH⁻ to form water neutralizes the solution. The salt produced is dissolved in the aqueous solution and disassociated into Na⁺ and Cl⁻ ions.

Salts are ionic compounds containing cations other than H⁺ and anions other than the hydroxyl ion, OH⁻. When salts are dissolved in water, they dissociate into their component ions. Sodium sulfate, Na₂SO₄, dissociates into two Na⁺ ions and one SO₄⁻². The salt dissociates because the ions are formed. The water overcomes the attraction between the oppositely charged ions, and they disassociate.

All ions are electrolytes which are substances that conduct an electrical current in solution. Salts dissociate in aqueous solutions into ions, and the most common salts are sodium salts. In their ionized form, salts play a vital role in nature and aqueous solutions.

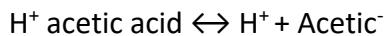
BUFFERS

Organisms are extremely sensitive to slight changes in the pH of the environment. In high concentrations, acids and bases are damaging to cells. Homeostasis of acid-base balance is regulated by chemical systems called buffers.

Buffers resist abrupt and large changes in the pH of a solution by releasing hydrogen ions when the pH begins to rise and by binding hydrogen ions when the pH drops.

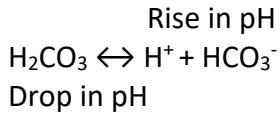
Chemical buffer systems react by binding hydrogen ions or by releasing hydrogen ions. The acidity of a solution reflects the free hydrogen ions and not the hydrogen ions bound to anions. Acids that dissociate completely and irreversibly in water are called strong acids. They can dramatically change the pH of a solution. Acids that do not dissociate completely, like carbonic acid (H₂CO₃) and acetic acid, are weak acids. Undissociated acids do not affect pH, so that acetic acid solutions are much less acidic than hydrochloric acid solution. Weak acids disassociate in predictable ways, and molecules of the intact acid are in dynamic equilibrium with the dissociated ions.

For this reason, when a strong acid is added to a solution of a weak acid the equilibrium will shift to the left and some H⁺ will recombine to form acetic acid. On the other hand, if a strong base is added and the pH begins to rise, the equilibrium shifts to the right and more acetic molecules disassociate to release H⁺ ions. This characteristic of weak acids allows them to play a role in the chemical buffer systems found in nature.



Bases are proton acceptors. Strong bases are those bases, like hydroxides, that dissociate easily in water and quickly bind H⁺ ions. Sodium bicarbonate ionizes incompletely and reversibly. Since it accepts relatively few protons, its released bicarbonate ion is considered to be a weak base.

One of the buffer system that helps to maintain the pH in aqueous solutions is the carbonic acid-bicarbonate system. Carbonic acid dissociates reversibly in aqueous solutions releasing bicarbonate ions and protons, H⁺. The chemical equilibrium between carbonic acid, a weak acid, and bicarbonate ion, a weak base, resists changes in pH by shifting to the right or the left as H⁺ ions are added to or removed from the solution:



As the pH rises and becomes more alkaline, the equilibrium shifts to the right, forcing more carbonic acid to dissociate. Similarly as the pH begins to drop, the equilibrium shifts to the left as more bicarbonate ions begin to bind with protons. Strong bases are replaced by a weak base, bicarbonate ion. Protons are released by strong acids and are tied up in weak acids, carbonic acid. As a result, the pH changes are much less than they would be in the absence of the buffering system.

Key Terms

- **acid** – a substance that dissociates into one or more hydrogen ions (H^+); proton donors; acids release hydrogen ions in measurable amounts; sour taste
- **base** – a substance that dissociates into one or more positive ions (cations) that can accept or combine with protons; proton acceptors; bases take up hydrogen ions in measurable amounts; bitter taste
- **buffer** – buffers prevent the pH of a solution from changing drastically
- **pH** – the potential of hydrogen ion concentration

REVIEW QUESTIONS

1. What properties of water make it essential for life?

2. What are acids and bases?

3. Define a buffer.

CHAPTER QUIZ

1. _____ is the most abundant and important inorganic compound on earth.
 - a. Salt
 - b. Water
 - c. Bicarbonate
 - d. Oxygen

2. A(n) _____ can be defined as a substance that dissociates into one or more hydrogen ions (H^+) and one or more negative ions (anions) an acid is also called a proton donor (H^+).
 - a. base
 - b. buffer
 - c. acid
 - d. salt

3. _____ are added to solutions or to the natural environment to prevent changes in pH.
 - a. Base
 - b. Buffer
 - c. Acid
 - d. Salt

4. _____ have a bitter taste, feel slippery, and are proton acceptors. They take up hydrogen ions in measureable amounts.
 - a. Bases
 - b. Buffers
 - c. Acids
 - d. Salts

5. When acids and bases are mixed, they react with each other in displacement reactions to form water and a(n) _____.
 - a. base
 - b. buffer
 - c. acid
 - d. salt

6. Nutrients are decomposed by adding _____ to each chemical bond that is broken.
- a. a salt
 - b. water
 - c. bicarbonate
 - d. oxygen
7. _____ system that helps to maintain the pH in aqueous solutions is the carbonic acid-bicarbonate system.
- a. A base
 - b. A buffer
 - c. An acid
 - d. A salt

CHAPTER 6: BASIC MICROBIOLOGY PRINCIPLES

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Describe the nomenclature and classification that is used for microorganisms
- Evaluate the factors that affect growth of microorganisms
- Describe the structure of microorganisms

Microorganisms are living things that are too small to be seen with the unaided eye. The group includes bacteria, fungi, protozoa, and microscopic algae as well as viruses.

The majority of microorganisms help maintain the balance of living organisms and chemicals in the environment. Marine and freshwater microorganisms form the basis of the food chain in oceans, lakes, and rivers. On land, soil microbes help break down wastes and incorporate nitrogen gas from the air into organic compounds recycling chemical elements between the soils, water, life, and air. Certain microbes play important roles in photosynthesis, a food and oxygen-generating process that is critical to life on earth. Humans and animals on earth also depend on microbes in their intestines for digestion.

Microorganisms have commercial applications. They are used in the synthesis of chemical products like vitamins, organic acids, enzymes, alcohols, and other drugs. The food industry uses microbes to produce vinegar, sauerkraut, pickles, soy sauce, cheese, yogurt, bread, and alcoholic beverages.



Figure 6.1: Beer¹⁵



Figure 6.2: White Vinegar¹⁶



Figure 6.3:Yogurt¹⁷

¹⁵ [Image](#) by [Engin Akyurt](#) on [Pixabay](#)

¹⁶ [Image](#) by [Willis Lam](#) is licensed under [CC BY-SA 2.0](#)

¹⁷ [Image](#) by [Jin Zan](#) is licensed under [CC BY-SA 4.0](#)

In addition, enzymes from microbes can now be manipulated to cause the microbes to produce substances that they normally do not synthesize, including cellulose, digestive aids, and drain cleaner, plus important therapeutic substances like insulin.

A minority of microorganism are **pathogenic** or disease-producing.



Pin It! Misconception Alert
People frequently think all microorganisms are pathogenic. But only a few are actually pathogenic or disease-producing!

BASIC NOMENCLATURE AND ORGANIZATION

The system of nomenclature and organization for microorganisms is broken down into prokaryotic cells and eukaryotic cells. Bacteria and archaea are referred to as prokaryotic cells, and fungi and protozoans are called eukaryotic cells. Viruses are a separate category of non-living things.

Bacteria are simple, single celled organisms. Because their genetic material is not enclosed in a nuclear membrane, bacterial cells are called **prokaryotes**.

Archaea are also prokaryotes. Archaea are often found in extreme environments such as the hot springs at Yellowstone National Park. Archaea are not known to cause disease in humans.

Fungi are **eukaryotes**, organisms whose cells have a distinct nucleus containing the cell's genetic material, surrounded by a special envelope called a nuclear membrane. Organisms in this kingdom can be unicellular or multicellular. Fungi cannot carry out photosynthesis. True fungi have cell walls composed of chitin.

Protozoa are unicellular eukaryotic microbes. Protozoa have a variety of shapes and live as free entities or as parasites that absorb or ingest organic compounds from their environment.

Algae are photosynthetic eukaryotes with a variety of shapes and sexual and asexual reproductive forms. Algae are abundant in freshwater and salt water, in soil, and in association with plants. Algae need light, water, and carbon dioxide for food production and growth. They receive their energy from sunlight.

Viruses are different from the other microorganisms. They are so small that most can be seen only with an electron microscope. They are considered to be acellular. Viruses can reproduce by using the cellular machinery of other organisms. Viruses are considered to be living when they multiply within the host cells that they infect. In this sense, viruses are parasites of other forms

of life. On the other hand, viruses are not considered to be living because they are inert outside living hosts.

GROWTH OF MICROORGANISMS

The requirements for microbial growth are divided into two primary categories. Physical and chemical requirements exist for microorganism to grow and reproduce. Physical aspects include temperature, pH, and osmotic pressure. Chemical requirements include sources of carbon, nitrogen, sulfur, phosphorus, oxygen, trace elements, and organic growth factors.

Differing temperatures are required for different microorganisms. Most bacteria grow only within a limited range of temperatures, and their maximum and minimum growth temperatures are about 30°C apart. They grow poorly at the high and low temperature extremes within their range. Each bacterial species grows at specific minimum, optimum, and maximum temperatures. The minimum growth temperature is the lowest temperature at which the organism will grow. The optimum growth temperature is the temperature at which the species grows best. The maximum growth temperatures are the highest temperature at which growth is possible.

Refrigeration is the most common method of preserving organic materials. It is based on the principle that microbial reproductive rates decrease at low temperatures. Microbes can survive subfreezing temperatures, they become dormant and their numbers gradually decline in low temperatures. Some species decline faster than other species.

pH value can also encourage or discourage growth of microorganisms. Most bacteria grow best in a narrow pH range near neutrality, between pH 6.5 and 7.5. Few bacteria grow at an acidity below pH 4. For this reason, a number of foods prevent spoilage by using acids produced by bacterial fermentation. Molds and yeast grow over a greater pH range than bacteria. However the optimum pH for molds and yeast is generally below that of bacteria, usually about pH 5 to 6. Alkalinity also inhibits microbial growth.

Besides water, carbon and oxygen are important requirements for growth in microorganisms. Carbon is the structural backbone of living matter. It is needed for organic compounds that make up a living cell. Carbon makes up half of the weight of bacterial cells.

CLASSIFYING MICROBES

The classification of organisms into progressively more inclusive groups is based on phylogeny and phenotype. The nomenclature is the process of applying formal rules in the naming of organisms.

Domains

Organisms are classified by cell type in the three domain systems. Animals, plants, and fungi are kingdoms in the **Domain Eukarya**. The **Domain Archaea** includes prokaryotes that do not have peptidoglycan in their cell walls. Peptidoglycan is a building block of cell walls of bacteria. The **Domain Bacteria** includes the pathogenic prokaryotes as well as many of the nonpathogenic prokaryotes found in soil and water.

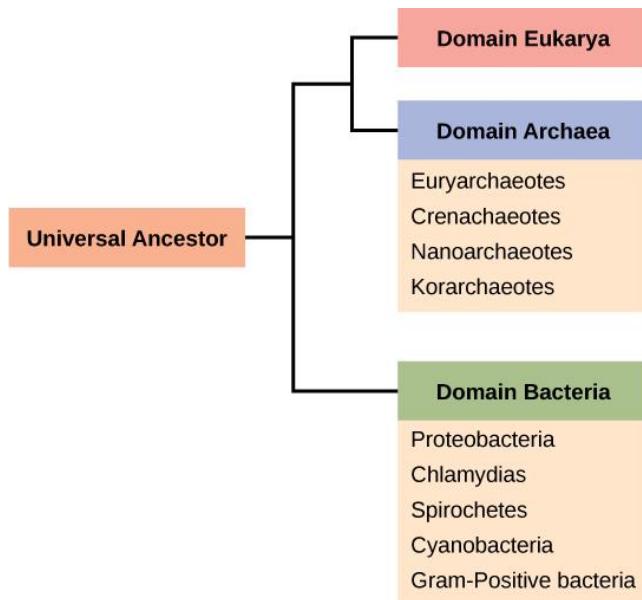


Figure 6.4: Three Domain system¹⁸

Bacteria are classified into five groups based on their basic shapes. These shapes include spherical (cocci), spiral (spirilla), rod (bacilli), comma (vibrios), or corkscrew (spirochaetes). These cells can exist as single cells, in pairs, chains, or in clusters.

¹⁸ [Image](#) by [OpenStax](#) is licensed under [CC BY 4.0](#)

Common Prokaryotic Cell Shapes			
Name	Description	Illustration	Image
Coccus (pl. cocci)	Round		 200 µm
Bacillus (pl. bacilli)	Rod		
Vibrio (pl. vibrios)	Curved rod		
Coccobacillus (pl. coccobacilli)	Short rod		
Spirillum (pl. spirilla)	Spiral		
Spirochete (pl. spirochetes)	Long, loose, helical spiral		

Figure 6.5: Basic Shapes of Bacteria¹⁹

Nomenclature

Scientific nomenclature is a binomial nomenclature so that every organism has a unique binomial identification that indicates the individual and its taxonomic placement among other

¹⁹ [Image](#) by [OpenStax](#) is licensed under [CC BY 4.0](#)

organisms. **Taxonomy** is the science of classification. Almost 2 million organisms have been identified so far, and the estimate is that 10-100 million total organisms occupy the earth. All cellular organisms evolved from a common ancestor.

The differences observed between organisms are due to random mutation and natural selection. Organisms are organized into taxonomic categories by relatedness. Systematics/Phylogeny are the study of the evolutionary history and relatedness of organisms. Modern taxonomy is based on genetic sequence information or molecular biology.

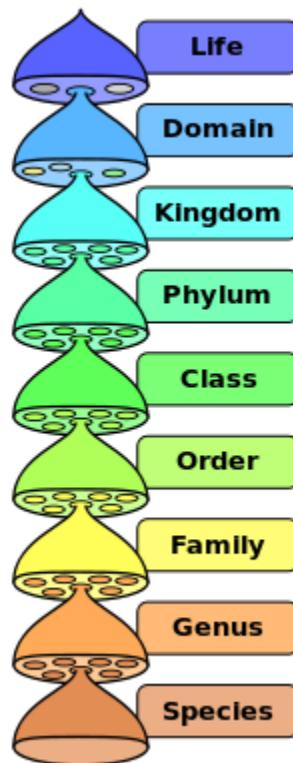


Figure 6.6: Hierarchical system of scientific nomenclature for classification of living organisms²⁰

Of all the different classification systems, the Gram stain has withstood the test of time. The Gram stain remains an important and useful technique. It allows a large proportion of clinically important bacteria to be classified as Gram positive or negative based on their morphology and differential staining properties. A Gram stain is a process during which a violet dye is applied, a decolorizing agent is applied, and then a red dye is applied. Gram positive bacteria have cell walls that will retain the violet dye. Gram negative bacteria will be red.

Phylogenetic Tree

A universal Phylogenetic Tree has been developed for living organisms that establishes a tripartite division of all living organisms—bacteria, archaea, and eukarya. The classification is based on a comparison of 16s ribosomal RNA sequences. These sequences are highly conserved

²⁰ [Image](#) by [Pengo](#) is in the public domain

and undergo change at a slow, gradual and consistent rate. They are therefore useful for making comparisons among different living organisms.

Phylogenetic Tree of Life

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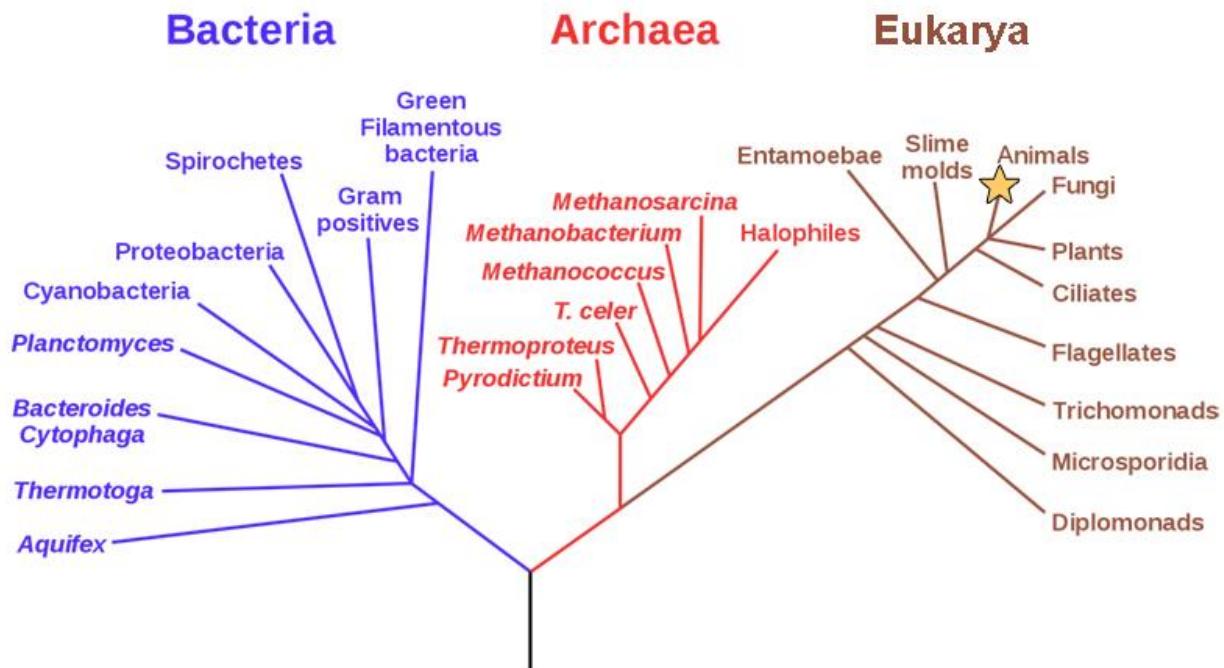


Figure 6.7: Phylogenetic Tree for microorganisms²¹

Taxonomic/Phylogenetic Hierarchy groups are based on similarities. The groups begin very general and become more restricted. DNA hybridization and rRNA sequencing are used to determine evolutionary relationships and classification. Organisms that are grouped together are based on relatedness; very general relatedness at the top, followed by more and more specific and restricted subgroups where genus is all related species, and species is a single unique organism group.

1. Kingdom Protista (unicellular eukaryotes) are algae and protozoa and they are nutritionally diverse: autotrophs, heterotrophs, and intracellular parasite.
2. Kingdom Fungi are yeasts, molds, and mushrooms that absorb organic material through their plasma membrane.
3. Kingdom Animalia are multicellular animals that ingest organic food through a mouth and have cells organized into tissues
4. Kingdom Plantae are multicellular plants that undergo photosynthesis to convert carbon dioxide and water into organic molecules, and this Kingdom has cells organized into tissues

²¹ [Image](#) by [OpenStax](#) is licensed under [CC BY 4.0](#)

Prokaryotic Classification-prokaryotes have two domains:

1. Bacteria are all pathogenic prokaryotes, many non-pathogenic prokaryotes, and all photoautotrophic prokaryotes
2. Archaea are all prokaryotes with walls that are not peptidoglycan, that carryout unusual metabolism and live in extreme environments, and are groupings based entirely on gene sequencing since most look similar

Prokaryotic species are defined as a population of cells with similar characteristics that do not demonstrate sexual reproduction. Pure cultures are clones because they are populations derived from a single cell. They are genetically identical. Strains are cells of the same species that are not genetically identical.

Viral Classification

Viruses do not fit into a domain system because they are acellular. They are usually only classified by Family and Genus. Viral species are defined as a population of viruses with similar characteristics (including morphology, genes, and enzymes) that occupy a particular ecological niche.

In early 2020, one virus that became very well-known was coronavirus-19, which swept the world as a pandemic. This virus was a type of coronavirus that was extremely contagious and had a wide range of symptoms. It is currently not well understood.

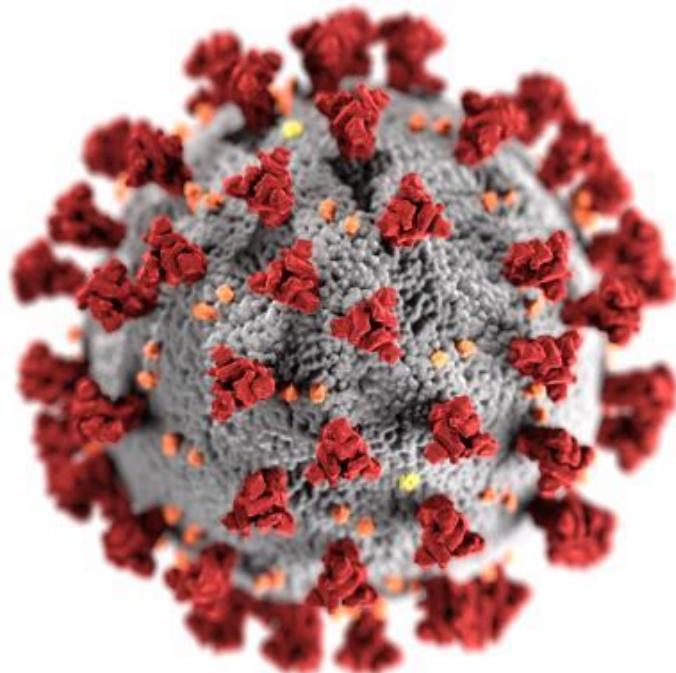


Figure 6.8: Coronavirus²²

²² [Image](#) by the [CDC](#) is in the public domain

STRUCTURE

Prokaryotes—Structure/Function

Prokaryotes are distinguished from eukaryotes by their smaller size (0.2- 10 μm), their lack of internal organelles (mitochondria), the presence of a cell wall, and their cell division by binary fission rather than mitosis. They lack introns, are not capable of endo/exocytosis, and have single-stranded circular DNA rather than multiple discrete chromosomes.

Gram positive bacteria have a large peptidoglycan structure. This structure accounts for the differential staining with Gram stain. Some Gram positive bacteria are also capable of forming spores under stressful environmental conditions such as when there is limited availability of carbon and nitrogen. Spores therefore allow bacteria to survive exposure to extreme conditions.

Gram negative bacteria have a small peptidoglycan layer but have an additional membrane, the outer cytoplasmic membrane. This membrane creates an additional permeability barrier and results in the need for transport mechanisms across it. A major component of the cytoplasmic membrane that is unique to Gram negatives is endotoxin.

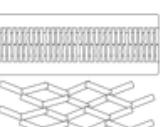
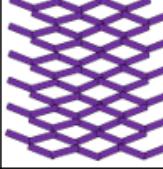
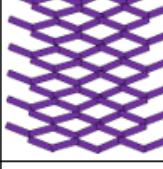
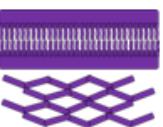
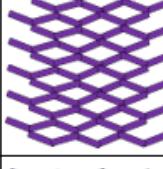
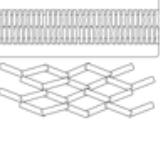
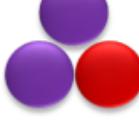
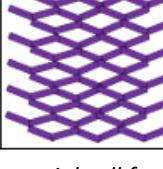
Gram Staining Procedure		Gram Positive Cell Wall		Gram Negative Cell Wall	
Process of test	Appearance of Cells	Effect of Step	Effect on Cell Wall	Effect of Step	Effect on Cell Wall
Step 1: Begin with heat fixed cells		Step 1: Cell wall remains clear.		Step 1: Cell wall remains clear.	
Step 2: Flood slide with crystal violet dye for 1 min.		Step 2: Peptidoglycan cell wall is flooded with crystal violet and appears purple.		Step 2: Cell wall is stained purple from the crystal violet dye.	
Step 3: Add iodine solution for 1 min.		Step 3: A crystal violet - iodine complex is formed within the peptidoglycan cell wall trapping the purple stain.		Step 3: A crystal violet - iodine complex is formed but does not adhere to the cell wall due to the thin layer of peptidoglycan.	
Step 4: Wash slide with alcohol for 20sec.		Step 4: The crystal violet - iodine complex is trapped within the peptidoglycan cell wall and doesn't wash out.		Step 4: The crystal violet - iodine complex is washed out of the thin peptidoglycan layer.	
Step 5: Counter stain with safranin.		Step 5: As the peptidoglycan cell wall remains stained purple the red safranin has no effect.		Step 5: The red safranin stains the washed gram negative cells.	

Figure 6.9: Gram staining of bacterial cell for identification²³

6.3.2 Microorganism Identification

The classification is based on morphological characteristics that refer to size, shape, cellular characteristics (capsule, flagella, endospores), differential staining (Gram stain, Acid fast stain), and biochemical tests that probe for specific enzyme activities that lead to carbohydrate fermentation, nitrogen fixation, sulfur oxidation, gas production, acid production, and nitrate reduction.

²³ [Image](#) by Michigan State University. Microbiology 301-702 Summer 2016 is licensed under [CC BY-SA 4.0](#)

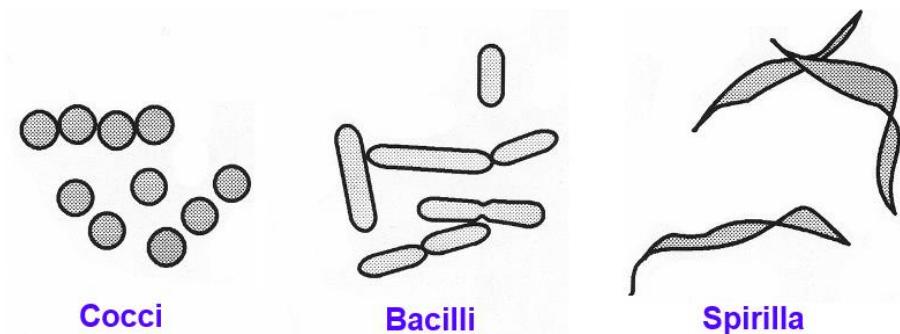


Figure 6.10: Classification of bacteria by shape and environmental appearance²⁴

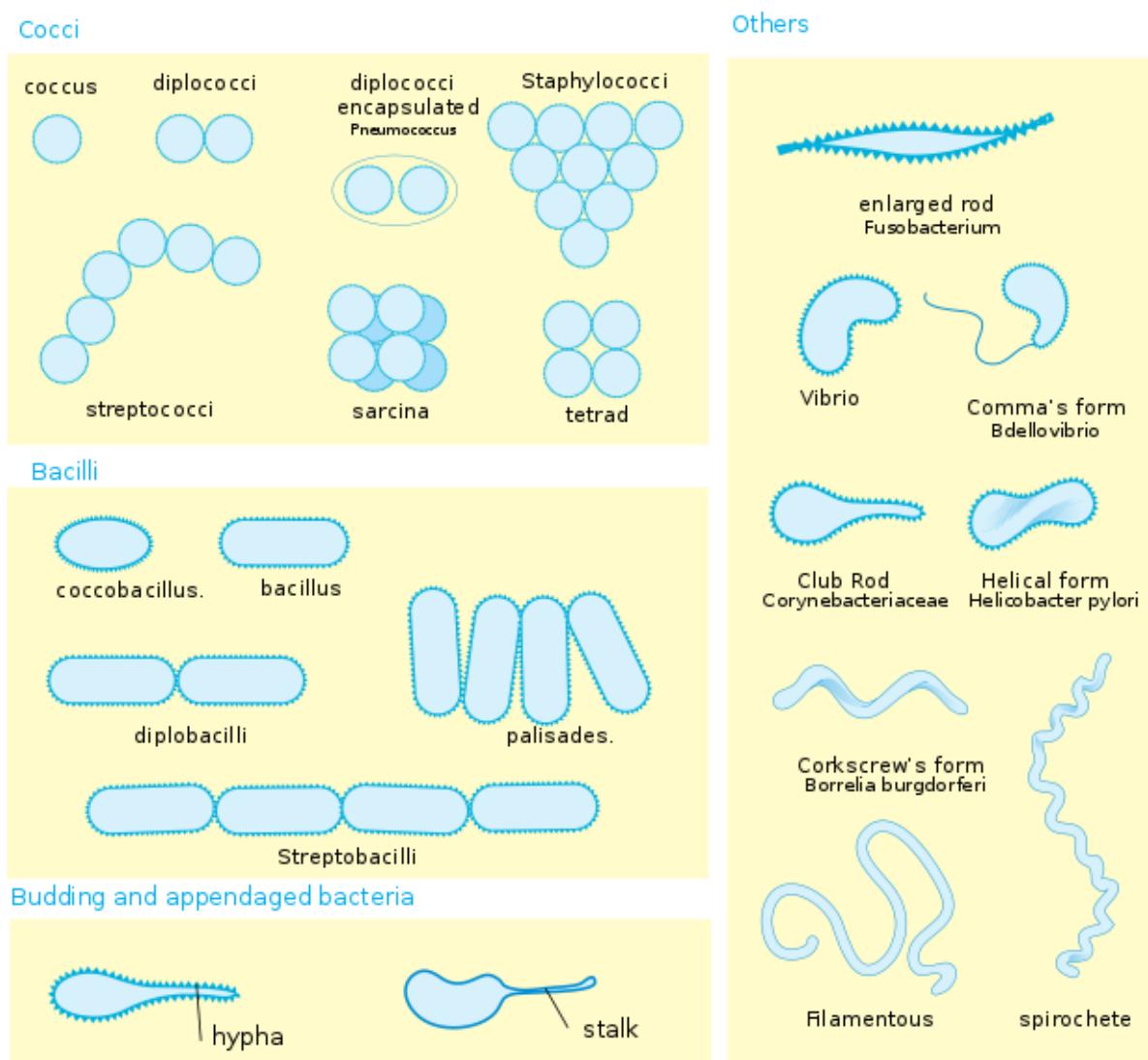


Figure 6.11: Morphology of bacterial cells²⁵

²⁴ [Image](#) by [CKRobinson](#) is licensed under [CC BY-SA 4.0](#)

²⁵ [Image](#) by [LadyofHats](#) is in the public domain

Key Terms

- **algae** – photosynthetic eukaryotes with a variety of shapes and sexual and asexual reproductive forms
- **Archaea** – prokaryotes that are found in extreme environments; non-disease causing
- **bacteria** – the domain that includes the pathogenic prokaryotes as well as many of the nonpathogenic prokaryotes found in soil and water; simple single-celled organisms
- **Eukarya (eukaryotes)** – the domain that includes animals, plants, and fungi
- **fungi** - eukaryotes. whose cells have a distinct nucleus containing the cell's genetic material, surrounded by a special envelope called a nuclear membrane; can be unicellular or multicellular
- **gram negative** – bacteria with a small peptidoglycan structure and additional membranes that creates additional permeability barriers and results in the need for transport mechanisms across it
- **gram positive** – bacteria with a large peptidoglycan structure and causes differential staining with Gram staining
- **pathogenic** – disease-causing
- **peptidoglycan** - a building block of cell walls of bacteria.
- **Prokarya (prokaryotes)** – distinguished from eukaryotes by their smaller size (0.2-10µm), their lack of internal organelles (mitochondria), the presence of a cell wall, and their cell division by binary fission rather than mitosis
- **protozoa** – unicellular eukaryotic microbes with a variety of shapes that live as free entities or as parasites that absorb or ingest organic compounds from their environment
- **scientific nomenclature** – a binomial nomenclature so that every organism has a unique binomial identification that indicates the individual and its taxonomic placement among other organisms
- **taxonomy** – the science of classification.
- **viruses** – microorganisms so small that most can be seen only with an electron microscope; acellular; reproduction occurs using cellular machinery of other organisms

REVIEW QUESTIONS

1. Name the two major types of cells found in nature.
 2. List and describe the five types of microorganisms.
 3. List the classifications in descending order for the hierachal system of scientific nomenclature for the classification of living organisms.
 4. Distinguish the features between gram positive and gram negative bacteria.

CHAPTER QUIZ

1. Microorganisms that are disease-producing are _____.
 - a. pathogenic
 - b. Streptococcus
 - c. Staphylococcus
 - d. gram negative

2. Bacteria and archaea are referred to as _____ cells.
 - a. eukaryotic
 - b. prokaryotic
 - c. gram negative
 - d. gram positive

3. Cells with cell walls that lack peptidoglycan are _____.
 - a. bacteria
 - b. algae
 - c. protozans
 - d. archaea

4. _____ are eukaryotes. They are organisms whose cells have a distinct nucleus containing the cell's genetic material, surrounded by a special envelope called a nuclear membrane.
 - (a) Archaea
 - (b) Bacteria
 - (c) Viruses
 - (d) Fungi

5. _____ bacteria have a large peptidoglycan structure.
 - a. Streptococcus
 - b. Staphylococcus
 - c. Gram negative
 - d. Gram positive

6. Most bacteria grow best in a narrow pH range near neutrality, between _____.
- 2.0 to 6.5
 - 6.5 to 7.5
 - 8.0 to 10.0
 - 11.0 to 14.0
7. _____ is a binomial nomenclature so that every organism has a unique binomial identification that indicates the individual and its taxonomic placement among other organisms.
- Taxonomy
 - Scientific nomenclature
 - DNA hybridization
 - Genus species
8. _____ is the science of classification.
- Taxonomy
 - Scientific nomenclature
 - DNA hybridization
 - Genus species

CHAPTER 7: MICROBIOLOGY REGULATIONS

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Explain the Total Coliform Rule
- Compare the Groundwater Treatment Rule and Surface Water Treatment Rule
- Describe the concern with Cryptosporidium

TOTAL COLIFORM RULE

The **Total Coliform Rule** (TCR), a National Primary Drinking Water Regulation (NPDWR), was published in 1989 and became effective in 1990. The rule sets a health goal (Maximum Contaminant Level Goal (MCLG)) and legal limits (Maximum Contaminant Levels, MCLs) for the presence of total coliforms in drinking water.

The Environmental Protection Agency (EPA) published the Revised Total Coliform Rule (RTCR) in the Federal Register (FR) in February 2013 (78 FR 10269) and minor corrections in February 2014 (79 FR 10665). The RTCR is the revision to the 1989 Total Coliform Rule (TCR) and is intended to improve public health protection. All public water systems (PWSs), except aircraft PWSs subject to the Aircraft Drinking Water Rule (ADWR) (40 CFR 141 Subpart X), must comply with the RTCR starting April 2016, or an earlier state effective date.

Total coliforms are a group of related bacteria that are, with few exceptions, not harmful to humans. This is very important to note. The EPA considers total coliforms a useful indicator of other pathogens for drinking water. Total coliforms are used to determine the adequacy of water treatment and the integrity of the distribution system.

Key provisions of the RTCR include:

1. Setting a maximum contaminant level goal (MCLG) and maximum contaminant level (MCL) for E. coli for protection against potential fecal contamination.
2. Setting a total coliform treatment technique (TT) requirement.
3. Requirements for monitoring total coliforms and E. coli according to a sample siting plan and schedule specific to the PWS.
4. Provisions allowing PWSs to transition to the RTCR using their existing Total Coliform Rule(TCR) monitoring frequency, including PWSs on reduced monitoring under the existing TCR.

5. Requirements for seasonal systems (such as, Non-Community Water Systems not operated on a year-round basis) to monitor and certify the completion of a state-approved start-up procedure.
6. Requirements for assessments and corrective action when monitoring results show that PWSs may be vulnerable to contamination.
7. Public notification (PN) requirements for violations.
8. Specific language for CWSs to include in their Consumer Confidence Reports (CCRs) when they must conduct an assessment or if they incur an E. coli MCL violation.

REVISED TOTAL COLIFORM RULE

Overview of the Rule

Revised Total Coliform Rule (RTCR) 78 FR 10269, February 2013, Vol. 78, No. 30

Purpose: Increase public health protection through the reduction of potential pathways of entry for fecal contamination into distribution systems.

General Description

The rule establishes a maximum contaminant level (MCL) for E. coli and uses E. coli and total coliforms to initiate a find and fix approach to address fecal contamination that could enter into the distribution system. It requires public water systems (PWSs) to perform assessments to identify sanitary defects and subsequently take action to correct them.

The Total Coliform Rule applies to all Public Water Systems.

Implementation of the Total Coliform Rule will result in:

1. A decrease in the pathways by which fecal contamination can enter the drinking water distribution system.
2. Reduction in fecal contamination should reduce the potential risk from all waterborne pathogens including bacteria, viruses, parasitic protozoa, and their associated illnesses.

Requirements:

1. Public Water Systems must develop a written sample siting plan that identifies the system's sample collection schedule and all sample sites, including sites for routine and repeat monitoring.
2. PWSs monitoring quarterly or annually must also identify additional routine monitoring sites in their sample siting plans.
3. Sample siting plans are subject to state review and revision.

Routine Sampling Requirements

1. Total coliform samples must be collected by Public Water Systems at sites which are representative of water quality throughout the distribution system according to a written sample siting plan subject to state review and revision.
2. For Public Water Systems collecting more than one sample per month, collect total coliform samples at regular intervals throughout the month, except that ground water systems serving 4,900 or fewer people may collect all required samples on a single day if the samples are taken from different sites.

Repeat Sampling Requirements

Within 24 hours of learning of a Total Coliform positive routine sample result, at least 3 repeat samples must be collected and analyzed for total coliform:

1. One repeat sample must be collected from the same tap as the original sample.
2. One repeat sample must be collected from within five service connections upstream.
3. One repeat sample must be collected from within five service connections downstream.
4. The PWS may propose alternative repeat monitoring locations that are expected to better represent pathways of contamination into the distribution system.

If one or more repeat sample is Total Coliform Positive:

1. The TC+ sample must be analyzed for the presence of E. coli.
2. If any repeat TC+ sample is also EC+, then the EC+ sample result must be reported to the state by the end of the day that the PWS is notified.
3. The PWS must collect another set of repeat samples, unless an assessment has been triggered and the PWS has notified the state.

Routine Sampling Requirements

1. Each total coliform-positive (TC+) routine sample must be tested for the presence of E. coli.
2. If any coliform-positive (TC+) sample is also E. coli-positive (EC+), then the EC+ sample result must be reported to the state by the end of the day that the PWS is notified.
3. If any routine sample is TC+, repeat samples are required.
4. Public Water Systems on quarterly or annual monitoring must take a minimum of three additional routine samples (known as additional routine monitoring) the month following a TC+ routine or repeat sample.
5. Reduced monitoring may be available for Public Water Systems using only ground water and serving 1,000 or fewer persons that meet certain additional Public Water System criteria.

Assessments and Corrective Action

The RTCR requires PWSs that have an indication of coliform contamination (e.g., as a result of TC+ samples, E. coli MCL violations, performance failure) to assess the problem and take

corrective action. Two levels of assessments exist (i.e., Level 1 and Level 2) based on the severity or frequency of the problem.

Purpose of Level 1 and Level 2 Assessments

To find sanitary defects at the Public Water System including:

1. Sanitary defects that could provide a pathway of entry for microbial contamination
2. Sanitary defects that indicate failure (existing or potential) of protective barriers against microbial contamination.

Deadline for Completing Corrective Actions

When sanitary defects are identified during a Level 1 or Level 2 Assessment, they should be corrected as soon as possible to protect public health. The Public Water System must complete corrective actions by one of the following timeframes:

1. No later than the time the assessment form is submitted to the state, which must be within 30 days of triggering the assessment, or
2. Within state-approved timeframe which was proposed in the assessment form.

Level 1 Assessments

Conducting Level 1 Assessments

1. Performed by the PWS owner or operator each time a Level 1 Assessment is triggered.
2. Upon trigger of a Level 1 Assessment, the Level 1 Assessment form must be submitted within 30 days to the state.

Level 1 Assessment Triggers

Level 1 Assessment is triggered if any one of the following occurs:

1. A Public Water System collecting fewer than 40 samples per month has 2 or more TC+ routine/ repeat samples in the same month.
2. A PWS collecting at least 40 samples per month has greater than 5.0 percent of the routine/repeat samples in the same month that are TC+.
3. A PWS fails to take every required repeat sample after any single TC+ sample.

Level 2 Assessments

Conducting Level 2 Assessments

Performed by the state or state-approved entity each time a Level 2 Assessment is triggered.

1. The Public Water System is responsible for ensuring that the Level 2 Assessment is conducted regardless of the entity conducting the Level 2 Assessment.
2. (3)Upon trigger of a Level 2 Assessment, the Level 2 Assessment form must be submitted within 30 days to the state.

Level 2 Assessment Triggers

Level 2 Assessment is triggered if any one of the following occurs:

1. A Public Water System incurs an E. coli MCL violation.
2. A Public Water System has a second Level 1 Assessment within a rolling 12-month period.
3. A Public Water System on state-approved annual monitoring has a Level 1 Assessment trigger in 2 consecutive years.

Seasonal System Provisions

The Total Coliform Rule defines seasonal systems and specifies additional requirements for these types of PWSs:

1. A seasonal system is defined as a non-community water system that is not operated as a PWS on a year round basis and starts up and shuts down at the beginning and end of each operating season.

Start-up Procedures for Seasonal Systems

At the beginning of each operating period, before serving water to the public, seasonal water systems must:

1. Conduct state-approved start-up procedures.
2. Certify completion of state-approved start-up procedures.
3. An exemption from conducting state-approved start-up procedures may be available for seasonal systems that maintain pressure throughout the distribution system during non-operating periods.

Examples of state-approved start-up procedures, which need to be completed prior to serving water to the public, may include one or more of the following:

1. Disinfection.
2. Distribution system flushing.
3. Sampling for total coliform and E. coli.
4. Site visit by state.
5. Verification that any current or historical sanitary defects have been corrected.

Routine Monitoring for Seasonal Systems

1. The baseline monitoring frequency for seasonal systems is monthly.
2. A reduced monitoring frequency may be available for seasonal systems that use ground water only and serve fewer than 1,000 persons.

Other Provisions for the State Drinking Water Agency Special Monitoring Evaluation

The state must perform a special monitoring evaluation at all ground water systems serving 1,000 or fewer persons during each sanitary survey to review the status of the Public Water

System and to determine whether the sample sites and monitoring schedule need to be modified.

Major Violations

E. coli MCL Violation

A Public Water System will receive an E. coli MCL violation when there is any combination of an E.coli positive sample result with a routine/repeat Total Coliform positive or E. coli positive sample result:

E. coli MCL Violation Occurs with the Following Sample Result Combination

Routine Repeat

EC+ TC+

EC+ Any missing sample

EC+ EC+

TC+ EC+

TC+ TC+ (but no E. coli analysis)

Treatment Technique Violation

A PWS will receive a Treatment Technique violation when any of the following occur:

1. Failure to conduct a Level 1 or Level 2 Assessment within 30 days of a trigger.
2. Failure to correct all sanitary defects from a Level 1 or Level 2 Assessment within 30 days of a trigger or in accordance with the state-approved timeframe.
3. Failure of a seasonal system to complete state-approved start-up procedures prior to serving water to the public.

Key Points for Public Water Systems to Remember

Find and correct sanitary defects as soon as you become aware of them. This can help reduce E. coli MCL violations, which trigger a Level 2 Assessment. This can help reduce TC+ sample results, which may trigger a Level 1 Assessment.

Make sure to collect all routine and repeat samples as required. Timely and correct monitoring can help reduce triggering a Level 1 or Level 2 Assessment because:

1. Failure to conduct repeat monitoring triggers a Level 1 Assessment.
2. A Level 1 Assessment triggered twice within a certain timeframe triggers a Level 2 Assessment.

GROUND WATER TREATMENT RULE

EPA issued the **Ground Water Rule (GWR)** to improve drinking water quality and provide protection from disease-causing microorganisms. Water systems that have groundwater

sources may be susceptible to fecal contamination. In many cases, fecal contamination can contain disease-causing pathogens.

The purpose of the Ground Water Rule (GWR) is to reduce disease incidence associated with harmful microorganisms in drinking water.

The Ground Water Rule applies to public water systems that use ground water as a source of drinking water. The rule also applies to any system that delivers surface and ground water to consumers where the ground water is added to the distribution system without treatment. The Ground Water Rule was published in the Federal Register in November 2006.

7.2.1 Overview of the Rule

Ground Water Rule (GWR)

71 FR 65574, November 2006, Vol. 71, No. 216

Correction 71 FR 67427, November 2006, Vol. 71, No. 224

Purpose

The rule should reduce the risk of illness caused by microbial contamination in public ground water systems (GWSs).

General Description

The Groundwater Rule establishes a risk-targeted approach to identify groundwater systems susceptible to fecal contamination, and the rule requires corrective action to correct significant deficiencies and source water fecal contamination in all public groundwater systems.

Utilities Covered

The Ground Water Rule applies to all public water systems that use groundwater, including consecutive systems, except that it does not apply to public water systems that combine their groundwater with surface water or with groundwater under the direct influence of surface water prior to treatment.

Public Health Benefits

Targeted protection for over 70 million people served by groundwater sources that are not disinfected or receive less than 4-log treatment or reduction in 99.99% harmful microorganisms. Implementation created an avoidance of 42,000 viral illnesses and 1 related death annually.

Requirements for Drinking Water Systems

New groundwater sources must meet triggered source water monitoring requirements or conduct compliance monitoring. Groundwater systems must conduct triggered source water monitoring if the system does not provide at least 4-log virus inactivation, removal, or a state-

approved combination of these technologies before or at the first customer and the system is notified that a sample collected for the Total Coliform Rule (TCR) is total coliform-positive.

Groundwater systems identified as a significant deficiency and systems that have had at least one of the five additional groundwater source samples has tested positive for fecal contamination must comply with the treatment technique requirements.

Analytical Methods for Source Water Monitoring

Fecal Indicator Methodology Method:

1. E. coli Colilert
2. Colisure
3. Membrane Filter Method with MI Agar
4. m-ColiBlue24 Test
5. E*Colite Test
6. EC-MUG
7. NA-MUG
8. 9223 B
9. 9223 B
10. EPA Method 1604
11. 9221 F
12. 9222 G
13. Enterococci Multiple-Tube Technique
14. Membrane Filter Technique
15. Enterolert
16. 9230 B
17. 9230 C
18. EPA Method 1600.
19. Coliphage Two-Step, Enrichment, Presence-Absence Procedure
20. Single Agar Layer Procedure
21. EPA Method 1601
22. EPA Method 1602

Major Provisions of Rule

1. Compliance Monitoring
2. Treatment
3. Technique
4. Compliance
5. Monitoring

In order not to be subject to triggered source water monitoring, a groundwater system can notify the state that it provides at least 4-log treatment of viruses using virus inactivation, removal, or a state-approved combination of 4-log virus inactivation and removal before or at

the first customer. The groundwater system must then begin compliance monitoring designed to show the effectiveness of their treatment processes.

Groundwater systems that use chemical disinfection and serve more than 3,300 people must continuously monitor their disinfectant concentration. These systems must maintain the minimum disinfectant residual concentration determined by the state.

Groundwater systems that use chemical disinfection and serve 3,300 people or fewer must take daily grab samples or meet the continuous monitoring requirements described for public groundwater systems serving more than 3,300 people.

Groundwater systems using membrane filtration for 4-log treatment of viruses must monitor the membrane filtration process according to state-specified monitoring requirements.

Groundwater systems may use alternative treatment technologies (e.g., ultraviolet radiation [UV]) approved by the state. Groundwater systems must monitor the alternative treatment according to state specified monitoring requirements, and must operate the alternative treatment according to compliance requirements established by the state.

Source Water Monitoring

Triggered Source Water Monitoring

Groundwater systems that do not conduct compliance monitoring and are notified of a total coliform-positive routine sample collected in compliance with the Total Coliform Rule (40 CFR 141.21) must conduct triggered source water monitoring.

Groundwater systems must collect at least one ground water source sample from each source in use at the time the total coliform-positive sample was collected. The triggered source water sample must be analyzed for the presence of a fecal indicator as specified in the rule.

If the triggered source water sample is fecal indicator-positive, the Groundwater system must either take corrective action, as directed by the state, or if corrective action is not required by the state and the sample is not invalidated by the state, the Groundwater system must conduct additional source water sampling.

States may waive the triggered source water monitoring requirement if the state determines and documents, in writing, that the total coliform-positive routine sample is the result of a documented distribution system deficiency.

States may develop criteria for distribution system conditions that cause total coliform positive samples. A Groundwater system can document to the state that it met the state criteria within 30 days of the total coliform-positive sample and be exempt from collecting triggered source water sample(s).

States may invalidate a fecal indicator-positive groundwater source sample under specific conditions. If a fecal indicator-positive source sample is invalidated, the Groundwater system must collect another source water sample within 24 hours of being notified by the state of its invalidation decision.

Additional Source Water Sampling

If the state does not require corrective action in response to a fecal indicator-positive triggered source water sample, the Groundwater system must collect five additional source water samples (from the same source), using the same indicator as used in triggered source water monitoring, within 24 hours of being notified of the fecal indicator-positive sample.

Assessment Source Water Monitoring

States have the opportunity to target higher risk GWSs for additional testing. States independently can determine on a case by case basis whether monitoring is necessary and when corrective action needs to be taken.

Treatment Technique Requirements

Groundwater Systems with Significant Deficiencies or Source Water Fecal Contamination

Groundwater systems must take corrective action if a significant deficiency is identified, or if the initial source samples (if required by the state) or one of the five additional groundwater source samples tests positive for fecal contamination. The Groundwater systems must implement at least one of the following corrective actions:

1. Correct all significant deficiencies
2. Provide an alternate source of water
3. Eliminate the source of contamination
4. Provide treatment that reliably achieves at least 4-log treatment of viruses (using inactivation, removal, or a state-approved combination of 4-log virus inactivation and removal) before or at the first customer for the groundwater source.

New Sources

New Ground Water Sources

New sources which come on line after November 2009 are required either to conduct triggered source water monitoring as required by the Groundwater Rule, or provide at least 4-log inactivation, removal, or a state-approved combination of these technologies and conduct compliance monitoring within 30 days of the source being put in service.

Sanitary Surveys

All Ground Water Systems

States are required to conduct sanitary surveys of all Groundwater systems in order to identify significant deficiencies, including deficiencies which may make a system susceptible to microbial contamination.

Following the initial sanitary survey, states must conduct sanitary surveys every 3 years for most Community Water Systems and every 5 years for Non-community Water Systems that provide at least 4-log treatment of viruses or have outstanding performance records, as determined by the state.

SURFACE WATER TREATMENT RULE

The purpose of the **Surface Water Treatment Rules (SWTRs)** is to reduce illnesses caused by pathogens in drinking water. The disease-causing pathogens include *Legionella*, *Giardia lamblia*, and *Cryptosporidium*.

The SWTRs requires water systems to filter and disinfect surface water sources. Some water systems are allowed to use disinfection only for surface water sources that meet criteria for water quality and watershed protection. This combination of rules is designed to provide protection from microbial pathogens.

Simultaneously, the rules minimize health risks to the population from disinfection byproducts.

For PWSs that use surface water sources and are not required to filter, existing regulations do not require any treatment for Cryptosporidium. New survey data suggest that typical Cryptosporidium levels in the treated water of unfiltered PWSs are higher than in the treated water of filtered PWSs. Thus, Cryptosporidium treatment by unfiltered PWSs is needed to achieve comparable public health protection.

Further, results from recent treatment studies has allowed EPA to develop standards for the inactivation of Cryptosporidium by ozone, ultraviolet (UV) light, and chlorine dioxide. Based on these developments, the EPA has established requirements for all unfiltered PWSs to treat for Cryptosporidium, with the required degree of treatment depending on the source water contamination level. Additionally, the long-term rule addresses risks in uncovered finished water storage facilities, in which treated water can be subject to significant contamination as a result of runoff, bird and animal wastes, human activity, algal growth, insects, fish, and airborne deposition. Existing regulations prohibit the building of new uncovered finished water storage facilities. Under the long-term rule, PWSs must limit potential risks by covering or treating the discharge of such storage facilities. The requirements in the Surface Water Treatment Rule reflect consensus recommendations from the Stage 2 Microbial and Disinfection Byproducts (M-DBP) Federal Advisory Committee. These recommendations are set forth in the Stage 2 M-DBP Agreement in Principle.

Long-Term Surface Water Treatment Rule

Source Water Monitoring. The rule requires PWSs using surface water or groundwater under the direct influence (GWUDI) of surface water to monitor their source water (the influent water entering the treatment plant) to determine an average *Cryptosporidium* level. Monitoring results determine the extent of *Cryptosporidium* treatment requirements.

Large PWSs (serving at least 10,000 people) must monitor for *Cryptosporidium* (plus *E. coli* and turbidity in filtered PWSs) for a period of two years. To reduce monitoring costs, small filtered PWSs (serving fewer than 10,000 people) initially monitor just for *E. coli* for one year as a screening analysis and are required to monitor for *Cryptosporidium* only if their *E. coli* levels exceed specified trigger values. Small filtered PWSs that exceed the *E. coli* trigger, as well as all small unfiltered PWSs, must monitor for *Cryptosporidium* for one or two years, depending on the sampling frequency.

Under the long-term rule, specific criteria are set for sampling frequency and schedule, sampling location, using previously collected data, providing treatment instead of monitoring, sampling by PWSs that use surface water for only part of the year, and monitoring of new plants and sources. The long-term rule also establishes requirements for reporting of monitoring results, using analytical methods, and using approved laboratories. The rule also requires a second round of monitoring to begin approximately 6.5 years after the first round concludes in order to determine if source water quality has changed to a degree that should affect treatment requirements.

The long-term rule establishes risk-targeted treatment technique requirements to control *Cryptosporidium* in PWSs using surface water or GWUDI. These treatment requirements supplement those established by existing regulations. Filtered PWSs are classified in one of four treatment categories (or bins) based on the results of the source water *Cryptosporidium* monitoring. This bin classification determines the degree of additional *Cryptosporidium* treatment, if any, that filtered PWS must provide. PWSs classified in Bins 2, 3, or 4 must achieve 1.0 to 2.5-log of treatment (90 to 99.7 percent reduction) for *Cryptosporidium* over and above that provided with conventional treatment. Different additional treatment requirements may apply to PWSs using other than conventional treatment, such as direct filtration, membranes, or cartridge filters.

Filtered PWSs must meet the additional *Cryptosporidium* treatment required in Bins 2, 3, or 4 by using one or more treatment or control processes from a microbial toolbox of options. The long-term rule requires all unfiltered PWSs to provide at least 2-log (99 percent) inactivation of *Cryptosporidium*. If the average source water *Cryptosporidium* level exceeds 0.01 oocysts/L, the unfiltered PWS must provide at least 3-log (99.9 percent) inactivation of *Cryptosporidium*. Further, under the long-term rule, unfiltered PWSs must achieve their overall inactivation requirements (including *Giardia lamblia* and virus inactivation) using a minimum of two disinfectants.

PWSs with uncovered finished water storage facilities must take steps to address contamination risks. Existing regulations require PWSs to cover all new storage facilities for finished water but do not address existing uncovered finished water storage facilities. Under the long-term rule, PWSs using uncovered finished water storage facilities must cover the storage facility or treat the storage facility discharge to achieve inactivation and/or removal of 4-log virus, 3-log *Giardia lamblia*, and 2-log *Cryptosporidium* on a state-approved schedule.

The rule applies to all PWSs using surface water or GWUDI, including large and small PWSs, community and non-community PWSs, and non-transient and transient PWSs. Wholesale PWSs must comply with the requirements of the rule based on the population of the largest PWS in the combined distribution system.

Consecutive PWSs that purchase treated water from wholesale PWSs that fully comply with the monitoring and treatment requirements of the rule are not required to take additional steps for that water.

Existing Regulations for Microbial Pathogens in Drinking Water

1. The Surface Water Treatment Rule (SWTR) (54 FR 27486, June 1989) applies to all PWSs using surface water or ground water under the direct influence (GWUDI) of surface water as sources (Subpart H PWSs). It established MCLGs of zero for *Giardia lamblia*, viruses, and *Legionella*, and includes the following treatment technique requirements to reduce exposure to pathogenic microorganisms:
 - a. Filtration, unless specific avoidance criteria are met
 - b. Maintenance of a disinfectant residual in the distribution system
 - c. Removal and/or inactivation of 3-log (99.9%) of *Giardia lamblia* and 4-log (99.99%) of viruses
 - d. Maximum allowable turbidity in the combined filter effluent (CFE) of 5 nephelometric turbidity units
 - e. (NTU) and 95th percentile CFE turbidity of 0.5 NTU or less for plants using conventional treatment or direct filtration
 - f. Watershed protection and source water quality requirements for unfiltered PWSs
2. The Total Coliform Rule (TCR) (54 FR 27544, June 1989) applies to all PWSs. It established an MCLG of zero for total and fecal coliform bacteria and an MCL based on the percentage of positive samples collected. Coliforms are used as an indicator of fecal contamination and to determine the integrity of the water treatment process and distribution system. Under the Total Coliform Rule, no more than 5 percent of distribution system samples collected in any month may contain coliform bacteria (no more than 1 sample per month may be coliform positive in those PWSs that collect

fewer than 40 samples per month). The number of samples to be collected in a month is based on the number of people served by the PWS.

3. Interim Enhanced Surface Water Treatment Rule (63 FR 69478, December 16, 1998) (USEPA 1998a) applies to PWSs serving at least 10,000 people and using surface water or GWUDI sources. Key provisions established by the interim rule include the following:
 - a. An MCLG of zero for *Cryptosporidium*
 - b. *Cryptosporidium* removal requirements of 2-log (99 percent) for PWSs that filter
 - c. More stringent turbidity performance standards of 1.0 NTU as a maximum and 0.3 NTU or less at the 95th percentile monthly for treatment plants using conventional treatment or direct filtration
 - d. Requirements for individual filter turbidity monitoring
 - e. Disinfection benchmark provisions to assess the level of microbial protection that PWSs provide as they take steps to comply with new disinfection by-products standards
 - f. Inclusion of *Cryptosporidium* in the definition of GWUDI and in the watershed control requirements for unfiltered PWSs
 - g. Requirements for covers on new finished water storage facilities
 - h. Sanitary surveys for all surface water systems regardless of size

The interim surface water treatment rule was developed in conjunction with the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) (63 FR 69389, December 1998), which reduced allowable levels of certain DBPs, including trihalomethanes, haloacetic acids, chlorite, and bromate.

4. Long Term 1 Enhanced Surface Water Treatment Rule (67 FR 1812, January 2002) builds on the microbial control provisions established by the interim rule for large PWSs through extending similar requirements to small PWSs. The long-term interim rule applies to PWSs that use surface water or GWUDI as sources and that serve fewer than 10,000 people. Like the interim rule, the long-term rule established the following:
 - a. 2- log (99 percent) *Cryptosporidium* removal requirements by PWSs that filter
 - b. Individual filter turbidity monitoring and more stringent combined filter effluent turbidity standards for conventional and direct filtration plants
 - c. Disinfection profiling and benchmarking; inclusion of *Cryptosporidium* in the definition of GWUDI and in the watershed control requirements for unfiltered PWSs
 - d. The requirement that new finished water storage facilities be covered.

5. Filter Backwash Recycle Rule (66 FR 31085, June 2001) requires PWSs to consider the potential risks associated with recycling contaminants removed during the filtration process. The provisions of the filter backwash rule apply to all PWSs that recycle, regardless of population served. In general, the provisions include the following:
 - a. PWSs must return certain recycle streams to a point in the treatment process that is prior to primary coagulant addition unless the State specifies an alternative location
 - b. Direct filtration PWSs recycling to the treatment process must provide detailed recycle treatment information to the State
 - c. Certain conventional PWSs that practice direct recycling must perform a one-month, one-time recycling self-assessment

Introduction to Cryptosporidium

Concern with Cryptosporidium in Drinking Water

EPA is promulgating the Long-Term Surface Water Treatment Rule to reduce the public health risk associated with *Cryptosporidium* in drinking water.

Cryptosporidiosis

(*Cryptosporidium*)

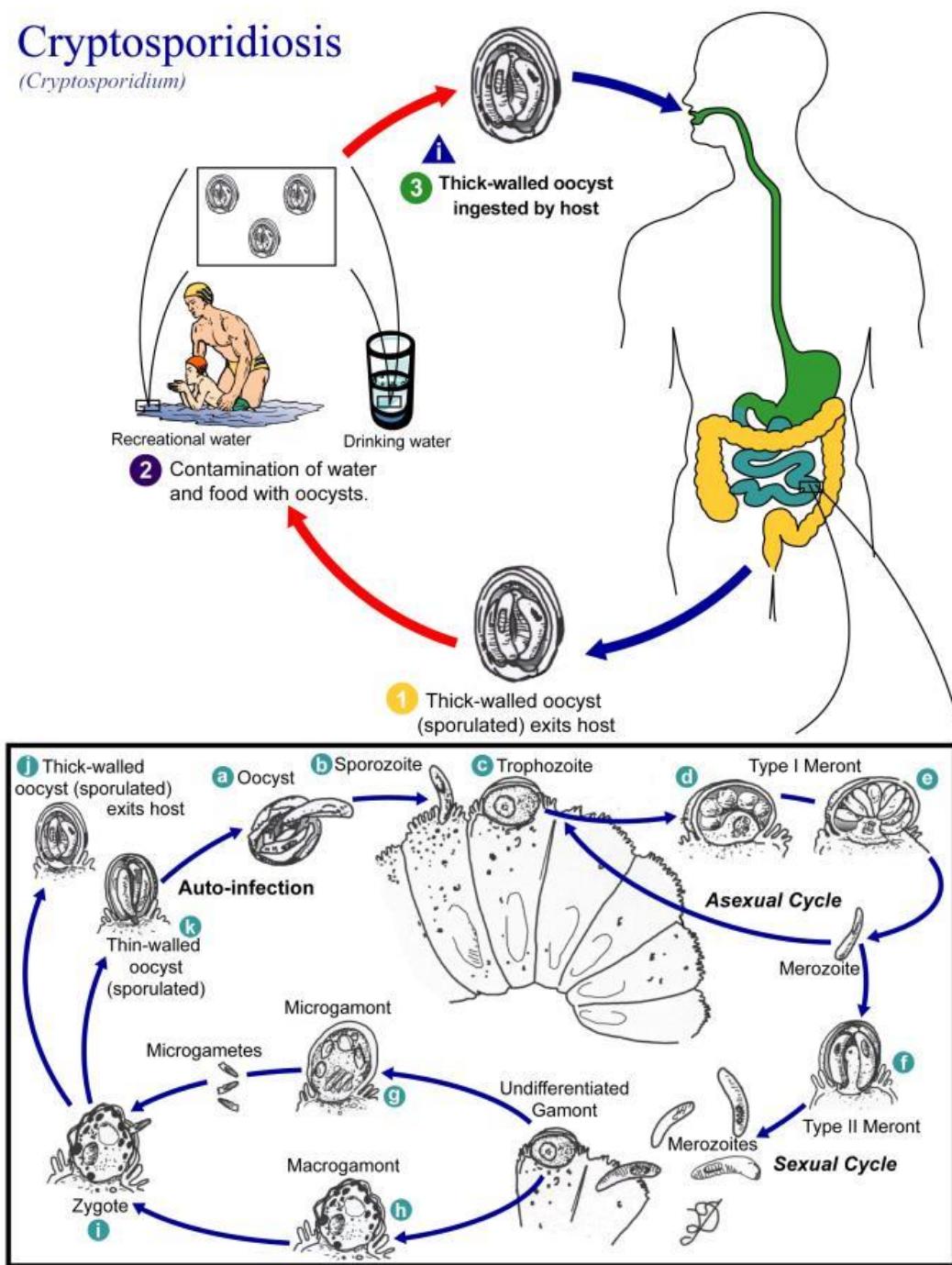


Figure 7.1²⁶

Cryptosporidium is a protozoan parasite that lives and reproduces entirely in one host. Ingestion of *Cryptosporidium* can cause cryptosporidiosis, a gastrointestinal (GI) illness. *Cryptosporidium* is excreted in feces. Transmission of cryptosporidiosis occurs through

²⁶ [Image](#) by the [CDC](#) is in the public domain

consumption of water or food contaminated with feces or by direct or indirect contact with infected persons or animals. In the environment, *Cryptosporidium* is present as a thick-walled oocyst containing four organisms (sporozoites).

The oocyst wall insulates the sporozoites from harsh environmental conditions. Oocysts are 4–5 microns in length and width. Upon a host's ingestion of oocysts, enzymes and chemicals produced by the host's digestive system cause the oocyst to excyst, or break open. The excysted sporozoites embed themselves in the surfaces of the epithelial cells of the lower small intestine. The organisms then begin absorbing nutrients from their host cells. When these organisms sexually reproduce, they produce thick and thin-walled oocysts. The host excretes the thick-walled oocysts in its feces. The thin-walled oocysts excyst within the host and contribute to further host infection.

The exact mechanism by which *Cryptosporidium* causes GI illness is not known. Factors may include damage to intestinal structure and cells, changes in the absorption/secretion processes of the intestine, toxins produced by *Cryptosporidium* or the host, and proteins that allow *Cryptosporidium* to adhere to host cell surfaces. Upon excretion, *Cryptosporidium* oocysts may survive for months in various environmental media, including soil, river water, seawater, and human and cattle feces at ambient temperatures. *Cryptosporidium* can also withstand temperatures as low as 20 °C for periods of a few hours, but they are susceptible to desiccation.

Cryptosporidium is a widespread contaminant in surface water used as drinking water supplies. *Cryptosporidium* contamination can come from animal agriculture, wastewater treatment plant discharges, slaughterhouses, birds, wild animals, and other sources of fecal matter. *Cryptosporidium parvum* (*C. parvum*) has been the primary species of concern to humans.

Cryptosporidium infection is characterized by mild to severe diarrhea, dehydration, stomach cramps, and/or a slight fever. Incubation is thought to range from 2 to 10 days. Symptoms typically last from several days to 2 weeks. In a small percentage of cases, the symptoms may persist for months or longer in healthy individuals. Symptoms may be more severe in immunocompromised persons. Such persons include those with AIDS, cancer patients undergoing chemotherapy, organ transplant recipients treated with drugs that suppress the immune system, and patients with autoimmune disorders.

Cryptosporidium oocysts are highly resistant to standard disinfectants like chlorine and chloramines. Consequently, control of *Cryptosporidium* in most treatment plants is dependent on physical removal processes. However, due to their size (4–5 microns), oocysts can sometimes pass through filters. Monitoring data on finished water show that *Cryptosporidium* is sometimes present in filtered, treated drinking water.

Certain alternative disinfectants can be more effective in treating for *Cryptosporidium*. Ozone and chlorine dioxide have been shown to inactivate *Cryptosporidium* at doses higher than those required to inactivate *Giardia*, which has typically been used to set disinfectant doses. Studies have also demonstrated a synergistic effect of treatment using ozone followed by chlorine or

monochloramine. UV light has recently been shown to achieve high levels of *Cryptosporidium* inactivation at feasible doses. Other processes that can help reduce *Cryptosporidium* levels in finished water include watershed management programs, pretreatment processes like bank filtration, and additional clarification and filtration processes during water treatment. Further, optimizing treatment performance and achieving very low levels of turbidity in the finished water has been shown to improve *Cryptosporidium* removal in treatment plants.

Cryptosporidium has caused a number of waterborne disease outbreaks since 1984 when the first was reported in the United States. Data from the Centers for Disease Control and Prevention include ten outbreaks caused by *Cryptosporidium* in drinking water between 1984 and 2000, with approximately 421,000 cases of illness. The most serious outbreak occurred in 1993 in Milwaukee; an estimated 403,000 people became sick, and at least 50 *Cryptosporidium*-associated deaths occurred among the severely immunocompromised.

A PWS that begins using a new surface water source after the date the PWS is required to conduct source water monitoring under the Long-Term 2 Surface Water Treatment Rule must monitor the new source on a schedule approved by the State. This applies to new plants that begin operation and previously operating plants that bring a new source on-line after the required monitoring date for the PWS. The State may determine that monitoring should be conducted before a new plant or source is brought on-line or initiated within some time period afterward.

The new source monitoring must meet all long-term rule requirements. The PWS must also determine its treatment bin classification and comply with any additional *Cryptosporidium* treatment requirements based on the monitoring results on a schedule approved by the State.

Background and Analysis Monitoring requirements in the rule are designed to ascertain *Cryptosporidium* levels with suitable accuracy for making treatment bin classifications and in a time frame that does not delay the installation of *Cryptosporidium* treatment where needed. A mean *Cryptosporidium* concentration of 0.01 oocysts/L determines whether unfiltered PWSs are required to provide 2 or 3-log *Cryptosporidium* inactivation. No *E. coli* concentration was effective in determining whether PWSs were likely to fall above or below this level. Consequently, the rule requires all unfiltered PWSs to monitor for *Cryptosporidium*, unless they choose to provide 3-log *Cryptosporidium* inactivation.

Sampling location

The requirements in the rule for the source water sample collection location are designed to achieve two objectives:

1. Characterize the influent water to the treatment plant at the time each sample is collected
2. Ensure that samples are not affected by treatment chemicals that could interfere with *Cryptosporidium* analysis.

The first objective is the basis for requiring PWSs that use multiple sources to analyze a blended source sample or calculate a weighted average of sources that reflects the influent at the time of sample collection. It is also the reason that PWSs are required to sample after certain pretreatment processes like bank filtration that do not involve chemical addition.

The second objective is why PWSs are generally required to sample upstream of chemical addition and prior to backwash addition (for PWSs that recycle filter backwash). However, EPA recognizes that in some situations, sampling prior to chemical addition will not be feasible and discontinuing chemical addition for a period of time prior to sampling will not be advisable. This situation could occur when a treatment chemical is added at an intake that is difficult to access. Further, some treatment chemicals may not interfere with *Cryptosporidium* analyses when present at very low levels. Consequently, the rule allows States to approve PWSs sampling after chemical addition when the State determines that collection prior to chemical treatment is not feasible and the treatment chemical is not expected to interfere with the analysis of the sample. EPA believes that States should review source water monitoring locations for their PWSs.

Sampling Schedule

The requirement will help to ensure that monitoring determines the mean concentration of *Cryptosporidium* in the treatment plant influent. To achieve this objective, the timing of sample collection must not be adjusted in response to fluctuations in water quality, such as the avoidance of sampling when the influent water is expected to be of poor quality. EPA believes that the 5-day window for sample collection and associated allowances for sampling outside this window provide sufficient flexibility. If circumstances arise that prevent the PWS from sampling within the scheduled 5-day window, such as a weather event or plant emergency, the PWS must collect a sample as soon as feasible. In this case, feasibility includes the ability of the PWS to safely collect a sample and the availability of an approved laboratory to conduct the analysis within method specifications. In addition, the rule allows States to authorize a different date for collecting the delayed sample.

Failing to Monitor

For most monitoring and testing procedure violations under the Long-Term Rule 2, PWSs must provide a Tier 3 public notification, which is standard for this type of violation under an NPDWR. However, if a PWS fails to collect three or more *Cryptosporidium* samples, the violation is elevated to a Tier 2 special public notice. The reason for elevating the public notice at this point is the persistence of the violation and the difficulty the PWS will have in collecting the required number of samples for bin classification by the compliance date. The rule requires bin classification within six months following the end of the monitoring period specified for the PWS. This six-month period provides some opportunity for collecting and analyzing missed samples. The number of samples that can be made up in this period is limited, though, due to the need for samples to be evenly distributed throughout the year, as well as for PWSs and States to spend time during this period evaluating monitoring results to determine bin classification.

Failure by a PWS to collect the required number of *Cryptosporidium* samples for bin classification by the compliance date is a treatment technique violation with a required Tier 2 public notice. This violation reflects the inability of the PWS to determine and comply with its *Cryptosporidium* treatment requirements under the rule and provide the appropriate level of public health protection. The violation ends when the State determines that the PWS is carrying out a monitoring plan that will lead to bin classification.

A PWS that has already provided a Tier 2 public notice for missing three sampling dates and is successfully meeting a State-approved sampling schedule is not required to issue another public notice for missing the bin classification date. Alternatively, the PWS can choose to provide the highest level of *Cryptosporidium* treatment required under the rule, which is 5.5-log for filtered PWSs and 3-log for unfiltered PWSs.

Requirements for grandfathering previously collected monitoring data in the rule based on the principle that to be eligible for grandfathering, previously collected data must be equivalent in quality to data that will be collected under the rule.

The Stage 2 M-DBP Advisory Committee recommended that EPA accept previously collected *Cryptosporidium* data that are equivalent in sample number, frequency, and data quality (volume analyzed, percent recovery) to data that would be collected under the long-term rule to determine bin classification in lieu of further monitoring.

Ongoing watershed assessment treatment requirements under the rule are based on source water quality. Consequently, the rule requires watershed assessment and, a second round of monitoring following initial bin classification to determine if source water quality has changed to the degree that the treatment level should be modified. States are allowed to use programs other than the sanitary survey to assess changes in the watershed. The rule leverages the existing requirement for States to perform sanitary surveys on surface water PWSs. During the source water review in the sanitary survey, the rule requires States to determine if significant changes have occurred in the watershed that could lead to increased contamination by *Cryptosporidium*. The State can also choose to make this determination through an equivalent review of the source water under a program other than the sanitary survey, such as a Source Water Protection Assessment. If the State determines that significant changes have occurred, the State may specify that the PWS conduct additional source water monitoring or treat the potential contamination. This approach allows the PWS and State to respond to a significant change in source water quality prior to initiating a second round of monitoring or any time thereafter.

Second Round of Monitoring

A more rigorous reassessment of the source water occurs through a second round of monitoring that begins six years after initial bin classification. If EPA does not develop and finalize modifications to the rule prior to the date when PWSs must begin the second round of monitoring, then this second round must conform to the same requirements that applied to the

initial round of monitoring. PWSs may be classified in a different treatment bin, depending on the results of the second round of monitoring.

Process Summary

Source water monitoring to determine additional treatment requirements for *Cryptosporidium*

1. Sampling parameters and frequency, sampling location, sampling schedule, monitoring plants that operate only part-year, failing to monitor, providing treatment instead of monitoring, grandfathering previously collected data, ongoing source water assessment, second round of monitoring, and new source monitoring.

The Rule requires filtered PWSs using surface water or GWUDI sources to provide greater levels of treatment if their source waters have higher concentrations of *Cryptosporidium*. Filtered PWSs are classified in one of four treatment bins based on results from the source water monitoring. PWSs classified in the lowest concentration bin are subject to no additional treatment requirements, while PWSs assigned to higher concentration bins must reduce *Cryptosporidium* levels. All PWSs must continue to comply with the requirements of the SWTR, IESWTR, and LT1ESWTR, as applicable. This section addresses procedures for classifying filtered PWSs in *Cryptosporidium* treatment bins and the treatment requirements associated with each bin. Microbial toolbox that PWSs must use to meet additional *Cryptosporidium* treatment requirements.

- Bin classification—after completing initial source water monitoring, filtered PWSs must calculate a *Cryptosporidium* bin concentration for each treatment plant where *Cryptosporidium* monitoring is required. This *Cryptosporidium* bin concentration is used to classify filtration plants in one of the four treatment bins.

In general, the *Cryptosporidium* bin concentration is calculated by averaging individual sample results from one or more years of monitoring. Specific procedures vary, however, depending on the frequency and duration of monitoring. These procedures are as follows:

- a. For PWSs that collect a total of at least 24 but not more than 47 *Cryptosporidium* samples over two or more years, the *Cryptosporidium* bin concentration is equal to the highest arithmetic mean of all sample concentrations in any 12 consecutive months of *Cryptosporidium* monitoring.
- b. For PWSs that collect a total of at least 48 samples, the *Cryptosporidium* bin concentration is equal to the arithmetic mean of all sample concentrations.
- c. For PWSs that serve fewer than 10,000 people and monitor for *Cryptosporidium* for only one year (collect 24 samples in 12 months), the *Cryptosporidium* bin concentration is equal to the arithmetic mean of all sample concentrations.
- d. For PWSs with plants that operate only part-year that monitor for less than 12 months per year, the *Cryptosporidium* bin concentration is equal to the highest arithmetic mean of all sample concentrations during any year of *Cryptosporidium* monitoring.

In data sets with variable sampling frequency, PWSs must first calculate an arithmetic mean for each month of sampling and then apply one of these four procedures using the monthly mean concentrations. PWSs may grandfather previously collected *Cryptosporidium* data where the sampling frequency varies (one year of monthly sampling and one year of twice-per-month sampling). Filtered PWSs serving fewer than 10,000 people are not required to monitor for *Cryptosporidium* if they demonstrate a mean *E. coli* concentration less than or equal to 10/ 100 mL for lake/reservoir sources or 50/ 100 mL for flowing stream sources or do not exceed an alternative State-approved indicator trigger. PWSs that meet this criterion are classified in Bin 1.

When determining the *Cryptosporidium* bin concentration, PWSs must calculate individual sample concentrations as the total number of oocysts counted, divided by the volume as saved. In samples where no oocysts are detected, the result is assigned a value of zero for the purpose of calculating the bin concentration. Sample analysis results are not adjusted for analytical method recovery or the percent of *Cryptosporidium* oocysts that are infectious. PWSs must report their treatment bin classification to the State for approval following initial source water monitoring. The report must include a summary of the data and calculation procedure used to determine the bin concentration. PWSs must recalculate their bin classification after completing the second round of monitoring and report the results to the State for approval. If the State does not respond to a PWS regarding its bin classification after either report, the PWS must comply with the *Cryptosporidium* treatment requirements of the rule based on the reported bin classification.

- Bin treatment requirements. All filtered PWSs must comply with the treatment requirements based on their bin classification.

The total *Cryptosporidium* treatment required for plants in Bins 2, 3, and 4 is 4.0-log, 5.0-log, and 5.5-log, respectively. Conventional treatment (including softening), slow sand, and diatomaceous earth filtration plants in compliance with the IESWTR or LT1ESWTR, as applicable, receive a prescribed 3.0-log *Cryptosporidium* treatment credit toward these total bin treatment requirements. Accordingly, these plant types must provide 1.0 to 2.5-log of additional treatment when classified in Bins 2–4, respectively. Direct filtration plants in compliance with existing regulations receive a prescribed 2.5-log treatment credit and, consequently, must achieve 0.5-log greater treatment to comply with Bins 2–4.

For PWSs using alternative filtration technologies, such as membranes, bag filters, or cartridge filters, no prescribed treatment credit is available because the performance of these processes is specific to individual products. Consequently, when PWSs using these processes are classified in Bins 2–4, the State must determine additional treatment requirements based on the credit the State awards to a particular technology. The additional treatment requirements must ensure that plants classified in Bins 2–4 achieve total *Cryptosporidium* reductions of 4.0- to 5.5-log, respectively. PWSs can achieve additional *Cryptosporidium* treatment credit through implementing pretreatment processes like pre-sedimentation or bank filtration, by developing a watershed control program, and by applying additional treatment steps like ozone, chlorine dioxide, UV, and membranes. In addition, PWSs can receive a higher level of credit for existing

treatment processes through achieving very low filter effluent turbidity or through a demonstration of performance.

A combination of options from the microbial toolbox can be used to gather additional credit. PWSs in Bin 2 can meet additional *Cryptosporidium* treatment requirements by using any option or combination of options from the microbial toolbox. For Bins 3 and 4, PWSs must achieve at least 1-log of the additional treatment requirement by using ozone, chlorine dioxide, UV, membranes, bag filtration, cartridge filtration, or bank filtration.

- The rule increases protection against *Cryptosporidium* and other pathogens in PWSs with the highest source water contamination levels. This targeted approach builds upon existing regulations under which all filtered PWSs must provide the same level of treatment regardless of source water quality. The rule is to ensure that PWSs with higher risk source waters achieve public health protection commensurate with PWSs with less contaminated sources.

The rule establishes risk-targeted *Cryptosporidium* treatment requirements and sets specific bin concentration ranges and treatment requirements that apply to filtered PWSs. The IESWTR established a *Cryptosporidium* MCLG of zero and requires large filtered PWSs to achieve 2-log *Cryptosporidium* removal. The LT1ESWTR extended this requirement to small PWSs. After these rules were promulgated, advances were made in analytical methods and treatment for *Cryptosporidium*, and EPA collected new information on *Cryptosporidium* occurrence and infectivity. Consequently, EPA assessed the implications of these developments for further controlling *Cryptosporidium* to approach the zero MCLG. The risk-targeted approach for filtered PWSs in the rule stems from four general findings based on new information on *Cryptosporidium*:

1. New data on *Cryptosporidium* infectivity suggest that the risk associated with a particular level of *Cryptosporidium* is most likely higher than EPA estimated at the time of earlier rules
2. New data on *Cryptosporidium* occurrence indicate that levels are relatively low in most water sources, but a subset of sources has substantially higher concentrations
3. The finding that UV light can readily inactivate *Cryptosporidium*, as well as other technology developments, makes achieving high levels of treatment for *Cryptosporidium* feasible for PWSs of all sizes
4. EPA Methods 1622 and 1623 are capable of assessing annual mean levels of *Cryptosporidium* in drinking water sources.

These findings led EPA to conclude that most filtered PWSs currently provide sufficient treatment for *Cryptosporidium*, but additional treatment is needed in those PWSs with the highest source water *Cryptosporidium* levels to protect public health. Further, PWSs can characterize *Cryptosporidium* levels in their source waters with available analytical methods and can provide higher levels of treatment with available technologies. Consequently, risk-targeted treatment requirements for *Cryptosporidium* based on source water contamination levels are appropriate and feasible to implement.

Basis for bin concentration ranges and treatment requirements. To establish the risk-targeted treatment requirements in today's rule, EPA had to determine the degree of treatment that should be required for different source water *Cryptosporidium* levels to protect public health. This determination involved addressing several questions:

1. What is the risk associated with *Cryptosporidium* in a drinking water source?
2. How much *Cryptosporidium* removal do filtration plants achieve?
3. What is the appropriate statistical measure for classifying PWSs into treatment bins?
4. What degree of additional treatment is needed for higher source water *Cryptosporidium* levels?
5. How should PWSs calculate their treatment bin classification?

The risk of infection from *Cryptosporidium* in drinking water is a function of exposure (the dose of oocysts ingested) and infectivity (likelihood of infection as a function of ingested dose). Primary (direct) exposure to *Cryptosporidium* depends on the concentration of oocysts in the source water, the fraction removed by the treatment plant, and the volume of water consumed (secondary exposure occurs through interactions with infected individuals). Thus, the daily risk of infection (DR) is as follows:

$DR = (\text{oocysts/L in source water}) \times (\text{fraction remaining after treatment}) \times (\text{liters consumed per day}) \times (\text{likelihood of infection per oocyst dose})$. Assuming 350 days of consumption per year for people served by community water systems (CWSs), the annual risk (AR) of infection is as follows: $AR = 1 \times (1 \times DR) \times 350$.

EPA has estimated the mean likelihood of infection from ingesting one *Cryptosporidium* oocyst to range from 4 to 16 percent. Median individual daily water consumption is estimated as 1.07 L/day.

Key Terms

- ***Cryptosporidium*** - a protozoan parasite that lives and reproduces entirely in one host; ingestion of *Cryptosporidium* can cause cryptosporidiosis, a gastrointestinal (GI) illness; *cryptosporidium* is excreted in feces.
- **Ground Water Rule (GWR)** – the purpose is to improve drinking water quality and provide protection from disease-causing microorganisms; water systems that have groundwater sources may be susceptible to fecal contamination; applies to public water systems that use ground water as a source of drinking water
- **Surface Water Treatment Rules (SWTRs)** – the purpose is to reduce illnesses caused by pathogens in drinking water, including *Legionella*, *Giardia lamblia*, and *Cryptosporidium*; the SWTRs requires water systems to filter and disinfect surface water sources.
- **Total Coliform Rule (TCR)** - a National Primary Drinking Water Regulation (NPDWR), published in 1989 and became effective in 1990; sets a health goal (Maximum Contaminant Level Goal (MCLG)) and legal limits (Maximum Contaminant Levels, MCLs)) for the presence of total coliforms in drinking water

REVIEW QUESTIONS

1. What are the primary components of the Total Coliform Rule?

2. What is the basis of the Total Coliform Rule?

3. What is the primary requirement in the Groundwater Rule?

4. List four EAP approved laboratory methods for testing for coliforms.

5. What are the major provisions of the Long-Term Surface Water Treatment Rule?

CHAPTER QUIZ

1. Total coliforms are used as a(n) _____ of the possible presence of pathogens in drinking water. Total coliforms are used to determine the adequacy of water treatment and the integrity of the distribution system.
 - a. indicator
 - b. model
 - c. log removal
 - d. alternative
2. The Revised Total Coliform Rule establishes _____ for E. coli and uses E. coli and total coliforms to initiate a find and fix approach to address fecal contamination that could enter into the distribution system.
 - a. a log removal
 - b. a maximum contaminant level (MCL)
 - c. a secondary maximum contaminant level (SMCL)
 - d. a model
3. Within 24 hours of learning of a Total Coliform positive routine sample result, at least _____ repeat samples must be collected and analyzed for total coliform.
 - a. 1
 - b. 2
 - c. 3
 - d. 4
4. States are required to conduct _____ of all groundwater systems in order to identify significant deficiencies, including deficiencies which may make a system susceptible to microbial contamination.
 - a. hydrologic studies
 - b. microbial examinations
 - c. a sanitary survey
 - d. laboratory studies

5. The Surface Water Treatment Rule requires water systems to _____ surface water sources.
- filter and disinfect
 - conserve
 - aerate
 - disinfect
6. In order not to be subject to triggered source water monitoring under the Groundwater Rule, a groundwater system can notify the state that it provides at least _____ treatment of viruses using virus inactivation, or removal, before or at the first customer.
- 2-log
 - 3-log
 - 4-log
 - 6-log
7. The Long-Term Surface Water Rule establishes risk-targeted treatment technique requirements to control _____ in PWSs using surface water or groundwater under the influence of surface water.
- E.coli*
 - Giardiasis lamblia*
 - Cryptosporidium*
 - Coliforms
8. What is the maximum allowable turbidity in the combined filter effluent?
- 0.5 NTU
 - 1.0 NTU
 - 3.0 NTU
 - 5.0 NTU
9. EPA promulgated the Long-Term Surface Water Treatment Rule to reduce the public health risk associated with _____ in drinking water.
- Giardiasis lamblia*
 - Cryptosporidium*
 - Coliforms
 - E. coli*

10. _____ is a protozoan parasite that lives and reproduces entirely in one host,

- a. *E. coli*
- b. Coliforms
- c. *Cryptosporidium*
- d. Fecal streptococcus

CHAPTER 8: TOTAL COLIFORM RULE

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Describe biofilms
- Explain common microbiological techniques
- Outline and describe coliform bacterial analysis

BIOFILMS

In nature, microorganisms do not typically live in isolation. They live in communities called **biofilms**. Today, using confocal microscopy, three-dimensional structures of biofilms are visible. Biofilms reside in a matrix called slime.

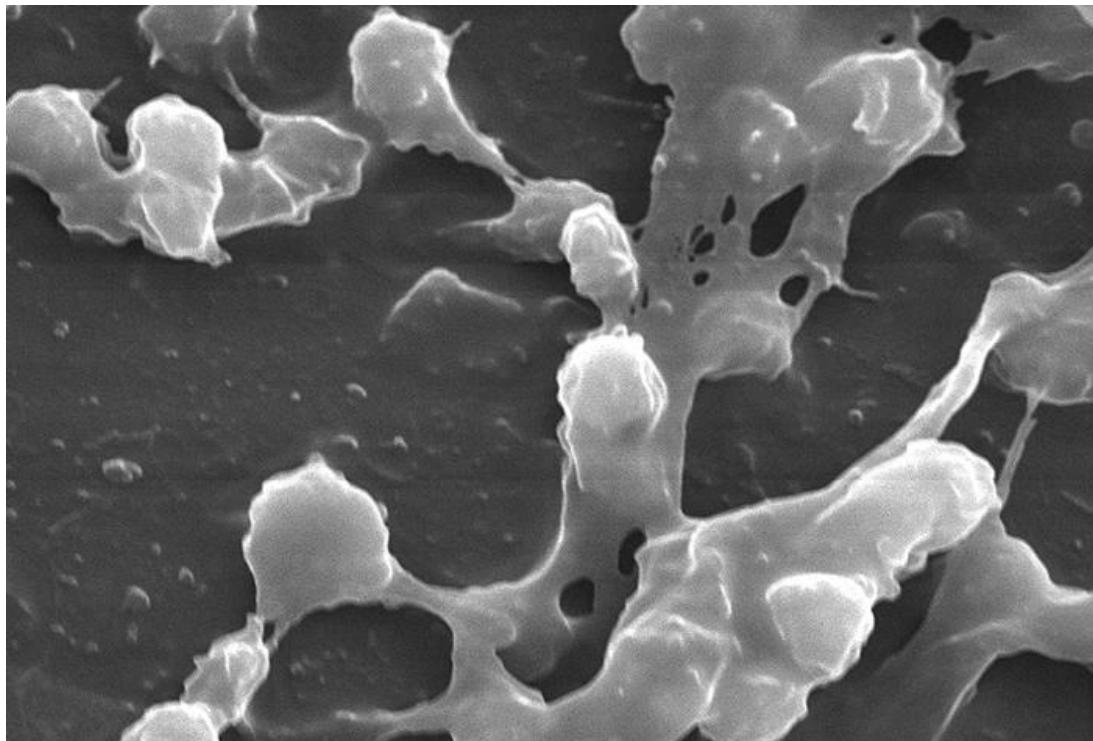


Figure 8.1²⁷

A biofilm is considered to be a hydrogel, which is a complex polymer containing many times its dry weight in water. Cell-to-cell chemical communication allows bacteria to coordinate their activities and to group together into communities that provide benefits like a multicellular organism. Biofilms are bacterial slime layers and biological systems. The bacteria are organized

²⁷ [Image](#) by [CDC](#) is in the public domain

into a coordinated functional community. Biofilms are attached to surfaces. The bacterial community may be a single species or a diverse group of microorganisms.

Biofilms can appear in different forms. An example would be the floc that forms in sewage treatment facilities. In fast-flowing streams, biofilms can form filamentous streamers. Within a biofilm community, the bacteria are able to share nutrients and be sheltered from harmful factors in the environment. The close proximity of microorganisms within a biofilm have the advantage of facilitating the transfer of genetic information.

CULTURE MEDIA

A nutrient material prepared for the growth of microorganisms in a laboratory is called a **culture medium**. Some bacteria can grow well on any culture medium, and other bacteria require special media. Other bacterial cannot grow on any nonliving medium. Microbes that are introduced into a culture medium to initiate growth are called an **inoculum**. The microbes that grow and multiply in or on a culture medium are referred to as a **culture**.

A wide variety of media are available for the growth of microorganisms in the laboratory. These media have premixed components and require only the addition of water and then sterilization. Media are constantly being developed or revised for use in the isolation and identification of bacteria that are of interest to researchers in such fields as food, water, and clinical microbiology.

When it is desirable to grow bacteria on a solid medium, a solidifying agent such as agar is added to the medium. Agar has long been used as a thickener in foods such as jellies and ice cream.

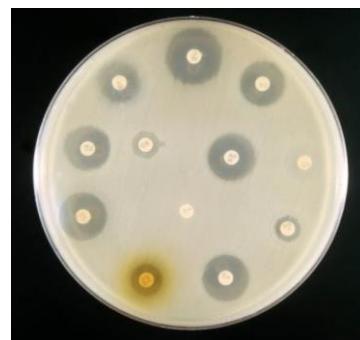
Agar media are contained in test tubes or Petri dishes, shallow dishes with a lid that nests over the bottom to prevent contamination. When the dish is filled, it is called petri plates.



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Figure 8.2: Petri dishes

Chemically Defined Medium

To support microbial growth, the media provide energy sources, as well as sources of carbon, nitrogen, sulfur, phosphorus, and any organic growth factors that the organism is unable to synthesize. A chemically defined media is where the exact chemical composition of the media is known.

Complex Media

Chemically defined media are usually reserved for laboratory experimental activities or for the growth of autotrophic bacteria. Most heterotrophic bacteria and fungi are grown on complex media made up of nutrients including extracts from yeasts, meat, or plants, or digests of proteins from these sources. The exact chemical composition varies slightly from batch to batch.

In complex media, the energy, carbon, nitrogen, and sulfur requirements of the growing microorganisms are provided by protein. Protein is a large, insoluble molecule that a minority of microorganism can utilize directly; however, a partial digestion of the proteins by acids or enzymes reduces protein to shorter chains of amino acids called peptones. These small soluble fragments can be digested by bacteria.

Vitamins and other organic growth factors are provided by meat extracts or yeast extracts. The soluble vitamins and minerals from the meats or yeasts are dissolved in the extracting water which is evaporated so that the factors are concentrated. If a complex media is in liquid form, it is called nutrient broth. When agar is added, it is called nutrient agar.

Anaerobic Growth Media and Methods

The cultivation of anaerobic bacteria poses a special problem. Because anaerobes can be killed by exposure to oxygen, special media called reducing media must be used. These media contain ingredients, such as sodium thioglycolate, that chemically combine with dissolved oxygen and deplete the oxygen in the culture medium. To routinely grow and maintain pure cultures of obligate anaerobes, microbiologists use reducing media stored in ordinary, tightly capped test tubes.

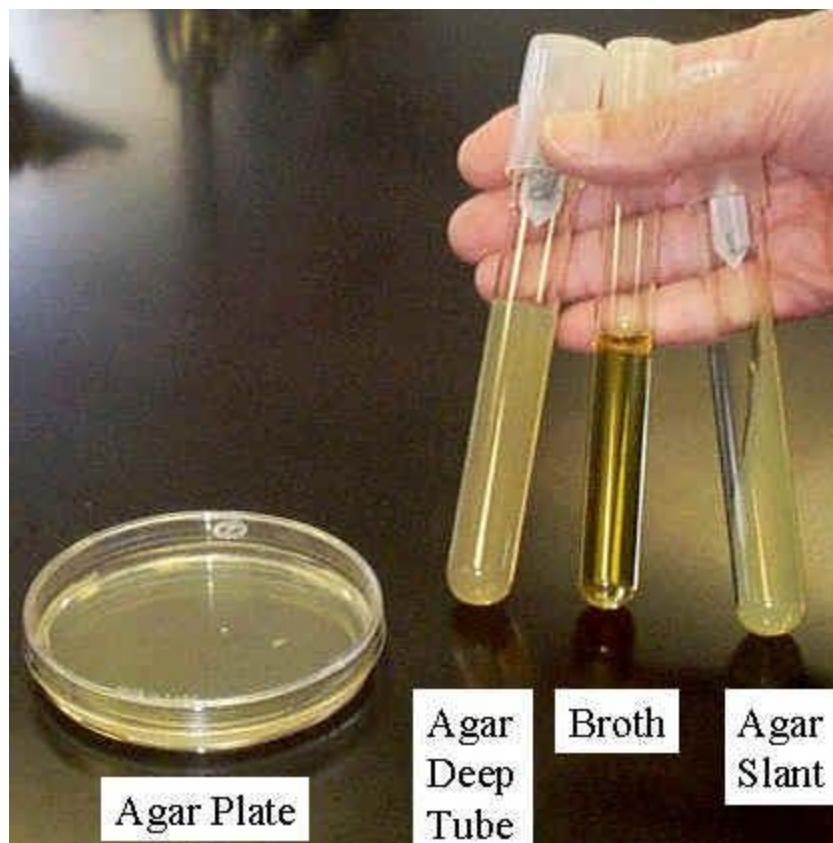


Figure 8.3: Nutrient Broth²⁸

Special Culture Techniques

Many bacteria have not been successfully grown on artificial laboratory media. *Mycobacterium leprae*, the leprosy bacillus, is grown in armadillos, which have a relatively low body temperature that matches the requirements of the microbe. Humans and armadillos are the only natural hosts for this bacillus. With few exceptions, the obligate intracellular bacteria, such as rickettsia and chlamydia, do not grow on artificial media. Viruses can only reproduce in a living host cell, as well. Special techniques are employed to isolate these types of organisms.

Pure Cultures

Most samples include several different kinds of bacteria. If these samples are plated onto the surface of a solid medium, colonies will form that are exact copies of the original organism. A visible colony theoretically is derived from a single spore or vegetative cell or from a group of the same microorganisms attached to one another in clumps or chains. Microbial colonies often have a distinctive appearance that distinguishes one microbe from another species. The bacteria must be distributed widely enough on the plate so that the colonies are visibly separated from other microbial species.

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Figure 8.4: Streak plate pure cultures²⁹

Most investigations of microbes require a pure culture, or clones of bacteria. The isolation method used to achieve pure cultures is the **streak plate method**. A sterile inoculating loop is dipped into a mixed culture that contains more than one type of microbe, and it is streaked in a pattern over the surface of the nutrient medium. As the pattern is traced, bacteria are rubbed off the loop onto the medium. The last cells to be rubbed off the loop are far enough apart to grow into isolated colonies. These colonies can be picked up with an inoculating loop and transferred to a test tube for nutrient medium to form a pure culture containing only one type of bacteria.

Streak plate methods work well when the organism to isolate presents in a large number relative to the total population. When the microbe to be isolated is present in small numbers, its numbers must be increased by selective enrichment before it can be isolated with the streak plate method.

COLIFORM BACTERIAL ANALYSIS

Municipal sewage contains human feces and water contaminated with these effluents may contain pathogenic (disease-causing) organisms and, consequently, may be hazardous to human health if used as drinking-water or in food preparation. Fecal contamination of water is routinely detected by microbiological analysis.

It is impractical to attempt the routine isolation of pathogens because they are present in relatively small numbers compared with other types of microorganism. Moreover, many types of pathogens exist, and each organism requires a unique microbiological isolation technique. The approach that has been adopted is to analyze samples for indicator organisms that inhabit

²⁹ [Image](#) by Bill Branson is in the public domain

the gut and are excreted in human feces. The presence of these indicator organisms in water is evidence that fecal contamination is present, and a risk exists that pathogens are present.

If indicator organisms are present in large numbers, the contamination is considered to be recent and/or severe. Bacteria in water are, in general, not present individually, but as clumps or in association with particulate matter. When enumerating bacteria in water it is not the number of individual bacteria present which are counted, but the number of clumps of bacteria or the particles and their associated bacteria. Each clump or particle may have many bacteria associated with it.

Total Coliforms

The term **total coliforms** refer to a large group of Gram-negative, rod-shaped bacteria that share several characteristics. The group includes heat-tolerant coliforms and bacteria of fecal origin, as well as some bacteria that may be isolated from environmental sources. The presence of total coliforms may or may not indicate fecal contamination. In extreme cases, a high count for the total coliform group may be associated with a low, or zero, count for thermos-tolerant coliforms. A result of this nature would not necessarily indicate the presence of fecal contamination. It might be caused by entry of soil or organic matter into the water or by conditions suitable for the growth of other types of coliform. In the laboratory total coliforms are grown in or on a medium containing lactose, at a temperature of 35 or 37 °C. They are provisionally identified by the production of acid and gas from the fermentation of lactose.

The term fecal coliform has been used in water microbiology to denote coliform organisms which grow at 44 or 44.5 C and ferment lactose to produce acid and gas. In practice, some organisms with these characteristics may not be of fecal origin and the term thermos-tolerant coliform is, therefore, more correct and is becoming more commonly used. Nevertheless, the presence of thermos-tolerant coliforms nearly always indicates fecal contamination.

Usually, more than 95 percent of thermos-tolerant coliforms isolated from water are the gut organism *Escherichia coli*, the presence of which is definitive proof of fecal contamination. As a result, it is often unnecessary to undertake further testing to confirm the specific presence of *E. coli*.

The presence of fecal streptococci is evidence of fecal contamination. Fecal streptococci tend to persist longer in the environment than thermos-tolerant or total coliforms and are highly resistant to drying. It is, therefore, possible to isolate fecal streptococci from water that contains few or no thermos-tolerant coliforms as, for example, when the source of contamination is distant in time or space from the sampling point. Fecal streptococci grow in or on a medium containing sodium azide, at a temperature of 37-44 °C. They are usually detected by the reduction of a dye (a tetrazolium-containing compound) or the hydrolysis of aesculin. Routine methods may give false positives and additional confirmatory tests may be required.

Key Terms

- **biofilm** – three-dimensional structures that create a matrix referred to commonly as a slime
- **culture** – the microbes that grow or multiply in or on a culture medium
- **culture medium** – a nutrient material prepared for the growth of microorganisms in a laboratory
- **inoculum** – microbes introduced into a culture medium to initiate growth
- **streak plate method** – an isolation method to achieve pure cultures by streaking a pattern over a surface of nutrient medium
- **total coliform** – a large group of Gram-negative, rod-shaped bacteria that share several characteristic and include heat-tolerant coliforms and bacteria of fecal origin, as well as some bacteria that may be isolated from environmental sources

REVIEW QUESTIONS

1. Describe a biofilm. Give two examples.
 2. What does the term “coliforms” refer to? How are “coliforms” different than “fecal coliform”?
 3. What is a culture medium?

CHAPTER QUIZ

1. A nutrient material prepared for the growth of microorganisms in a laboratory is called a _____.
 - a. enrichment medium
 - b. culture medium
 - c. selective media
 - d. complex media
2. Most investigations of microbes require a pure culture, or clones of bacteria. The isolation method used to achieve pure cultures is the _____.
 - a. selective selection
 - b. streak plate method
 - c. inoculation method
 - d. defined medium method
3. The term _____ refer(s) to a large group of Gram-negative, rod-shaped bacteria that share several characteristics. The group includes heats-tolerant bacteria of fecal origin.
 - a. virus
 - b. protozoan
 - c. parasite
 - d. total coliforms
4. _____ assume that each bacterium, clump of bacteria, or particle with bacteria attached, will give rise to a single visible colony. Each clump or particle is, therefore, a colony forming unit (cfu) and the results are expressed as colony forming units per unit volume.
 - a. Multiple Fermentation Tube Technique
 - b. Membrane Filter Technique
 - c. Heterotrophic Plate Count
 - d. Sabouraud
5. _____ count includes microorganisms that are capable of growing in or on a nutrient-rich solid agar medium.
 - a. Multiple Fermentation Tube Technique
 - b. Membrane Filter Technique
 - c. Heterotrophic Plate Count
 - d. Sabouraud

6. More than 95-percent of thermos-tolerant coliforms isolated from water are the gut organism, _____, the presence of which is definitive proof of fecal contamination.
- a. Streptococcus
 - b. *E. coli*
 - c. Staphylococcus
 - d. Bacteroides

CHAPTER 9: PRIMARY STANDARDS

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Define primary standards
- Describe the primary metal contaminants
- Describe the primary organic contaminants
- Describe the primary synthetic organic contaminants
- Describe sampling guidelines
- Describe the Radiologic Rule
- Describe the Total Coliform Rule

FEDERAL (ENVIRONMENTAL PROTECTION AGENCY, EPA)

The process by which EPA sets drinking water standards is long and complicated. It involves deciding which contaminants may endanger public health, conducting studies of the effects of these contaminants, defining the maximum safe level of each contaminant, estimating the costs and benefits of regulation, proposing a standard or limit, listening to and evaluating public reactions to the proposed standard, revising the standard (if needed), proposing the standard in final form, seeking and evaluating additional public input, and finally, publishing the standard. The **primary standards** are referred to as the Maximum Contaminant Level (MCL). When the level of a contaminant is above the MCL, it is considered to be a health hazard. MCLs are enforceable by law.

The entire process by which a standard is proposed and promulgated is governed by strict procedural guidelines. It often takes three or more years to produce a standard.

Types of Contaminants

Five types of primary contaminants are considered to be of public health importance:

1. **Inorganic contaminants**, such as lead and mercury;
2. **Organic contaminants**, which include pesticides, herbicides, THMs, solvents, and other synthetic organic compounds;
3. **Turbidity**, such as small particles suspended in water that interfere with light penetration and disinfection;
4. **Microbial contaminants**, such as bacteria, viruses, and protozoa; and
5. **Radiologic contaminants**, which include natural and manmade sources of radiation.

Identifying Contaminants to Be Regulated

The 1986 Safe Drinking Water Act (SDWA) required EPA to establish a priority list of contaminants that may have adverse health effects and may require regulation. The 1996 SDWA amendments retained the list of 83 contaminants developed earlier but revised the process by which contaminants are selected for regulation. Before selecting a contaminant for regulation, the EPA must now consult with the scientific community, solicit public comments, and demonstrate that the contaminant actually occurs in public water systems. For this latter purpose, the 1996 amendments required EPA to establish an occurrence database by August 1999. The database contains information concerning regulated and unregulated contaminants and the information is available to the public.

To regulate a substance, EPA must demonstrate that the contaminant meets three criteria:

1. The contaminant has an adverse effect on human health;
2. It occurs, or is likely to occur, in public water systems at a frequency and concentration of significance to public health; and
3. Regulation of the contaminant offers a meaningful opportunity to reduce health risks for people served by public water systems.

In addition to meeting these three criteria, EPA must also weigh the relative health risks of various contaminants being considered for regulation, the risk reduction that regulation would accomplish, and the costs of implementing the regulations.

Working on a 5-year cycle, the EPA is required to select at least five contaminants from its Drinking Water Contaminant Candidate List (DWCL) and decide whether there sufficient reason exists to regulate them. The first DWCL included 50 chemicals and 10 microbial contaminants. In June 2002, the EPA announced a preliminary finding that their research revealed no need to regulate ten of the listed contaminants. Based on public comments and continued research and evaluation, EPA will make a final determination about regulating any of these contaminants and will begin to develop proposed regulations as necessary.

Unregulated Contaminants

EPA uses the Unregulated Contaminant Monitoring (UCM) program to collect data for contaminants suspected to be present in drinking water, although they do not have health-based standards set under the SDWA. Every 5 years, EPA reviews the list of contaminants, largely based on the Contaminant Candidate List.

The SDWA Amendments of 1996 provide for the following:

- Monitoring no more than 30 contaminants per 5-year cycle
- Monitoring only a representative sample of public water systems
- serving fewer than 10,000 people
- Storing analytical results in a National Contaminant Occurrence Database (NCOD)

The UCM program has progressed in several stages. Currently, EPA manages the program directly as specified in the Unregulated Contaminant Monitoring Regulation (UCMR). EPA has established a timeline and plans for monitoring unregulated contaminants through 2015.

Under the UCMR, community water systems and non-transient non-community water systems serving more than 10,000 people are required to monitor for unregulated contaminants; smaller systems may also have to conduct monitoring if required by the state. Transient water systems are not affected by the UCMR.

Always keep in mind that EPA's regulatory process is basically just a process. No list is permanent; regulations change frequently as new information becomes available. Water treatment plant operators must continually seek opportunities to learn about the regulations that affect the water industry. Also, operators should feel free to express their concerns regarding the regulations and the regulatory process to EPA.

PRIMARY STANDARDS

Inorganic chemicals are metals, salts, and other chemical compounds that do not contain carbon. The health concerns about inorganic chemicals are not centered on cancer, but rather on their suspected links to several different human disorders. For example, lead is suspected of contributing to mental retardation in children. Waters exceeding the MCL for these elements for short periods of time will pose no immediate threat to health. However, studies show that these substances must be controlled because consumption of drinking water that exceeds these standards over long periods of time may prove harmful.

Antimony

In the Code of Federal Regulations Reference: 40 CFR 721.1930, antimony is used in the production of ceramics, glassware, and pigments. The major sources of antimony in drinking water are discharged from petroleum refineries, fire retardants, ceramics, electronics, and solder. Most exposures to antimony occur in industrial settings where workers may inhale dust containing particles of the metal.

Purpose of Regulating Antimony: To improve public health protection by reducing exposure to the amount of antimony in drinking water.

Public Health Benefit: Some people who drink water containing antimony well in excess of the MCL for many years could experience increases in blood cholesterol and decreases in blood sugar. Ingestion of antimony can alter cholesterol and glucose levels and may cause chromosome damage.

MCL/MCLG: 0.006 mg/L/0.006 mg/L

Monitoring Requirements: Once a year for surface water; once every 3 years for groundwater. To minimize monitoring costs, use historical data, waivers, susceptibility waivers, or make composite samples.

Arsenic

In the Code of Federal Regulations Reference: 40 CFR 141 Subpart B. arsenic occurs naturally in the environment, especially in the western United States, and it is used in insecticides. Arsenic is found in foods, tobacco, shellfish, drinking water, and in the air in some locations. Anyone who drinks water that continuously exceeds the national standard by a substantial amount over a lifetime may experience fatigue and loss of energy. Extremely high levels of arsenic can cause poisoning.

The regulation of arsenic has been vigorously debated. In 1997, EPA released a health effects study plan. Under this plan, EPA worked with the Water Research Foundation (WRF) and the Association of California Water Agencies to assess the health risks from exposure to low levels of arsenic. Based on the results of these studies, EPA proposed an MCL for arsenic in June 2000, and a final rule was issued January 22, 2001. Technologies available for removing arsenic include ion exchange, iron hydroxide coagulation followed by microfiltration, and activated alumina.

Purpose of Regulating Arsenic: To improve public health protection by reducing exposure to arsenic in drinking water.

Public Health Benefit: The avoidance of bladder and lung cancer, dental problems, and a reduction in the frequency of non-carcinogenic diseases.

MCL/MCLG: 0.010 mg/L/zero

Monitoring Requirements: Once a year for surface water; once every 3 years for groundwater. To minimize monitoring costs, use historical data, waivers, susceptibility waivers, or make composite samples.

Asbestos

In the Code of Federal Regulations Reference: 40 CFR 141.62, the general term asbestos refers to a family of fibrous silicate minerals that have been widely used in the manufacture of commercial products. Some examples of products containing asbestos include floor and ceiling tiles, paper products, paint and caulk, plastics, brake linings, insulation, cement, and filters.

Asbestos in cement pipes is a potential source of contamination of drinking water. Deterioration of this material with age and exposure to corrosive water is thought to release asbestos particles. Mining for asbestos minerals has also contributed to the contamination of some drinking water sources throughout the United States. Scientific evidence on the harmful

effects of asbestos consumed in drinking water is less conclusive than the evidence relating to inhaled asbestos.

Purpose of Regulating Asbestos: To improve public health protection by reducing exposure to asbestos in drinking water.

Public Health Benefit: To reduce the risk of developing benign intestinal polyps.

MCL/MCLG: 7 million fibers per liter (MFL)/7 MFL

Monitoring Requirements: Once every 9 years.

Barium

Code of Federal Regulations Reference: 40 CFR 141.62, although not as widespread as arsenic, this element also occurs naturally in the environment in some areas of the US. Barium can also enter water supplies through industrial waste discharges. Small doses of barium are not harmful. However, it is quite dangerous when consumed in large quantities and will bring on increased blood pressure, nerve damage, and death.

Purpose of Regulating Barium: To improve public health protection by reducing exposure to large quantities of barium in drinking water.

Public Health Benefit: To reduce the risk of high blood pressure.

MCL/MCLG: 2 mg/L/2 mg/L

Monitoring Requirements: Once a year for surface water; once every 3 years for groundwater. To minimize monitoring costs, use historical data, waivers, susceptibility waivers, or make composite samples.

Beryllium

In the Code of Federal Regulations Reference: 40 CFR 141.62, the major source of beryllium in the environment is the combustion of coal and oil. Airborne particulates containing beryllium can be inhaled or washed by precipitation into drinking water supplies. Animal studies show that when large doses of beryllium are ingested, it is carried by the bloodstream from the stomach to the liver; however, it is gradually transferred to the animal's bones.

Purpose of Regulating Beryllium: To improve public health protection by reducing exposure to large quantities of beryllium in drinking water.

Public Health Benefit: To reduce the risk of intestinal lesions.

MCL/MCLG: 0.004 mg/L/0.004 mg/L

Monitoring Requirements: Once a year for surface water; once every 3 years for groundwater. To minimize monitoring costs, use historical data, waivers, susceptibility waivers, or make composite samples.

Bromate

In the Code of Federal Regulations Reference: 40 CFR Parts 9, 141, and 142, bromate is formed as a byproduct of ozone disinfection of drinking water. Ozone reacts with the naturally occurring bromide ion in the water to form bromate. Bromate is an inorganic ion that is tasteless, colorless, and has a low volatility. Bromate dissolves easily in water and is fairly stable. Bromate is not typically derived from natural sources. It is commonly found in raw water supplies such as streams, lakes, and reservoirs.

Purpose of Regulating Bromate: To improve public health protection by reducing exposure to bromate in drinking water.

Public Health Benefit: To reduce the risk of cancer.

MCL/MCLG: 0.010 mg/L/zero

Monitoring Requirements: Monthly (ozone systems only).

Cadmium

In the Code of Federal Regulations Reference: 40 CFR 141.62, only extremely small amounts of cadmium are found in natural waters in the United States. Waste discharges from the electroplating, photography, insecticide, and metallurgy industries can increase cadmium levels. The most common source of cadmium in drinking water is from galvanized pipes and fixtures.

Purpose of Regulating Cadmium: To improve public health protection by reducing exposure to cadmium in drinking water.

Public Health Benefit: To prevent kidney damage.

MCL/MCLG: 0.005 mg/L/0.005 mg/L

Monitoring Requirements: Once a year for surface water; once every 3 years for groundwater. To minimize monitoring costs, use historical data, waivers, susceptibility waivers, or make composite samples.

Chlorite

In the Code of Federal Regulations Reference: 40 CFR Parts 9, 141, and 142, the main source of chlorite in drinking water is chlorine dioxide used for disinfection. Chlorite forms as the chlorine

dioxide breaks down during the disinfection process. Chlorite is an inorganic ion that is colorless, odorless, tasteless, and dissolves easily in water. Chlorite is one of the two or three chemicals involved in the process of generating chlorine dioxide for water treatment. Chlorite is not typically derived from natural sources.

Purpose of Regulating Chlorite: To improve public health protection by reducing exposure to chlorite in drinking water, especially for infants and young children.

Public Health Benefit: To prevent adverse effects of the nervous system and anemia.

MCL/MCLG: 1.0 mg/L/0.8 mg/L

Monitoring Requirements: For systems that add chlorine dioxide, daily samples are required at distribution system entry points.

Chromium

In the Code of Federal Regulations Reference: 40 CFR 141.62, chromium is found in cigarettes, some foods, and the air. It is also discharged from steel and pulp mills and the erosion of natural deposits. Some studies suggest that in very small amounts, chromium may be essential to human beings, but it has not been proven.

Purpose of Regulating Chromium: To improve public health protection by reducing exposure to chromium in drinking water.

Public Health Benefit: To prevent allergic dermatitis.

MCL/MCLG: 0.1 mg/L/0.1 mg/L

Monitoring Requirements: Once a year for surface water; once every 3 years for groundwater. To minimize monitoring costs, use historical data, waivers, susceptibility waivers, or make composite samples.

Copper

In the Code of Federal Regulations Reference: 40 CFR 141.86, copper in drinking water usually results from the reaction of water on copper plumbing. Treatment of surface water in storage reservoirs to control algae may also cause high levels of copper. Copper is an essential nutrient; adults require 2 mg daily and children of preschool age require about 0.1 mg daily for normal growth.

The presence of copper in drinking water is also undesirable because of its aesthetic effects. At low levels (0.5 mg/L in soft waters) blue or blue-green staining of porcelain occurs. At higher

levels (4 mg/L), it will stain clothing and blond hair. Concentrations greater than 1 mg/L can produce insoluble green curds when reacting with soap.

The primary standard for copper includes a treatment technique of the taps sampled exceed the action level (AL) of 1.3 mg/L.

Action levels communicate health or physical hazards by categorizing these hazards into levels. Action levels are used by OSHA and NIOSH to determine how harmful a substance or activity is.

Purpose of Regulating Copper: To improve public health protection by reducing water corrosivity.

Public Health Benefit: To prevent gastrointestinal, kidney, and liver problems.

MCL/MCLG: A treatment technique (TT) is triggered at AL = 1.3 mg/L/1.3 mg/L

Monitoring Requirements: Residential sample taken at the kitchen or bathroom sink tap. ALs must be met in 90 percent of the samples. Follow-up monitoring every 6 months after corrosion controls initiated or optimized. Reduced monitoring for systems consistently meeting AL.

Cyanide

In the Code of Federal Regulations Reference: 40 CFR 141.62, cyanide is a common ingredient of rat poisons, silver and metal polishes, and photo processing chemicals. The major source of cyanide in drinking water is discharge from industrial chemical factories.

Ingestion of even very small amounts of sodium cyanide or potassium cyanide can cause death within a few minutes to a few hours. Typical symptoms of cyanide poisoning include nausea without vomiting, anxiety, vertigo, lower jaw stiffness, convulsions, paralysis, irregular heartbeat, and coma.

Purpose of Regulating Cyanide: To improve public health protection by reducing long-term exposure to cyanide.

Public Health Benefit: To prevent thyroid/neurological damage.

MCL/MCLG: 0.2 mg/L/0.2 mg/L

Monitoring Requirements: Once a year for surface water; once every 3 years for groundwater. To minimize monitoring costs, use historical data, waivers, susceptibility waivers, or make composite samples.

Fluoride

In the Code of Federal Regulations Reference: 40 CFR 141.62, fluoride is a natural mineral and many sources of drinking water contain some fluoride. Fluoride produces two effects, depending on its concentration. EPA has set primary and secondary limits to regulate it. Many communities add fluoride to their drinking water to promote dental health. The decision to fluoridate a water supply is made by the state or local municipality, and is not mandated by EPA or any other federal entity.

However, EPA has completed and peer-reviewed a quantitative dose-response assessment based on the available data for severe dental fluorosis as recommended by the National Research Council (NRC). At levels of 6 to 8 mg/L, fluoride may cause brittle bones and stiffening of the joints. On the basis of this health hazard, fluoride has been added to the list of primary standards.

At levels of 2 mg/L and greater, fluoride may cause dental fluorosis, which is discoloration and mottling of the teeth, especially in children. EPA has reclassified dental fluorosis as a cosmetic effect, raised the primary drinking water standard from 1.4–2 mg/L to 4 mg/L, and established a secondary standard of 2 mg/L for fluoride.

Purpose of Regulating Fluoride: To improve public health protection by preventing long-term exposure to fluoride.

Public Health Benefit: To prevent bone disease.

MCL/MCLG: 4.0 mg/L/4.0 mg/L

Monitoring Requirements: Once a year for surface water; once every 3 years for groundwater. To minimize monitoring costs, use historical data, waivers, susceptibility waivers, or make composite samples.

Lead and Copper

In the Code of Federal Regulations Reference: 40 CFR 141 Subpart I, is concerned with the control of lead and copper. Basic Requirements of the Lead and Copper Rule (LCR) are:

1. Require water suppliers to optimize their treatment system to control corrosion in customers' plumbing.
2. Determine tap-water levels of lead and copper for customers who have lead service lines or lead-based solder in their plumbing system.
3. Rule out the source water as a source of significant lead levels.
4. If lead ALs are exceeded, require the suppliers to educate their customers about lead and suggest actions they can take to reduce their exposure to lead through public notices and public education programs. If a water system, after installing and optimizing

corrosion control treatment, continues to fail to meet the lead AL, it must begin replacing the lead service lines under its ownership.

Revisions to the Lead and Copper Rule (LCR)—EPA is promulgating a rule that makes several targeted regulatory revisions to the existing national primary drinking water regulations (NPDWRs) for lead and copper. The revisions to the LCR will do the following:

1. Enhance the implementation of the LCR in the areas of monitoring, treatment, customer awareness, and lead service line replacement
2. Improve compliance with the public education requirements of the LCR to ensure drinking water consumers receive meaningful, timely, and useful information needed to help them limit their exposure to lead in drinking water

Lead is a naturally occurring metal that was used regularly in a number of industrial capacities and commonly used in household plumbing materials and water service lines. Lead was used as a component of paint, piping, solder, brass, and as a gasoline additive until the 1980s. The greatest exposure to lead is swallowing or breathing it in lead paint chips and dust. Research has confirmed that lead is highly toxic.

Lead is rarely found in source water. Mostly, lead contamination occurs after water has left the treatment plant due to corrosion of plumbing materials. Since water is naturally corrosive, it corrodes the pipes and plumbing through which it passes. Homes built before 1986 are more likely to have lead pipes, fixtures, and solder. However, new homes are also at risk because even legally lead-free plumbing may contain up to 8-percent lead. Grounding of electrical circuits in homes to water pipes and galvanic action between two dissimilar metals may increase corrosion that could cause lead to leach into the water.

Purpose of Regulating Lead: To protect public health by minimizing lead levels in drinking water, primarily by reducing water corrosivity.

Public Health Benefit: To prevent kidney problems, high blood pressure, and delays in physical and mental development in infants and children.

MCL/MCLG: A TT is triggered at AL = 0.015 mg/L/zero

Monitoring Requirements/Comments: Residential samples taken at the kitchen or bathroom sink tap. ALs must be met in 90 percent of the samples. Follow-up monitoring every 6 months after corrosion controls initiated or optimized. Reduced monitoring requirements for systems consistently meeting the AL. An AL exceedance is not a violation but can trigger other requirements that include monitoring for the following water quality indicators: pH, corrosion, control treatment, source water monitoring/treatment, public education, and lead service line replacement.

Copper is a metal found in natural deposits such as ores containing other elements. Copper is widely used in household plumbing materials.

Purpose of Regulating Copper: To protect public health by minimizing the risk of ingesting copper in drinking water, primarily from the corrosion of pipes.

Public Health Benefit: To prevent gastrointestinal distress due to short-term exposure and to prevent liver or kidney damage from long-term exposure.

MCL/MCLG: A TT is triggered at AL = 1.3 mg/L/1.3 mg/L

Monitoring Requirements/Comments: Residential samples taken at the kitchen or bathroom sink tap. ALs must be met in 90 percent of the samples. Follow-up monitoring every 6 months after corrosion controls initiated or optimized. There are reduced monitoring requirements for systems consistently meeting the AL. An AL exceedance is not a violation but can trigger other requirements that include monitoring for the following water quality indicators: pH, corrosion control treatment, source water monitoring/treatment, public education, and lead service line replacement.

All water systems are required to optimize corrosion control; that is to say, they must do the best they can to control corrosion. Small- and medium-sized systems are considered to have optimized corrosion control if they meet the lead and copper action levels during each of two consecutive six-month sampling periods. Large systems have optimized corrosion control if the difference between the source water lead level and the 90th percentile tap-water lead level is less than 0.005 mg/L, and the 90th percentile copper concentration is less than or equal to half the copper action level (0.65 mg/L) for two consecutive six-month periods.

Any system that is achieving optimal corrosion control and meeting the action limits is permitted to reduce monitoring and reporting frequencies. Large water systems that do not meet the guidelines for optimal corrosion control are required to conduct studies of various types of corrosion control treatment and then submit to the state a plan that would adequately control corrosion in their distribution system.

Small- and medium-sized systems exceeding the action levels must make a written recommendation to the state for a proposed treatment method, but may also be required to conduct similar studies before the state makes a final determination.

Once the state directs a water supplier to install treatment, the agency has 24 months to install the specified treatment and 12 months to collect follow-up samples to determine if the system is working. The state will also determine maximum acceptable levels for pH, alkalinity, calcium (if carbonate stabilization is used), orthophosphate (if an inhibitor with a phosphate compound is used), and silica (if an inhibitor with a silicate compound is used). The system must then continue to operate within these water quality guidelines.

If corrosion control methods fail to reduce lead and copper concentrations below the action levels, the water supplier must collect and analyze source water samples. Data from this sampling is sent to the state along with the water agency's recommended treatment plan for

reducing contaminant levels. The state may accept the agency's recommended plan or may require some alternative treatment such as ion exchange, reverse osmosis, lime softening, or coagulation-filtration.

When required to install source water treatment, the agency is allowed 24 months for installation and 12 months to collect follow-up samples of specific water quality indicators. Based on the results of the follow-up sampling, the state determines the maximum allowable source water lead and copper concentrations and the water system is required to meet these state limits on an ongoing basis.

Water systems that continue to exceed the lead action level after installing optimal corrosion control treatment and source water treatment will have to begin a program to replace lead service lines within a maximum of 15 years.

Sampling Guidelines

The sampling required by the Lead and Copper Rule includes tap-water sampling at the consumer's faucet and distribution system sampling. Tap-water samples for initial and routine lead and copper monitoring must be collected at high-risk locations, which are defined as homes with lead solder installed after 1982, homes with lead pipes, and homes with lead service lines.

Tap-water samples for water quality indicators should be taken from representative taps throughout the distribution system. The representative taps can be the same as total coliform sampling sites. These samples will be analyzed for water quality indicator levels to identify optimal treatment and monitor compliance with the rule.

The rule calls for first-draw or first-flush samples, which are water samples taken after the water stands motionless in the plumbing pipes for at least six hours. This rule usually means taking a sample early in the day before water is used in the kitchen or bathroom. The rule permits water utilities to instruct consumers in sampling techniques so that they may collect the samples.

One-liter samples are needed.

Distribution system sampling conducted in connection with corrosion control studies requires samples from representative taps throughout the system as well as samples from entry points to the distribution system.

Initial and Base Monitoring Sample Sites

Compliance with the Lead and Copper Rule depends on meeting the action levels during two consecutive six-month monitoring periods. All public water systems are required to collect one sample for lead and copper analysis from a number of sites depending on population during each six-month monitoring period.

If a system meets the lead and copper action levels or maintains optimal corrosion control treatment for two consecutive six-month periods, tap-water sampling for lead and copper can be reduced to once per year and half the number of sites. After three consecutive years of acceptable performance, tap-water sampling can be reduced to once every three years at the reduced number of sites listed above.

Water Quality Indicator Frequency

All large systems (more than 50,000 persons) and any small- or medium-sized system that exceeds the lead or copper action level will be required to monitor for the following water quality indicators: pH, alkalinity, calcium, conductivity, orthophosphate, silica, and water temperature. Samples must be taken from representative taps throughout the system and at entry points to the distribution system. Two tap-water samples must be collected for each applicable water quality indicator.

In addition to the sampling from representative taps, one sample must be collected every two weeks for each applicable water quality indicator at each entry point to the distribution system. All large water systems and any small- and medium-sized system that exceed the lead or copper action levels after installing optimal corrosion control treatment must continue to collect samples as follows:

1. 2 samples for each applicable water quality indicator at each of the sampling sites (taps) every 6 months.
2. 1 sample for each applicable water quality indicator at each entry point to the distribution system every 2 weeks.
3. After meeting water quality guidelines for 2 consecutive 6-month monitoring periods, systems may reduce the number of tap samples collected, and after 3 consecutive years of acceptable performance they will be permitted to collect annual samples at the reduced number of sampling points.

Calculation of the 90th Percentile

The action levels that trigger implementation of treatment techniques to reduce lead and copper concentrations are based on the principle that no more than 10 percent of the samples should exceed the limit. To determine whether a system meets this test, it is necessary to figure out the lead or copper concentration on the sample that falls at the 90th percentile.

To calculate the 90th percentile value, write down the results from a set of samples arranging them in order of increasing or decreasing concentration. Number each sample beginning with the number 1 for the smallest concentration. Multiply the total number of samples (which will be the same as the number assigned to the highest concentration) by 0.9. Then, use the value from this calculation to identify the sample with the same number.

The concentration of the sample whose number matches the calculated value is the 90th percentile and is used in determining compliance with the action level. For systems serving

fewer than 100 people, the 90th percentile is the average of the highest concentration and the second highest concentration.

Public Education

A public education program developed by the EPA must be delivered to water system customers within 60 days whenever the system exceeds the lead or copper action levels. The information describes the harmful effects of lead in drinking water and tells customers what they can do to reduce their exposure. The education program should continue as long as the system fails to meet the lead or copper action levels. In conjunction with the public education program, the water system must offer to sample a customer's water if asked to do so. However, the water system is not required to pay for the sampling and analysis and is not required to collect and analyze the sample.

Lead Service Line Replacement

Any water system that continues to exceed the lead and copper action levels even after optimizing corrosion control and installing source water treatment will be required to replace its lead distribution pipes within a maximum of 15 years. A lead pipeline qualifies for replacement if it contributes more than 15 parts per billion to the total tap-water lead levels. Seven percent of the lines meeting this standard must be replaced annually. Customers must be notified 45 days before replacing the lines.

Mercury

In the Code of Federal Regulations Reference: 40 CFR 141.62, mercury is found naturally throughout the environment. Large increases in mercury levels in water can be caused by industrial and agricultural use. The health risk from mercury is greater from mercury in fish than simply from waterborne mercury.

Mercury poisoning may have an acute health effect in large doses, or a chronic health effect in lower doses taken over an extended time period.

Purpose of Regulating Mercury: To improve public health protection and reduce ingestion of mercury.

Public Health Benefit: To prevent kidney damage.

MCL/MCLG: 0.002 mg/L/0.002 mg/L

Monitoring Requirements: Once a year for surface water; once every 3 years for groundwater. To minimize monitoring costs, use historical data, waivers, susceptibility waivers, or make composite samples.

Nitrate

In the Code of Federal Regulations Reference: 40 CFR 141.62, nitrate (as N) in drinking water above the national standard of 10 mg/L poses an immediate threat to children under three months of age. In some infants, excessive levels of nitrate have been known to react with intestinal bacteria that change nitrate to nitrite. It is often difficult to pinpoint sources of nitrate because so many possibilities exist.

Sources of nitrogen may include runoff or seepage from fertilized agricultural lands, municipal and industrial wastewater, refuse dumps, animal feedlots, septic tanks and private sewage disposal systems, urban drainage, and decaying plant debris.

Purpose of Regulating Nitrate: To improve public health protection.

Public Health Benefit: To prevent methemoglobinemia (blue baby syndrome)/diuresis.

MCL/MCLG: 10 mg/L/10 mg/L

Monitoring Requirements: Groundwater annually; surface water quarterly initially, then annually.

Nitrite

Code of Federal Regulations Reference: 40 CFR 141.62, nitrite reacts with hemoglobin in the blood. This reaction will reduce the oxygen-carrying ability of the blood and produce an anemic condition commonly known as blue baby syndrome. Sources of nitrite may include runoff or seepage from fertilized agricultural lands, municipal and industrial wastewater, refuse dumps, animal feedlots, septic tanks and private sewage disposal systems, urban drainage, and decaying plant debris.

Purpose of Regulating Nitrite: To improve public health protection.

Public Health Benefit: To prevent methemoglobinemia (blue baby syndrome)/diuresis.

MCL/MCLG: 1 mg/L/1 mg/L

Monitoring Requirements: One sample during first 3-year compliance period. Repeat frequency determined by state.

Selenium

In the Code of Federal Regulations Reference: 40 CFR 141.62, this mineral occurs naturally in soil and plants, especially in western states. Selenium is found in meat and other foods. Although it is believed to be essential in the diet, indications exist that excessive amounts of selenium may be toxic.

Studies are underway to determine the amount required for good nutrition and the amount that may be harmful. If a person's intake of selenium came only from drinking water, it would take an amount many times greater than the standard to produce any ill effects.

Purpose of Regulating Selenium: To improve public health protection.

Public Health Benefit: To prevent hair or fingernail loss, numbness of fingers or toes, and circulatory problems.

MCL/MCLG: 0.05 mg/L/0.05 mg/L

Monitoring Requirements: Once a year for surface water; once every 3 years for groundwater. To minimize monitoring costs, use historical data, waivers, susceptibility waivers, or make composite samples.

Thallium

In the Code of Federal Regulations Reference: 40 CFR 141.62, thallium is a metal found in natural deposits such as ores containing other elements. The major sources of thallium in drinking water are leaching from ore-processing sites and discharge from electronics, glass, and drug factories. Thallium is an extremely toxic metal that is used in refining iron, cadmium, and zinc.

The greatest use of thallium is in specialized electronic research equipment. It is also used for production of optical lenses, jewelry, semiconductors, dyes, and pigments. The most common source of thallium poisoning is ingestion of rat poisons and insecticides.

Purpose of Regulating Thallium: To improve public health protection.

Public Health Benefit: To prevent hair loss, changes in blood, and kidney/liver/intestinal problems.

MCL/MCLG: 0.002 mg/L/0.0005 mg/L

Monitoring Requirements: Once a year for surface water; once every 3 years for groundwater. To minimize monitoring costs, use historical data, waivers, susceptibility waivers, or make composite samples.

ORGANIC STANDARDS

Organic chemicals are either natural or synthetic chemical compounds that contain carbon. Synthetic organic chemicals (SOCs) are manmade compounds and are used throughout the world as pesticides, paints, dyes, solvents, plastics, and food additives. **Volatile organic**

chemicals (VOCs) are a subcategory of organic chemicals. These chemicals are termed volatile because they evaporate easily.

The most commonly found VOCs are THMs, trichloroethylene (TCE), tetrachloroethylene, and 1,1-dichloroethylene. THMs were the first regulated VOCs when EPA finalized regulations in 1979. The most common sources of organic contamination of drinking water are pesticides and herbicides, industrial solvents, and DBPs (THMs and haloacetic acids).

Millions of pounds of pesticides are used on croplands, forests, lawns, and gardens in the United States each year. They drain off into surface waters or seep into underground water supplies. Spills, poor storage, improper application, and haphazard disposal of organic chemicals have resulted in widespread groundwater contamination. A critical problem occurs once groundwater is contaminated, it may remain that way for a long time. Many organic chemicals pose health problems if they get into drinking water and the water is not properly treated.

In 2011, EPA decided to address up to 16 volatile organic compounds (VOCs) as a group that may cause cancer. The agency determined that they represent a near-term opportunity and it is likely that the public health goal for all VOCs would likely be set at zero because they may cause cancer. A preliminary evaluation of occurrence indicates that some of these VOCs may co-occur. This group will include trichloroethylene (TCE) and tetrachloroethylene (PCE).

EPA determined in March 2010 that the drinking water standards for TCE and PCE need to be revised. Addressing these VOCs as a group will help reduce exposure to these contaminants.

Trichloroethylene (TCE)

In the Code of Federal Regulations Reference: 40 CFR 141.50, although the use of TCE is declining because of stringent regulations, it was, for many years, a common ingredient in household products (spot removers, rug cleaners, and air fresheners), dry cleaning agents, industrial metal cleaners and polishes, refrigerants, and even anesthetics. Its wide range of use is perhaps why TCE is the organic contaminant most frequently encountered in groundwater.

Purpose of Regulating Trichloroethylene: To improve public health protection.

Public Health Benefit: To prevent cancer risks; liver problems.

MCL/MCLG: 0.005 mg/L/zero

Monitoring Requirements: Four consecutive quarterly samples during first compliance period. Compliance is based on annual average of quarterly samples. If no detections are found during the initial round, two quarterly samples are required each year for systems serving greater than 3,300; one sample is required every 3 years for smaller systems. These requirements apply to community and non-community water systems.

1,1-Dichloroethylene

In the Code of Federal Regulations Reference: 40 CFR 141.50, this solvent is used in manufacturing plastics and, more recently, in the production of 1,1,1-trichloroethane.

Purpose of Regulating 1,1-Dichloroethylene: To improve public health protection.

Public Health Benefit: To prevent impacts to the liver, kidneys, heart, and central nervous system

MCL/MCLG: 0.007 mg/L/0.007 mg/L

Monitoring Requirements/Comments: For VOCs: Four consecutive quarterly samples during first compliance period. Compliance is based on annual average of quarterly samples. If no detections are found during the initial round, two quarterly samples are required each year for systems serving greater than 3,300; one sample is required every 3 years for smaller systems. With the completion of source water assessments, primacy agencies are allowed to develop alternative monitoring requirements. Applies to community water systems and non-transient Non-community water systems.

Vinyl Chloride

In the Code of Federal Regulations Reference: 40 CFR 141.50, billions of pounds of this solvent are used annually in the United States to produce polyvinyl chloride (PVC), the most widely used ingredient for manufacturing plastics throughout the world. Also evidence exists that vinyl chloride may be a biodegradation end-product of TCE and PCE under certain environmental conditions.

Purpose of Regulating Vinyl Chloride: To improve public health protection.

Public Health Benefit: To prevent cancer in humans.

MCL/MCLG: 0.002 mg/L/zero

Monitoring Requirements/Comments: For VOCs: Four consecutive quarterly samples during first compliance period. Compliance is based on annual average of quarterly samples. If no detections are found during the initial round, two quarterly samples are required each year for systems serving greater than 3,300; one sample is required every 3 years for smaller systems. With the completion of source water assessments, primacy agencies are allowed to develop alternative monitoring requirements. Applies to community water systems and non-transient non-community water systems.

Carbon Tetrachloride

In the Code of Federal Regulations Reference: 40 CFR 141.50, carbon tetrachloride was once a popular household solvent, a frequently used dry cleaning agent, and a charging agent for fire extinguishers. Since 1970, however, carbon tetrachloride has been banned from all use in consumer goods in the United States.

In 1978, carbon tetrachloride was banned as an aerosol propellant. Currently, its principal use is in the manufacture of fluorocarbons, which are used as refrigerants.

Purpose of Regulating Carbon Tetrachloride: To improve public health protection.

Public Health Benefit: To prevent liver problems and cancer.

MCL/MCLG: 0.005 mg/L/zero

Monitoring Requirements: Four consecutive quarterly samples during first compliance period. Compliance is based on annual average of quarterly samples. If no detections are found during the initial round, two quarterly samples are required each year for systems serving greater than 3,300; one sample is required every 3 years for smaller systems. These requirements apply to community and non-community water systems.

Benzene

In the Code of Federal Regulations Reference: 40 CFR 141.50, benzene is used primarily in the synthesis of styrene (for plastics), phenol (for resins), and cyclohexane (for nylon). Other uses include the production of detergents, drugs, dyes, and insecticides. Benzene is still being used as a solvent and as a component of gasoline. It is also discharged from factories and leaches from gas storage tanks and landfills.

Purpose of Regulating Benzene: To improve public health protection.

Public Health Benefit: To prevent anemia, a decrease in blood platelets, and cancer.

MCL/MCLG: 0.005 mg/L/zero

Monitoring Requirements: Four consecutive quarterly samples during first compliance period. Compliance is based on annual average of quarterly samples. If no detections are found during the initial round, two quarterly samples are required each year for systems serving greater than 3,300; one sample is required every 3 years for smaller systems. These requirements apply to community and non-community water systems.

Para-Dichlorobenzene (p-Dichlorobenzene)

In the Code of Federal Regulations Reference: 40 CFR 141.50, the principal uses of p-dichlorobenzene are in moth control (moth balls and powders) and as lavatory deodorants. It is also used as an insecticide and fungicide on crops; in the manufacture of other organic chemicals; and in plastics, dyes, and pharmaceuticals.

The major source of p-dichlorobenzene in drinking water is discharge from industrial chemical factories.

Purpose of Regulating Para-Dichlorobenzene (p-Dichlorobenzene): To improve public health protection.

Public Health Benefit: To prevent kidney/liver/spleen/circulatory system problems.

MCL/MCLG: 0.075 mg/L/0.075 mg/L

Monitoring Requirements: Four consecutive quarterly samples during the first compliance period. Compliance is based on annual average of quarterly samples. If no detections are found during the initial round, two quarterly samples are required each year for systems serving greater than 3,300; one sample is required every 3 years for smaller systems. These requirements apply to community and non-community water systems.

Disinfection By-Products

Disinfection of drinking water by the addition of chlorine has long been considered a highly effective yet relatively low-cost method of preventing widespread outbreaks of waterborne diseases. In addition to reacting with disease-causing organisms in water, however, chlorine also reacts with many other types of organic materials.

Growing scientific evidence suggests that the byproducts of these chemical reactions can produce adverse health effects in humans. The highest priority health risk concern in the regulation of drinking water is the potential risk-risk tradeoff between the control of microbiological contamination (bacteria, viruses, and protozoa) on one side and DBPs on the other. This risk-risk tradeoff arises because, typically, the least expensive way for a public water system to increase microbial control is to increase disinfection (which generally increases byproduct formation) and the easiest way to reduce byproducts is to decrease disinfection (which generally increases microbial risk).

Microbiological contamination often causes flu-like symptoms; however, it can also cause serious diseases such as hepatitis, giardiasis, cryptosporidiosis, and Legionnaire's Disease. DBPs may pose the risk of cancer and developmental effects.

THMs are an example of a compound formed by the reaction of chlorine with organic matter in water. THMs are suspected of being carcinogenic and have been regulated by EPA in the 1996 SDWA amendments. The MCL for TTHMs is 0.080 milligram per liter or 80 micrograms per liter.

In May 1996, EPA published the Information Collection Rule (ICR). This rule required large public water systems to undertake extensive monitoring of microbial contaminants and DBPs in their water systems. Also, some water systems conducted studies on the use of granular activated carbon and membrane processes. The data reported under the ICR were used by EPA to learn more about the occurrence of microbial contamination and DBPs, the health risks posed, appropriate analytical methods, and effective forms of treatment. The ICR data form the scientific basis for EPA's development of the Enhanced Surface Water Treatment Rule and the Disinfectants and Disinfection Byproducts Rule.

EPA issued the Stage 1 DBPR on December 16, 1998 (Federal Register 63, No. 241). This rule set new MCLGs and MCLs for TTHMs, HAA5, bromate, and chlorite. Maximum residual disinfectant level goals (MRDLGs) and maximum residual disinfectant levels (MRDLs) have also been set for chlorine, chloramine, and chlorine dioxide.

The Stage 1 DBPR attempts to further reduce potential formation of harmful DBPs by requiring the removal of THM precursors. A treatment technique of enhanced coagulation, enhanced softening, or use of granular activated carbon (GAC) applies to conventional filtration systems. In most cases, systems must reduce total organic carbon (TOC) levels based on specific source water quality factors.

For large systems (serving more than 10,000 persons) that use surface water or groundwater under the direct influence of surface water, the compliance date for the Stage 1 DBPR was January 1, 2002. Small systems (serving fewer than 10,000) that use surface water or groundwater under the direct influence of surface water and all groundwater systems must have complied by January 1, 2004.

The Stage 1 DBPR has very specific laboratory and monitoring requirements. The routine monitoring requirements include the following regulated contaminants/disinfectants:

1. TTHM/HAA5
2. Bromate
3. Chlorite
4. Chlorine/chloramines
5. Chlorine dioxide
6. DBP precursors (TOC/alkalinity/specific UV absorbance)

Also, the Stage 1 DBPR specifies the monitoring coverage in terms of surface water, groundwater, and groundwater under direct influence (GWUDI), population served, and the type of filtration system and disinfection system. Monitoring frequency depends on the type of source water, population served, and type of treatment and disinfection system. The routine monitoring requirements are based on the regulated contaminants/disinfectants and include

the MCL, MRDL, analytical method, preservation/quenching agent, holding time for sample/extract, and sample container size and type.

On December 15, 2005, EPA promulgated the Stage 2 DBPR. This rule reduces potential cancer and reproductive and developmental health risks from DBPs in drinking water, which form when disinfectants are used to control microbial pathogens. This final rule strengthens public health protection for consumers by tightening compliance monitoring requirements for two groups of DBPs: TTHMs and HAA5.

The rule targets systems with the greatest risk and builds incrementally on existing rules. This regulation reduces DBP exposure and related potential health risks and provides more equitable public health protection. The Stage 2 DBPR was promulgated simultaneously with the Long Term 2 Enhanced Surface Water Treatment Rule to address concerns about risk tradeoffs between pathogens and DBPs.

Under the Stage 2 DBPR, systems will conduct an evaluation of their distribution systems, known as an Initial Distribution System Evaluation (IDSE), to identify the locations with high DBP concentrations. These locations are used by the systems as the sampling sites for Stage 2 DBPR compliance monitoring.

Compliance with the maximum contaminant levels for two groups of DBPs (TTHMs and HAA5) is calculated for each monitoring location in the distribution system. This approach, referred to as the locational running annual average (LRAA), differs from previous requirements, which determine compliance by calculating the running annual average of samples from all monitoring locations across the system.

The Stage 2 DBPR also requires each system to determine if they have exceeded an operational evaluation level, which is identified using their compliance monitoring results. The operational evaluation level provides an early warning of possible future MCL violations, which allows the system to take proactive steps to remain in compliance. A system that exceeds an operational evaluation level is required to review their operational practices and submit a report to their state that identifies actions that may be taken to mitigate future high DBP levels; particularly, those levels that may jeopardize their compliance with the DBP MCLs.

9.3 Radionucleotide Standards

EPA promulgated the Radionuclides Rule on December 7, 2000. The purpose of the Radionuclides Rule is to reduce the exposure to radionuclides in drinking water, which reduces the risk of cancer. This rule also improves public health protection by reducing exposure to all radionuclides. The rule applies to all community water systems.

The public health benefits from the rule include reduced exposure to uranium, which can cause toxic kidney effects and cancer.

In the Code of Federal Regulations Reference: 40 CFR 141.24, radioactivity is the only contaminant that has been shown to cause cancer for which standards have been set. Three radioactive elements, radon, radium, and uranium, occur naturally in the ground and dissolve into groundwater supplies. However, the possible exposure to radiation in drinking water is only a fraction of the exposure from all natural sources. The main source of radioactive material in surface water is fallout from nuclear testing. Other sources could be nuclear power plants, nuclear fuel processing plants, and uranium mines. Those sources are monitored constantly and no great risk of contamination exists, barring accidents.

Alpha and radium radioactivity occur naturally in groundwater in parts of the West, Midwest, and Northeast. Standards for those types of radioactivity and for manmade, or beta radiation, have been set at levels of safety comparable to other contaminants. The MCLs for radiological contaminants are divided into two categories: natural radioactivity that results from well water passing through deposits of naturally occurring radioactive materials and manmade radioactivity such as that which might result from industrial wastes, hospitals, or research laboratories.

A pCi/L, picoCurie per Liter, is a measure of radioactivity. One picoCurie of radioactivity is equivalent to 0.037 nuclear disintegrations per second. For surface water systems serving more than 100,000 persons and systems determined by the state to be vulnerable. Monitoring for natural radioactivity contamination is required every four years for surface water and groundwater community systems. Routine monitoring procedures to follow are:

1. Test for gross alpha activity; if gross alpha exceeds 5 pCi/L, then
2. Test for radium 226; if radium 226 exceeds 3 pCi/L, then
3. Test for radium 228.

The MCL for gross beta particle activity is 4 mrem/yr for water systems using surface water and serving more than 100,000 people, and for any other community system determined by the state to be vulnerable to this type of contamination. After the initial monitoring period, beta radiation must be monitored every 4 years unless the MCL is exceeded or the state determines that more frequent monitoring is appropriate.

Regulation of radon continues to be a source of considerable debate. EPA proposed a maximum contaminant level in 1991 and then withdrew the proposed MCL in 1997 in response to the 1996 SDWA amendments. EPA published a proposed regulation for radon in 1999, but the final MCL has not been published.

The final Radionuclides Rule was published in 2000. The rule retains the current standards for radium 226 and 228, gross alpha activity, and gross beta particle activity, but establishes a new MCL 30 µg/L for uranium. The EPA has indicated that it will continue to review the standard for beta particle activity and may revise the MCL in the future. EPA must base its new rules on a scientific risk assessment and an analysis of the amount of health risk reduction that will be achieved and the cost of implementing the new rules.

MICROBIAL STANDARDS

Microbial contamination of drinking water can pose a potential public health risk in terms of acute outbreaks of disease. Bacteria, viruses, and other organisms have long been recognized as serious contaminants of drinking water. Organisms such as *Giardia*, *Cryptosporidium*, and *E. coli* (a type of coliform bacteria) cause almost immediate gastrointestinal illness when people consume them in water. Waterborne diseases such as typhoid, cholera, infectious hepatitis, and dysentery have been traced to improperly disinfected drinking water.

In most communities, drinking water is treated to remove contaminants before being piped to consumers, and bacterial contamination of municipal water supplies has been largely eliminated by adding chlorine or applying other forms of disinfection to drinking water to prevent waterborne diseases. By treating drinking water and wastewater, diseases such as typhoid and cholera have been virtually eliminated.

Many types of coliform bacteria from human and animal wastes may be found in drinking water if the water is not properly treated. Often, the bacteria do not cause diseases transmitted by water, although certain coliforms have been identified as the cause of traveler's diarrhea. In general, however, the presence of coliform bacteria indicates that other harmful organisms may be present in the water.

Throughout the early 1990s, chemical contaminants in drinking water were the focus of EPA's regulatory efforts. With passage of the 1996 SDWA amendments, Congress directed EPA to focus on microbial contaminants and to promulgate a series of new regulations to improve treatment effectiveness. Significant new regulations of the microbial contaminant *Cryptosporidium* were promulgated in December 1998. The new regulations consist of mandatory treatment techniques similar to the current regulations for *Giardia* and coliform bacteria. Filtration and disinfection requirements for surface water systems are currently in place and the final Ground Water Rule was signed in 2006. These regulations significantly affect the water treatment processes of most water suppliers.

Total Coliform Rule

In the Code of Federal Regulations Reference: 40 CFR 141 Subpart C, coliforms are bacteria that are always present in the digestive tracts of animals, including humans, and are found in their wastes. They are also found in plant and soil material. The most basic test for bacterial contamination of a water supply is the test for total coliform bacteria. Total coliform counts give a general indication of the sanitary condition of a water supply.

Coliforms include the following:

1. Total coliforms—include bacteria that are found in the soil, in water that has been influenced by surface water, and in human or animal waste.
2. Fecal coliforms—are the group of the total coliforms that are considered to be present specifically in the gut and feces of warm-blooded animals. Because the

origins of fecal coliforms are more specific than the origins of the more general total coliform group of bacteria, fecal coliforms are considered a more accurate indication of animal or human waste than the total coliforms.

Escherichia coli (*E. coli*) is the major species in the fecal coliform group. Of the five general groups of bacteria that comprise the total coliforms, only *E. coli* is generally not found growing and reproducing in the environment. Consequently, *E. coli* is considered to be the species of coliform bacteria that is the best indicator of fecal pollution and the possible presence of pathogens.

2012 Revised Total Coliform Rule (RTCR)

EPA has revised the Total Coliform Rule so that public water systems in the US take steps to ensure the integrity of the drinking water distribution system and monitoring for the presence of microbial contamination. Public water systems and the state and local agencies that oversee them must comply with the RTCR beginning April 1, 2016. The final RTCR requires the following:

1. Public water systems are to notify the public if a test exceeds the MCL for *E. coli* in drinking water
2. Public water systems that are at risk and therefore vulnerable to microbial contamination are required to identify and fix the problems, including the potential sources and the pathways of contamination
3. Criteria will be used for public water systems that are well operated to qualify for and stay on reduced monitoring, which could reduce water system burden
4. Provide incentives for better system operation, in particular small systems
5. Require additional monitoring requirements for seasonal systems such as campgrounds and state and national parks

The RTCR establishes an MCLG and an MCL for *E. coli* and eliminates the MCLG and MCL for total coliforms, replacing them with treatment techniques for coliforms that require assessment and corrective action. EPA has established an MCLG of zero for *E. coli*, which is a more specific indicator of fecal contamination and those pathogens that are potentially more harmful than total coliform. EPA has removed the 1989 MCLG and MCL for total coliforms, although the acute total coliform MCL violation under the 1989 TCR has been maintained as the MCL for *E. coli* under the RTCR.

Under the new treatment technique, total coliforms serve as the indicator of a potential pathway of contamination into the system's distribution system. Public water supplies that exceed a specified frequency of total coliform occurrence must conduct an assessment to determine if any sanitary deficiencies exist; if found, they must be corrected. A public water system that experiences an *E. coli* MCL violation must conduct an assessment and correct any sanitary defects that are identified.

Monthly notification requirements based only on the presence of total coliforms will no longer be required. Instead, the RTCR will require public notification when an *E. coli* MCL violation

occurs, indicating a potential health threat or when a water system fails to assess and take corrective action.

Sanitary Survey

In the Code of Federal Regulations Reference: 40 CFR 141.2, sanitary surveys are conducted to identify possible health risks that may not be discovered by routine coliform sampling. The Total Coliform Rule requires community water systems serving fewer than 4,100 persons to complete an initial sanitary survey by June 1994 and to conduct subsequent surveys every 5 years.

Non-community water systems are required to complete an initial sanitary survey by June 1999 and subsequent surveys every 5 years with the exception of those systems with protected and disinfected groundwater sources, which are allowed 10 years for subsequent surveys.

A sanitary survey requires detailed planning, a thorough system survey, and reporting of the results. The planning portion involves a review of water quality records for compliance with applicable microbial, inorganic chemical, organic chemical, and radiological contaminant MCLs as well as the records of compliance with the monitoring requirements for those contaminants. The actual field survey is a detailed evaluation and inspection of the source of the water supply and all conveyances, storage, treatment, and distribution facilities to ensure protection from all pollution sources.

The final report includes the date(s) of the survey, who was present during the survey, the survey findings, the recommended improvements to correct identified problems, and the target dates of completion for any improvements.

Sampling Plan

The Total Coliform Rule requires each water supply system to develop and follow a written sampling plan. Each plan must specifically identify sampling points throughout the distribution system. Sampling plans must be approved by the state regulatory agency and it is necessary to check with the state agency to determine the details of their review process and what documents need to be submitted.

Laboratory Procedures

In the Code of Federal Regulations Reference: 40 CFR 141.21 and 40 CFR 141 Subpart C, with regard to coliform testing methodology, EPA maintains a current list of analytical methods that are approved for monitoring drinking water supplies that is published and updated in 40 CFR 141. Examples of the acceptable analytical methods for determining total coliforms include the following:

1. Multiple-tube fermentation technique (MTF)
2. Membrane filter technique (MF)
3. Presence-absence coliform test (P-A)
4. Colilert™ system (ONPG-MUG test)

5. Colisure test

Regardless of the method used, the standard sample volume for total coliform testing is now 100 mL. This volume is an increase over the past testing method using 50 mL for the MTF technique.

The multiple-tube fermentation method of testing for coliforms determines the presence or absence of coliforms by the multiple-tube dilution method. This test is a process whereby equal portions of a sample (100 mL) are added to 10 tubes containing a culture medium and an inverted vial. If gas accumulates in the inverted vial, it indicates presumptive evidence of coliform organisms and the sample is considered coliform-positive. If no gas forms in any of the vials, the sample is coliform-negative.

The membrane filter method provides for filtering a 100 mL water sample through a thin, porous, cellulose membrane filter under a partial vacuum. The filter is placed in a sterile container and incubated in contact with a special liquid called a culture medium, which the bacteria use as a food source. Colonies of bacteria then grow on the media. The coliform colonies are visually identified, counted, and recorded as the number of coliform colonies per 100 mL of sample.

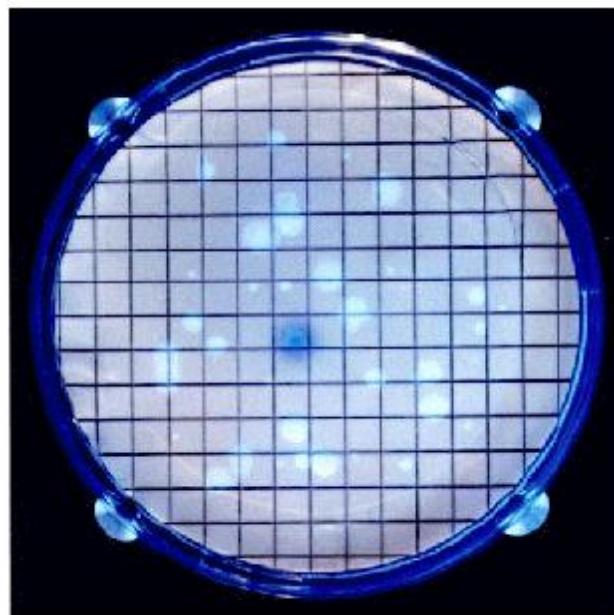


Figure 9.1: Membrane filter test for coliforms³⁰

The presence-absence (P-A) test for the coliform group is a simple modification of the multiple-tube procedure. Even though this simplified test uses only one large test portion (100 mL) in a single culture bottle, the results still indicate the presence or absence of coliform bacteria and thus meet the testing requirements.

³⁰ [Image](#) by the [EPA](#) is in the public domain

The Colilert™ system is a privately developed version of the ONPG-MUG test procedure that meets the EPA's laboratory methods requirements. The ONPG-MUG test indicates the presence or absence of coliform bacteria within 24 hours. Although the Colilert™ method can yield presence-absence results within 24 hours and is easier to perform than the Membrane Filtration (MF) method, operators should be aware of the limitations of these tests in evaluating samples for regulatory purposes. The results for the Colilert™ and MF tests are not always comparable, which may be due to the following:

1. Interferences in the sample that may suppress or mask bacterial growth
2. Greater sensitivity of the Colilert™ media
3. Added stress to organisms related to filtering
4. The fact that different media may obtain better growth for some bacteria

These test methods are approved by the EPA for reporting under the Safe Drinking Water Program. When these tests produce conflicting results, however, the safest course of action is to increase monitoring and treatment efforts until the results for each test is negative.

The Colisure test is a presence-absence test for coliform bacteria. A sample of water is added to a dehydrated medium and, after 24 to 48 hours, the medium is examined for the presence of coliforms.

Table 9-2: Total Coliform Indicator Color Chart

Positive Test	Negative Test
<ul style="list-style-type: none">• Many gas bubbles present• Gel rises to surface• Liquid below gel is cloudy• Indicator turns yellow	<ul style="list-style-type: none">• Liquid above gel is clear• Indicator remains red or turns yellow with no gas bubbles• Gel remains at bottom of tube

Water supply systems may contain various other types of bacteria besides coliforms. These organisms are nonpathogenic bacteria and are sometimes referred to as heterotrophic bacteria. During the analyses of water samples for coliforms, heterotrophic bacteria sometimes interfere with the test causing one of the following reactions:

1. MTF technique: a turbid culture with no gas production
2. P-A test: a turbid culture in the absence of an acid reaction
3. MF technique: confluent growth or a coliform colony number too numerous to count

The sample being tested can be considered invalid if any of these situations occurs and total coliforms are not detected. A replacement sample must be taken from the same location within 24 hours of receiving the laboratory results. If the replacement sample also shows heterotrophic interference but tests positive for total coliforms, the sample is considered valid.

Monitoring Frequency

The routine monitoring frequency for community water systems is based on the population served. Routine monitoring frequencies for non-community systems are based on the source of supply and, in some cases, the population served. Whenever a routine sample tests positive for total coliform, two provisions of the Total Coliform Rule take effect: repeat samples (formerly referred to as check samples) must be taken and the original coliform-positive sample must be tested for the presence of fecal coliforms or *E. coli* to determine whether an actual or potential violation of the coliform MCL exists.

The reason repeat samples are required is to investigate whether the original coliform-positive sample was caused by a contamination problem that exists throughout the distribution system or if it is a localized problem that exists only at that one sampling point. With this information, appropriate corrective action can be taken to eliminate the problem as quickly as possible.

The Total Coliform Rule specifies how many repeat samples must be taken, when, and from what locations. It also directs the water utility to collect a specific number of samples the following month, based on the number of routine samples ordinarily collected.

Non-community systems serving more than 1,000 people have the same requirements as community water systems. Non-community systems serving fewer than 1,000 people are required to collect one routine sample per quarter. When the routine sample tests positive, four repeat samples are required in the same quarter and five samples are required the following quarter.

Whenever a routine or repeat sample tests positive for total coliform, the water agency must collect a set of three or four repeat samples within 24 hours of receiving the laboratory results. At least one of the repeat samples must be taken from the same tap as the original coliform-positive sample; the remaining repeat samples in the set must be collected at nearby taps (within five service connections of the original sampling point), upstream and downstream of the original.

Repeat samples must be taken until no coliforms are detected or until the MCL is exceeded and the state is notified.

Determining Compliance

The MCLG for total coliforms (including fecal coliforms and *E. coli*) is zero. The MCL, based on the presence-absence concept, is as follows:

1. For water systems analyzing at least 40 samples per month, no more than 5.0 percent of the samples (including routine and repeat samples) may be positive for total coliforms.
2. For water systems analyzing fewer than 40 samples per month, no more than one sample per month may be positive for total coliforms.

The Revised Total Coliform Rule makes another significant change in the way compliance is calculated. All valid coliform-positive samples, routine and repeat samples, must be counted when calculating compliance with the monthly MCL. Under previous regulations, check or repeat samples were not included in the monthly MCL calculation. On a case-by-case basis, the state may declare a sample invalid for one of several reasons, including interference by heterotrophic bacteria during laboratory analysis, as previously discussed.

Total-coliform-positive samples may be invalidated by the state under any of the following conditions:

1. The analytical laboratory acknowledges that improper sample analysis caused the positive result
2. The state determines that the contamination is a local plumbing problem
3. The state has substantial grounds to believe that the positive result was unrelated to the quality of drinking water in the distribution system

Reporting and Notification Requirements

Reporting frequencies for coliform test results increase in step with the urgency of the problem. A water agency must report the results of monthly coliform testing to the state regulatory agency within the first 10 days of the following month.

Any time a water agency fails to collect a sample as required, the state must be notified within 10 days after the system learns of the violation. An invalid sample result is considered a failure to monitor and must be reported.

If the MCL is exceeded, the state must be notified no later than the end of the next business day and the public within 14 days. This requirement could occur when the water agency exceeds its monthly coliform-positive limit or when test results show the presence of fecal coliforms or *E. coli* in any sample.

The most critical situation exists when either of two situations occurs:

1. A routine sample tests positive for total coliforms and for fecal coliforms or *E. coli*, and any repeat sample tests positive for total coliforms.
2. A routine sample tests positive for total coliforms and negative for fecal coliforms or *E. coli*, and any repeat sample tests positive for fecal coliforms or *E. coli*.

These situations are considered an acute risk to health. This occurrence is a Tier 1 violation, which requires that the state and the public be notified within 24 hours.

Key Terms

- **Inorganic contaminants** – non-Carbon-based contaminants, such as lead and mercury;
- **Microbial contaminants** - bacteria, viruses, and protozoa
- **Organic contaminants** – Carbon-based contaminants, which include pesticides, herbicides, THMs, solvents, and other synthetic organic compounds
- **Primary standards** – federal and state standards of contaminants with health effects; the Maximum Contaminant Level (MCL) for a contaminant
- **Secondary standards** – federal and state standards for contaminants that affect the aesthetic qualities relating to the public acceptance of drinking water
- **Radiologic contaminants** - natural and manmade sources of radiation, including uranium
- **Volatile organic compounds** – a subcategory of organic chemicals. These chemicals are termed volatile because they evaporate easily.
- **Turbidity**, such as small particles suspended in water that interfere with light penetration and disinfection

REVIEW QUESTIONS

1. List the metals in the Safe Drinking Water Act that are considered to be primary contaminants.

Contaminant	MCLG (mg/L)	MCL or TT (mg/L)	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water

Contaminant	MCLG (mg/L)	MCL or TT (mg/L)	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water

Contaminant	MCLG (mg/L)	MCL or TT (mg/L)	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water

2. List the radiologic contaminants that drinking water plants are required to be tested for in the Safe Drinking Water Act.

3. What is the action level for lead and copper in the Safe Drinking Water Act?

4. What is the MCL for nitrate in drinking water?

5. Which contaminant has a primary and secondary contaminant limit?

6. List the disinfection by-products that are monitored and controlled in the Safe Drinking Water Act?

7. Describe a Sanitary Survey.

CHAPTER QUIZ

1. In the Code of Federal Regulations, 40CFR 141.2, a sanitary survey should be conducted every _____.
 - a. one per year
 - b. every two years
 - c. every five years
 - d. every six years
 2. EPA uses the _____ to collect data for contaminants suspected to be present in drinking water, although they do not have health-based standards set under the Safe Drinking Water Act.
 - a. Maximum Contaminant Level
 - b. Maximum Contaminant Level Goal
 - c. Unregulated Contaminant Monitoring
 - d. Secondary Maximum Contaminant Level
-
1. Which of the primary contaminants has an action level rather than a MCL?
 - a. THMs and HAA5s
 - b. Arsenic
 - c. Mercury
 - d. Lead and Copper
 2. In the Code of Federal Regulations Reference: 40 CFR 141.62, the amounts of cadmium that are found in natural waters in the United States is small. Waste discharges from the electroplating, photography, insecticide, and metallurgy industries can increase cadmium levels. The most common source of cadmium in drinking water is from galvanized pipes and fixtures. What is the MCL and MCLG for Cadmium?
 - a. 5 ppb
 - b. 50 ppb
 - c. 5 ppm
 - d. 50 ppm

3. In the Code of Federal Regulations Reference: 40 CFR 141.62, chromium is found in cigarettes, some foods, and the air. It is also discharged from steel and pulp mills and the erosion of natural deposits. Some studies suggest that in very small amounts, chromium may be essential to human beings, but it has not been proven. Chromium VI or Hexavalent Chromium was the subject of the Erin Brockovich case and movie. What is the MCL and MCLG for Chromium?
- a. 1.0 ppb
 - b. 10 ppb
 - c. 1.0 ppm
 - d. 0.1 ppm
4. In order to prevent methemoglobinemia (blue baby syndrome)/diuresis, _____ is monitored annually in groundwater and quarterly in surface water initially and then annually. The MCL is 10 mg/L.
- a. nitrite
 - b. nitrate
 - c. sodium
 - d. chloride
5. Microbiological contamination often causes flu-like symptoms; however, it can also cause serious diseases. Which of the following is not a water borne disease?
- a. Hepatitis
 - b. AIDS
 - c. Giardiasis
 - d. Legionnaire's Disease
6. The Revised Total Coliform Rule establishes an MCLG and an MCL for *E. coli* and eliminates the MCLG and MCL for total coliforms, replacing them with treatment techniques for coliforms that require assessment and corrective action. EPA has established an MCLG of _____ for *E. coli*, which is a more specific indicator of fecal contamination than those pathogens that are potentially more harmful than total coliform.
- a. zero
 - b. one
 - c. three
 - d. depends on the number of samples that are taken each month by the water purveyor

7. In the Code of Federal Regulations Reference: 40 CFR 141.24, _____ is the only contaminant that has been shown to cause cancer for which standards have been set.
- a. Arsenic
 - b. Chromium
 - c. Radioactivity
 - d. THMs
8. Which of the following contaminants can potentially cause mental deficiencies primarily in children, if found in drinking water above the maximum level allowed by Safe Drinking Water Act?
- a. Copper
 - b. Arsenic
 - c. Mercury
 - d. Lead

CHAPTER 10: SECONDARY STANDARDS

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Describe the secondary standards
- Outline the secondary contaminants
- Explain physical standards
- Outline levels of violations

SECONDARY STANDARDS

Enforcement of Regulations

The National Secondary Drinking Water Regulations control contaminants in drinking water that primarily affect the aesthetic qualities relating to the public acceptance of drinking water. These regulations are called **secondary standards**. At considerably higher concentrations of these contaminants, health implications may also exist as well as aesthetic (or appearance) degradation. These regulations are not federally enforceable; however, some states have passed laws requiring the state health agency to enforce the regulations.

SECONDARY MAXIMUM CONTAMINANT LEVELS

Secondary Maximum Contaminant Levels (SMCLs) apply to public water systems and, in the judgment of the EPA Administrator, are necessary to protect the public welfare or for public acceptance of the drinking water. The SMCL means the maximum permissible level of a contaminant that is delivered to the free-flowing outlet of the ultimate user of a public water system.

Contaminants added to the water under circumstances controlled by the user, except those contaminants resulting from corrosion of piping and plumbing caused by water quality, are excluded by definition. The only exceptions are those resulting from corrosion of piping and plumbing caused by water quality. Currently, 15 secondary standards exist. States may establish higher or lower levels depending on local conditions, providing that public health and welfare are adequately protected.

Aesthetic qualities are important factors in public acceptance and confidence in a public water system. States are encouraged to implement SMCLs so that the public will not be driven to obtain drinking water from potentially lower-quality, higher risk sources. Many states have chosen to enforce Primary and SMCLs to ensure that the consumer is provided with the best quality water available.

MONITORING

In order to monitor, you must collect samples for secondary contaminants at a free-flowing outlet of water being delivered to the consumer. Monitor contaminants in these regulations at least as often as the monitoring performed for inorganic chemical contaminants listed in the Primary Drinking Water Regulations as applicable to community water systems. For surface water systems, the rule means yearly monitoring is required; for groundwater systems, monitor at least once every three years. Collect monthly distribution system physical water quality monitoring samples for color and odors. More frequent monitoring would be appropriate for specific contaminants such as pH, color, odor, or others, under certain circumstances as directed by the state.

SECONDARY CONTAMINANTS

Aluminum

Until relatively recently, most environmental aluminum was found in forms that did not greatly affect humans and other animals. Acid rain, however, has caused a significant increase in aluminum exposure. The average daily intake of aluminum in the general population is about 20 milligrams per day; the SMCL is 0.05 to 0.2 mg/L. Although aluminum is regulated as a secondary contaminant because precipitates of the metal can cause cloudy-looking water, aluminum compounds may also interfere with absorption of fluoride in the gastrointestinal tract and may decrease the absorption of calcium, iron, and cholesterol. Many over-the-counter antacids contain aluminum and use of these products frequently causes constipation, which is thought to be the result of the gastrointestinal effects.

Chloride

The SMCL for chloride is 250 mg/L.

Undesirable Effects

- Objectionable salty taste in water
- Corrosion of the pipes in hot water systems and other pipelines

Studies Concerning the Mineralization Effects of Water Indicate

- Major taste effects are produced by anions (where TDS was studied).
- Chloride produces a taste effect somewhere between the milder sulfate and the stronger carbonate.
- Laxative effects are caused by highly mineralized waters.

Mineralized waters often contain chloride as well as high levels of sodium and magnesium sulfate.

Corrosion Effects

- Studies indicate that corrosion depends on concentration of TDS (TDS may contain 50 percent chloride ions).
- Domestic plumbing, water heaters, and municipal waterworks equipment will deteriorate when high concentrations of chloride ions are present.

Example

Where the TDS = 200 mg/L (Chloride = 100 mg/L), water heater life will range from 10 to 13 years. Water heater life declines uniformly as a function of TDS-1 year shortened life per 200 mg/L additional TDS.

Color

The SMCL for color is 15 color units. The level of this water quality indicator is not known to be a measure of the safety of water. However, high color content may indicate the following:

- High organic chemical contamination
- Inadequate treatment
- High disinfectant demand and the potential for production of excess amounts of DBPs

Color may be caused by:

- Natural color-causing solids such as aromatic, polyhydroxy, methoxy, and carboxylic acids
- Fulvic and humic acid fractions
- Presence of metals such as copper, iron, and manganese

Rapid changes in color levels may provoke more citizen complaints than relatively high, constant color levels.

Copper

The SMCL for copper is 1.0 mg/L. Soft water containing a low level (0.5 mg/L) of copper may cause blue or blue-green staining of porcelain. Higher levels (4 mg/L) of copper will stain clothing and blond hair. When soap is used with water having a copper concentration greater than 1 mg/L, insoluble green curds will form.

Corrosivity

The corrosivity of water indicates the rate at which water causes the gradual decomposition or destruction of a material (such as a metal or cement lining). The severity and type of corrosivity are dependent on the chemical and physical characteristics of the water and the material.

Corrosivity causes materials to deteriorate and go into solution (be carried by the water). Corrosion of toxic metal pipe materials such as lead can create a serious health hazard.

Corrosion of iron may produce a flood of unpleasant telephone calls from consumers complaining about rusty water, stained laundry, and bad tastes.

Corrosivity can cause the reduction of the carrying capacity of a water main. This reduced carrying capacity can cause an increase in pump energy costs and may reduce distribution system pressures. Leaks in water mains due to corrosivity may eventually require replacement of a water main.

Fluoride

Fluoride produces two effects, depending on its concentration. At levels of 6 to 8 mg/L, fluoride may cause skeletal fluorosis (the bones become brittle) and stiffening of the joints. For this reason, fluoride has been added to the list of primary standards (having health effects).

At levels of 2 mg/L and greater, fluoride may cause dental fluorosis, which is discoloration and mottling of the teeth, especially in children. EPA has recently reclassified dental fluorosis as a cosmetic effect, raised the primary drinking water standard from 1.4 to 2 mg/L to 4 mg/L, and established a secondary standard of 2 mg/L for fluoride.

Foaming Agents

The SMCL for foaming agents is 0.5 mg/L.

Undesirable Effects

1. Causes frothing and foaming, which are associated with contamination (greater than mg/L)
2. Imparts an unpleasant taste (oily, fishy, perfume-like) (less than 1.0 mg/L)

Information

1. Because no convenient foamability test exists and because surfactants are one major class of substances that cause foaming, this property is determined indirectly by measuring the anionic surfactant (MBAS) concentration in the water.
2. Surfactants are synthetic organic chemicals and are the principal ingredient of household detergents.
3. The requirement for biodegradability led to the widespread use of linear alkylbenzene sulfonate (LAS), an anionic surfactant.
4. Concentrations of anionic surfactants found in drinking waters range from 0 to 2.6 mg/L in well supplies and 0 to 5 mg/L in surface water supplies.
5. LAS is essentially odorless. The odor and taste characteristics are likely to arise from the degradation of waste products rather than the detergents.
6. If water contains an average concentration of 10 mg/L surfactants, the water is likely to be entirely of wastewater origin.
7. From a toxicological standpoint, an MCL of 0.5 mg/L, assuming a daily adult human water intake of 2 liters, would give a safety factor of 15,000.

Iron and Manganese

1. Iron and manganese are frequently found together in natural waters and produce similar adverse environmental effects and color problems. Excessive amounts of iron and manganese are usually found in groundwater and in surface water contaminated by industrial waste discharges.
2. Before 1962, these elements were covered by a single recommended limit.
3. In 1962, the US Public Health Service recommended separate limits for iron and manganese to reflect more accurately the levels at which adverse effects occur for each.
4. Each are highly objectionable in large amounts in water supplies for domestic and industrial use.
5. Each element imparts color to laundered goods and plumbing fixtures.
6. Taste thresholds in drinking water are considerably higher than the levels that produce staining effects.
7. Each element is part of the daily nutritional requirements; however, these requirements are not met by the consumption of drinking water.

Iron

The SMCL for iron is 0.3 mg/L.

Undesirable Effects

1. At levels greater than 0.05 mg/L some color may develop, staining of fixtures may occur, and precipitates may form.
2. The magnitude of the staining effect is directly proportional to the concentration.
3. Depending on the sensitivity of taste perception, a bitter, astringent taste can be detected from 0.1 mg/L to 1.0 mg/L.
4. Precipitates that are formed create not only color problems but also lead to bacterial growth of slimes and of the iron loving bacteria, *Crenothrix*, in wells and distribution piping.

Nutritional Requirements

1. Daily requirement is 1 to 2 mg; however, intake of larger quantities is required as a result of poor absorption.
2. The limited amount of iron permitted in water (because of objectionable taste or staining effects) constitutes only a small fraction of the amount normally consumed and does not have toxicologic (poisonous) significance.

Manganese

The SMCL for manganese is 0.05 mg/L.

Undesirable Effects

1. A concentration of more than 0.02 mg/L may cause buildup of coatings in distribution piping.
2. If these coatings slough off, they can cause brown blotches in laundry items and black precipitates.
3. Manganese imparts a taste to water above 0.15 mg/L.
4. The application of chlorine, even at low levels, increases the likelihood of precipitation of manganese at low levels.
5. Unless the precipitate is removed, precipitates reaching pipelines will promote bacterial growth.

Toxic Effects

1. Toxic effects are reported as a result of inhalation of manganese dust or fumes. Liver cirrhosis has arisen in controlled feeding of rats.
2. Neurological effects have been suggested; however, these effects have not been scientifically confirmed.

Nutritional Requirements

1. Daily intake of manganese from a normal diet is about 10 mg.
2. Manganese is essential for proper nutrition.
3. Diets deficient in manganese will interfere with growth, blood and bone formation, and reproduction.

Odor

The SMCL for odor is a Threshold Odor Number (TON) of 3.

Important facts to remember when dealing with odors include:

1. Taste and odor go hand-in-hand.
2. Absence of taste and odor helps to maintain the consumers' confidence in the quality of their water, even though it does not guarantee that the water is safe.
3. Research indicates that there are only four true taste sensations: sour, sweet, salty, and bitter.
4. All other sensations ascribed to the sense of taste are actually odors, even though the sensation is not noticed until the material is taken into the mouth.
5. Odor tests are less fatiguing to people than taste tests when testing for tastes and odors.
6. Taste and odor tests are useful:
 - a. As a check on the quality of raw and treated water

- b. To help control odor throughout the plant
- 7. Odor is a useful test:
 - a. For determining the effectiveness of different kinds of treatment
 - b. As a means for tracing the source of contaminants
- 8. Hydrogen sulfide is included under the odor SMCL.

pH

The SMCL for pH is defined as pH values beyond the acceptable range from 6.5 to 8.5. A wide range of pH values in drinking water can be tolerated by consumers.

Undesirable Effects

- 1. When the pH increases, the disinfection activity of chlorine falls significantly.
- 2. High pH may cause increased halogen reactions, which produce chloroform and other THMs during chlorination.
- 3. Both excessively high and low pHs may cause increased corrosivity, which can, in turn, create taste problems, staining problems, and significant health hazards.
- 4. Metallic piping in contact with low-pH water will impart a metallic taste.
- 5. If the piping is iron or copper, high pH will cause oxide and carbonate compounds to be deposited, leaving red or green stains on fixtures and laundry.
- 6. At a high pH, drinking water acquires a bitter taste.
- 7. The high degree of mineralization often associated with basic waters results in encrustation of water pipes and water-using appliances.

Silver

Silver is a nonessential element, providing no beneficial effects from its ingestion in trace amounts. Chronic toxicity causes an unsightly blue-gray discoloration of the skin, mucous membranes, and eyes. Apparently, beside cosmetic changes, no physiologic effects are known. Ingestion of trace amounts of silver or silver salts results in its accumulation in the body, particularly the skin and eyes. Some evidence exists that changes to the kidneys, liver, and spleen can occur.

The SMCL for silver is 0.10 mg/L.

Sulfate

The SMCL for sulfate is 250 mg/L.

Undesirable Effects

- 1. Tends to form hard scales in boilers and heat exchangers.
- 2. Causes taste effects.
- 3. Causes a laxative effect. This effect is commonly noted by newcomers or casual or intermittent users of water high in sulfate. Water containing more than 750 mg/L of

sulfate usually produces the laxative effect while water with less than 600 mg/L sulfate usually does not. An individual can adjust to sulfate in drinking water.

4. Sodium sulfate and magnesium sulfate are more active as laxatives, whereas calcium sulfate is less active.
5. When the magnesium sulfate content is 200 mg/L, the most sensitive person will feel the laxative effect; however, magnesium sulfate levels between 500 mg/L and 1,000 mg/L will induce diarrhea in most individuals.
6. Tastes may sometimes be detected at 200 mg/L of sulfate, but generally are detected in the range of 300 to 400 mg/L.

Total Dissolved Solids (TDS)

The SMCL for total dissolved solids is 500 mg/L.

Undesirable Effects

1. TDS imparts adverse taste effects at greater than 500 mg/L.
2. Highly mineralized water influences the deterioration of distribution systems as well as domestic plumbing and appliances (the life of a water heater will decrease one year with each additional 200 mg/L of TDS above a typical 200 mg/L value).
3. Mineralization can also cause precipitates to form in boilers and other heating units, sludge in freezing processes, rings on utensils, and precipitates in food being cooked.
4. There may be a great difference between a detectable concentration and an objectionable concentration of the neutral salts. Many people can become accustomed to high levels.
5. Studies show that the temperature of mineralized waters influences their acceptability to the public.

Zinc

The SMCL for zinc is 5 mg/L.

Undesirable Effects

1. High concentrations of zinc produce adverse physiological effects.
2. Zinc imparts a bitter, astringent taste that is distinguishable at 4 mg/L. Also, at 4 mg/L a metallic taste will exist.
3. Zinc will cause a milky appearance in water at 30 mg/L.
4. Zinc may increase lead and cadmium concentrations.
5. The activity of several enzymes is dependent on zinc. Enzymes are proteins that catalyze chemical reactions. Zinc is an essential enzyme growth element in terms of nutrition at low doses (zinc must be present) and is toxic to enzymes at high doses.
6. Cadmium and lead are common contaminants of zinc used in galvanizing steel pipe.

Physiological Effects

1. A concentration of 30 mg/L can cause nausea and fainting.
2. Zinc salts act as gastrointestinal irritants. This symptom of illness is acute and transitory.
3. The vomiting concentration range is 675 to 2,280 mg/L.
4. A wide margin of safety exists between normal food intake and concentrations in water high enough to cause oral toxicity.

Dietary Requirements

1. The daily requirement for preschool children is 0.3 mg Zn/ kg of weight.
2. Total zinc in an adult human body averages two grams.
3. Zinc most likely concentrates in the retina of the eye and in the prostate.
4. Zinc deficiency in animals leads to growth retardation.

Key Terms

- **Secondary standards** – federal and state standards for contaminants that affect the aesthetic qualities relating to the public acceptance of drinking water
- **Secondary Maximum Contaminant Level** – levels that apply to public water systems and are necessary to protect public welfare or for public acceptance of the drinking water

REVIEW QUESTIONS

1. Explain the Secondary Maximum Contaminant Levels found in the Safe Drinking Water Act.
 2. What is the SMCL for chloride?
 3. What is the SMCL for color?
 4. What is the MCL and the SMCL for fluoride?
 5. What is the SMCL for TDS (total dissolved solids)?

CHAPTER QUIZ

1. _____ apply to public water systems and, in the judgment of the EPA, are necessary to protect the public welfare or for public acceptance of the drinking water. The rule means the maximum permissible level of a contaminant that is delivered to the free-flowing outlet of the ultimate user of a public water system. This maximum is not enforceable under EPA, but recommended: however, in some states, these levels are enforceable by law.
 - a. Maximum Contaminant Levels
 - b. Maximum Contaminant Level Goals
 - c. Secondary Maximum Contaminant Levels
 - d. Unregulated Contaminant Levels
2. _____ are important factors in public acceptance and confidence in a public water system. States are encouraged to implement SMCLs so that the public will not be driven to obtain drinking water from potentially lower-quality, higher risk sources. Many states have chosen to enforce Primary and Secondary Contaminant Levels to ensure that the consumer is provided with the best quality water available.
 - a. Biological contaminants
 - b. Chemical contaminants
 - c. Aesthetic qualities
 - d. Radiologic contaminants
3. Although _____ is regulated as a secondary contaminant because precipitates of the metal can cause cloudy-looking water, this contaminant may interfere with absorption of fluoride in the gastrointestinal tract and may decrease the absorption of calcium, iron, and cholesterol.
 - a. aluminum
 - b. zinc
 - c. silver
 - d. manganese
4. _____ may be caused by aromatic, polyhydroxy, methoxy, and carboxylic acids, as well as fulvic and humic acid fractions, and the presence of metals such as copper, iron, and manganese. Changes these levels may provoke citizen complaints.
 - a. Taste
 - b. Odor
 - c. Color
 - d. Laxative effects

5. The SMCL for _____ are a TON of 3. This contaminant is a useful test for determining the effectiveness of different kinds of treatments and as means for tracing the source of contaminants.
- tastes
 - odors
 - colors
 - Laxative effects
6. Sulfates tend to form hard scales in boilers and heat exchangers, cause taste effects, and _____ are commonly noted by newcomers or casual or intermittent users of water high in sulfate.
- tastes
 - odors
 - colors
 - laxative effects
7. The SMCL for _____ is 5 mg/L. High concentrations produce adverse physiological effects. It imparts a bitter, astringent taste that is distinguishable at 4 mg/L and will cause a milky appearance in water at 30 mg/L. The daily requirement for preschool children is 0.3 mg / kg of weight. A deficiency in animals leads to growth retardation.
- silver
 - TDS
 - zinc
 - manganese
8. The SMCL for _____ is 250 mg/L. The undesirable effects of this contaminant is an objectionable salty taste in water and corrosion of the pipes in hot water systems and other pipelines. Domestic plumbing, water heaters, and municipal waterworks equipment will deteriorate when high concentrations are present.
- chloride
 - TDS
 - zinc
 - manganese

9. The SMCL for _____ is 0.05 mg/L. Undesirable effects include coatings in distribution piping, brown blotches in laundry items and black precipitates, and a taste to water above 0.15 mg/L. Unless the precipitate is removed, precipitates reaching pipelines will promote bacterial growth. Liver cirrhosis has arisen in controlled feeding of rats. It is essential for proper nutrition, and diets deficient in manganese will interfere with growth, blood and bone formation, and reproduction.
- a. chloride
 - b. TDS
 - c. zinc
 - d. manganese
10. The SMCL for _____ is 500 mg/L. The undesirable effects include adverse taste effects at greater than 500 mg/L, the deterioration of distribution systems as well as domestic plumbing and appliances, and it causes precipitates to form in boilers and other heating units.
- a. chloride
 - b. TDS
 - c. zinc
 - d. manganese

CHAPTER 11: DISTRIBUTION SYSTEM WATER QUALITY

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Describe sampling procedures
- Describe water quality parameters
- Explain the causes behind water degradation in the distribution system
- Explain the risks of cross-connection
- Explain corrosion
- Describe data reporting
- Outline problem resolution

SAMPLING

All of the drinking water regulations apply to all public water systems. It makes no difference whether the water system is publicly or privately owned. A **public water system (PWS)** is defined as any system that has the following characteristics:

1. Has at least 15 service connections
2. Regularly serves an average of at least 25 individuals daily at least 60 days out of the year



Figure 11.1³¹

Any water system that provides services for fewer connections or persons than these rules outline are not covered by the Safe Drinking Water Act. Certain other individuals and

³¹ [Image](#) by [Bob White](#) is licensed under [CC BY-NC-ND 2.0](#)

residences also are excluded, such as those whose water is supplied by an irrigation, mining, or industrial water system. However, regardless of size, all operators must strive to provide consumers with a potable drinking water.

Drinking water regulations also take into account the type of population served by the system and classify water systems as community or non-community systems. Therefore, in order to understand what requirements apply to any specific system, it is first necessary to determine whether the system is considered a community system or a non-community system.

A **community water system** is defined as a public water system that has the following characteristics:

1. Has at least 15 service connections used by all-year residents
2. Regularly serves at least 25 all-year residents

Any public water system that is not a community water system is classified as a non-community water system. Restaurants, campgrounds, and hotels could be considered non-community systems for purposes of drinking water regulations.



Figure 11.2³²

In addition to distinguishing between community and non-community water systems, EPA identifies some small systems as non-transient non-community systems if they regularly serve at least 25 of the same persons over 6 months per year. This classification applies to water systems for facilities such as schools or factories where the consumers served are nearly the

³² [Image](#) by the [NPS](#) is in the public domain

same every day but do not actually live at the facility. In general, non-transient non-community systems must meet the same requirements as community systems.

A transient non-community water system is a system that does not regularly serve drinking water to at least 25 of the same persons over 6 months per year. This classification is used by EPA only in regulating nitrate levels and total coliform. Examples of a transient non-community system might be campgrounds or service stations if those facilities do not meet the definition of a community, non-community, or non-transient non-community system.

EPA has revised the Total Coliform Rule so that public water systems in the US take steps to ensure the integrity of the drinking water distribution system and monitoring for the presence of microbial contamination. Public water systems and the state and local agencies that oversee them must comply with the Revised Total Coliform Rule (RTCR) beginning April 1, 2016. The final RTCR requires the following:

1. Public water systems are to notify the public if a test exceeds the MCL for *E. coli* in drinking water
2. Public water systems that are at risk and therefore vulnerable to microbial contamination are required to identify and fix the problems, including the potential sources and the pathways of contamination
3. Criteria will be used for public water systems that are well operated to qualify for and stay on reduced monitoring, which could reduce water system burden
4. Provide incentives for better system operation, in particular small systems
5. Require additional monitoring requirements for seasonal systems such as campgrounds and state and national parks

The RTCR establishes an MCLG and an MCL for *E. coli* and eliminates the MCLG and MCL for total coliforms, replacing them with treatment techniques for coliforms that require assessment and corrective action. EPA has established an MCLG of zero for *E. coli*, which is a more specific indicator of fecal contamination and those pathogens that are potentially more harmful than total coliform. EPA has removed the 1989 MCLG and MCL for total coliforms, although the acute total coliform MCL violation under the 1989 TCR has been maintained as the MCL for *E. coli* under the RTCR.

Under the new treatment technique, total coliforms serve as the indicator of a potential pathway of contamination into the system's distribution system. Public water supplies that exceed a specified frequency of total coliform occurrence must conduct an assessment to determine if any sanitary deficiencies exist; if found, they must be corrected. A public water system that experiences an *E. coli* MCL violation must conduct an assessment and correct any sanitary defects that are identified.

Monthly notification requirements based only on the presence of total coliforms will no longer be required. Instead, the RTCR will require public notification when an *E. coli* MCL violation occurs, indicating a potential health threat or when a water system fails to assess and take corrective action.

Sampling Plan

The Total Coliform Rule requires each water supply system to develop and follow a written sampling plan. Each plan must specifically identify sampling points throughout the distribution system. Sampling plans must be approved by the state regulatory agency and it is necessary to check with the state agency to determine the details of their review process and what documents need to be submitted.

DATA AND REPORTING

Monitoring Frequency

The routine monitoring frequency for community water systems is based on the population served. Routine monitoring frequencies for non-community systems are based on the source of supply and, in some cases, the population served. Whenever a routine sample tests positive for total coliform, two provisions of the Total Coliform Rule take effect: repeat samples (formerly referred to as check samples) must be taken and the original coliform-positive sample must be tested for the presence of fecal coliforms or *E. coli* to determine whether an actual or potential violation of the coliform MCL exists.

The reason repeat samples are required is to investigate whether the original coliform-positive sample was caused by a contamination problem that exists throughout the distribution system or if it is a localized problem that exists only at that one sampling point. With this information, appropriate corrective action can be taken to eliminate the problem as quickly as possible.

The Total Coliform Rule specifies how many repeat samples must be taken, when, and from what locations. It also directs the water utility to collect a specific number of samples the following month, based on the number of routine samples ordinarily collected.

Non-community systems serving more than 1,000 people have the same requirements as community water systems. Non-community systems serving fewer than 1,000 people are required to collect one routine sample per quarter. When the routine sample tests positive, four repeat samples are required in the same quarter and five samples are required the following quarter.

Whenever a routine or repeat sample tests positive for total coliform, the water agency must collect a set of three or four repeat samples within 24 hours of receiving the laboratory results. At least one of the repeat samples must be taken from the same tap as the original coliform-positive sample; the remaining repeat samples in the set must be collected at nearby taps (within five service connections of the original sampling point), upstream and downstream of the original.

Repeat samples st be taken until no coliforms are detected or until the MCL is exceeded and the state is notified.

Determining Compliance

The MCLG for total coliforms (including fecal coliforms and *E. coli*) is zero. The MCL, based on the presence-absence concept, is as follows:

1. For water systems analyzing at least 40 samples per month, no more than 5.0 percent of the samples (including routine and repeat samples) may be positive for total coliforms.
2. For water systems analyzing fewer than 40 samples per month, no more than one sample per month may be positive for total coliforms.

The Total Coliform Rule makes another significant change in the way compliance is calculated. All valid coliform-positive samples, routine and repeat samples, must be counted when calculating compliance with the monthly MCL. Under previous regulations, check or repeat samples were not included in the monthly MCL calculation. On a case-by-case basis, the state may declare a sample invalid for one of several reasons, including interference by heterotrophic bacteria during laboratory analysis, as previously discussed.

Total-coliform-positive samples may be invalidated by the state under any of the following conditions:

1. The analytical laboratory acknowledges that improper sample analysis caused the positive result
2. The state determines that the contamination is a local plumbing problem
3. The state has substantial grounds to believe that the positive result was unrelated to the quality of drinking water in the distribution system

Reporting and Notification Requirements

Reporting frequencies for coliform test results increase in step with the urgency of the problem. A water agency must report the results of monthly coliform testing to the state regulatory agency within the first 10 days of the following month.

Any time a water agency fails to collect a sample as required, the state must be notified within 10 days after the system learns of the violation. An invalid sample result is considered a failure to monitor and must be reported.

If the MCL is exceeded, the state must be notified no later than the end of the next business day and the public within 14 days. This requirement could occur when the water agency exceeds its monthly coliform-positive limit or when test results show the presence of fecal coliforms or *E. coli* in any sample.

The most critical situation exists when either of two situations occurs:

1. A routine sample tests positive for total coliforms and for fecal coliforms or *E. coli*, and any repeat sample tests positive for total coliforms.
2. A routine sample tests positive for total coliforms and negative for fecal coliforms or *E. coli*, and any repeat sample tests positive for fecal coliforms or *E. coli*.

These situations are considered an acute risk to health. This occurrence is a Tier 1 violation, which requires that the state and the public be notified within 24 hours.

WATER QUALITY

The water industry supplies one product. Potable water as in any industry, must be of good quality to ensure the acceptability of the product. Water quality standards have been prepared and set by law. Water quality standards have changed considerably over the years. Increased knowledge of the substances found in water supplies and their effects has led to substantial revisions in the types and the concentrations of substances allowable in water supplies.

Water quality is used to describe the chemical, physical, and biological characteristics of a water source or a water supply. Water quality depends on the context of usage that is the suitability of the water for a particular use. A domestic water supply is considered to be of high quality when it is free of disease-causing organisms (pathogenic), toxic chemicals, attractive in taste and appearance, of such chemical composition that it may be distributed without corrosive or scale-forming effects on the water distribution system, and will satisfy the requirements of domestic and industrial customers.

The quality of water that is received by the distribution systems depends on the quality of the water sources that are used and the type of treatment that is provided. Initially, water quality depends on the prevention of contamination and pollution of the source water. If water quality control is not established at the source, then any problems during the treatment process can result in delivery of questionable water quality to the distribution system. The primary responsibility of the treatment plant is to produce a safe and aesthetically pleasing water. And the treatment plant must deliver to the distribution system water that is minimally corrosive to the distribution system.

The importance of providing water of acceptable quality is paramount. Delivering a poor quality water can result in a range of consequences from the water not being acceptable to the consumer because of its appearance or taste to illnesses caused by contamination. Utilities and operators are responsible for the quality of the water that is served to customers. The quality of treated water put into the water distribution system from water treatment plants is high. The most pervasive water quality problem that affects most American communities results from the deterioration of water quality within water distribution systems.

DISTRIBUTION SYSTEMS

Conditions exist in the distribution system that could result in degradation of water quality in the distribution system. The system operator must be aware of them and take corrective or protective measures where possible.

Causes of Quality Degradation

Cross-connections

A **cross-connection** is an unprotected connection between a part of a water system used or intended to be used to supply water for drinking purposes and any source or system containing water or a substance that is not or cannot be approved as safe drinking water. It is a connection between a regulated and approved drinking source and an unregulated drinking water source.

Contamination from backflow of unacceptable substances through cross-connection to distribution systems has consistently caused more water borne disease outbreaks in the United States than any other reported factor. Backflow can occur through a cross-connection by backsiphonage or back pressure.

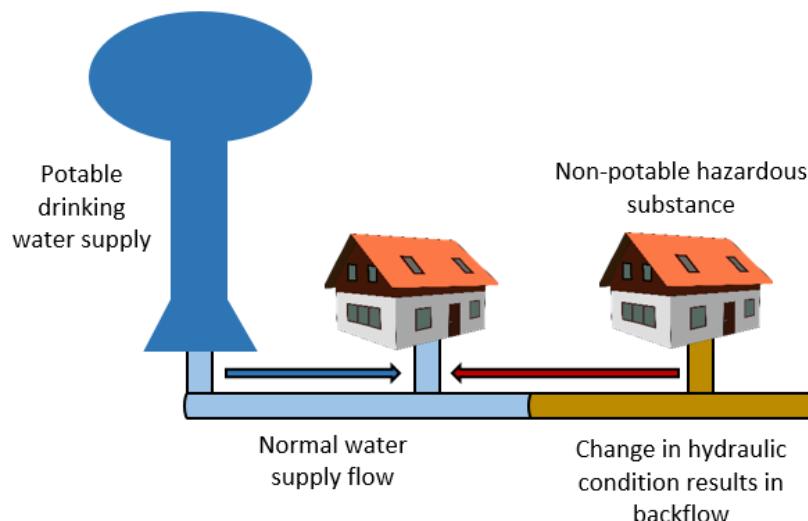


Figure 11.3: Cross-connection in distribution system³³

Backsiphonage is a form of backflow caused by a negative or below atmospheric pressure within the water supply piping. Backsiphonage can develop from such causes as main breaks, an inadequate source of supply capacity, undersized mains, unusual water demands, planned shutdowns for maintenance or repair, or the use of on-line booster pumps. Backflow caused by back pressure can occur when the user's water system is at a higher pressure than the public water system.

Cross-connections in the distribution system are potentially very hazardous, and they can be a source of taste and odor complaints. Cross-connections commonly occur in these instances:

1. A sprinkler system using non-potable water is connected to a potable water supply.
2. A potable water source is used as a seal supply is connected to a pump delivering unapproved or non-potable water.

³³ [Image](#) by [Machovka](#) is licensed under [CC0 1.0](#) (modified by [COC OER](#))

3. A hose connected to a house is left in a swimming pool. When water is drawn from indoor taps, the hose sucks the pool water into the potable water supply because of the pressure differences.
4. A hose connected to the house is used to apply chemical fertilizers or pesticides. Without a vacuum breaker or other backflow-prevention device at the house connection, the chemicals will enter the potable water supply.

Corrosion

Corrosion is the gradual deterioration or destruction of a substance or material by chemical action proceeding inward from the surface. Corrosion is frequently induced by electrochemical reaction. Corrosion is of significant health and economic, as well as aesthetic, significance. Elevated levels of toxic or suspected toxic substances such as lead, cadmium, copper, zinc, asbestos, and certain organic compounds have been found in water being served from distribution systems as the result of corrosive action of water on distribution system materials. Increased incidences of cardiovascular disease have been associated with consumption of soft corrosive water.

The greatest water quality nuisance is the corrosive and precipitation of iron. Across the United States, red water is the most common consumer complaint as a result of iron in pipes. In this instance, it appears that a number of different microorganisms are involved. Bacteria are rarely absent where iron is found in abundance in treated water. The iron bacteria, *Crenothrix*, are of special concern. These bacteria precipitate iron, which forms the deposits in pipes, reduces carrying capacity, and produces color in water. The dead organisms also impart a disagreeable taste to the water. Improper potassium permanganate feed may also cause red-colored water.



Figure 11.4: Pipe with corrosion³⁴

Of the materials used for construction of water systems, metals are the most susceptible to corrosion; however asbestos cement pipe is also susceptible. Plastic pipe is the least susceptible to corrosion. To prevent corrosion of cast-iron (ductile-iron) or steel pipes and to aid in the curing of cement-lined pipes, the inner side of these pipes may be lined with asphalt or coal tar materials. The types and durability of coating for corrosion control are of special importance.

³⁴ [Image](#) by [Mr pantswearer](#) is licensed under [CC BY-SA 4.0](#)

Some coatings, on the other hand, can impart taste and odors to the water. Because of its importance and complexity, corrosion is attempted to be mitigated and controlled during the water treatment process at the water treatment plant.

Biofilm

Some microorganisms enter the water and can interact with distribution system. Water with turbidity as low as 3.8 units has been reported to have coliform bacteria, and these bacteria have been reported to have survived consistently observed 0.1 to 0.5 mg/L free chlorine residual after 30 minutes contact time. Some non-coliform bacteria are more resistant. The survival and regrowth of these organism is affected by such factors as the amount of exposure to residual concentrations of chlorine, the amount of bacterial nutrients in the deposits, and water temperatures. The term after growth has been used to describe the development of coliform organisms in distribution systems even though water delivered to the system meets bacterial standards and where other causes of contamination of the water appear unlikely.

Pockets of sediment deposited in the distribution system or pipe encrusted with chemical deposits may form a protected habitat for these organisms. Such deposits often consist of silt, coagulants, precipitated chemicals, or products of corrosion. Some deposits have been found to contain bacterial populations of several thousand organisms.

Slimes are organic substances of a viscous nature formed from microbiological growth. Tastes and odors can be produced by slime growths of organisms that thrive on ammonia, iron, sulfide, and methane. The development of iron bacteria, *Crenothrix*, also results in slime growths.

Increasing levels of microbial activity ultimately results in increased consumer complaints as well as accelerated corrosion and reduced flow from grater turbulence along the pipe walls. Taste and odor problems can result from the death and decay of organisms after heavy chlorination.

Biofilms are the result of interactions among microorganisms. The organisms form micro-colonies and secrete extracellular material that makes them highly resistant to biocides. A common example of a biofilm is the black stain around the bottom of a shower curtain. Biofilms appear as a patchy mass within a pipe or as a uniform film inside a storage tank. The majority of microbial growth within a water distribution system occurs within the biofilms at the surface of the pipe and not in the water flowing in the pipe.

Biofilms grow easier on materials that supply nutrients, such as rubber gaskets or certain oils used in pumps. They need carbon, nitrogen, and phosphate in a ratio of 100:10:1. Iron is also an essential growth nutrient of limited supply in the water in a distribution system. Biofilm activity proceeds year round; however, the growth rate is faster during warmer months. Corrosion area in iron pipe are often sites with the highest microbial activity.

Microbial control requires a good disinfectant residual. This residual can be accomplished with chlorine as either free chlorine, chloramines, or chlorine dioxide. Chlorine is considered the more powerful disinfectant than chloramines. Chloramines are more persistent in a distribution system and will eventually penetrate farther into the system for a longer period of time. This persistence is the reason chloramines are more effective against troublesome biofilms, than free chlorine. Free chlorine will attack biofilms and exhaust quickly, whereas chloramines will continue to attack the biofilm and slowly break down the defense of the biofilm. In chloraminated distribution systems, switching to free chlorine a few weeks before flushing each year can be an effective method to remove bacteria that have become accustomed to chloramines.

The link between corrosion and biofilm control is a concern of distribution system operators. Iron corrosion control is more difficult to control than lead and copper corrosion control. When iron pipe corrodes, the accumulation of corrosion products on the pipe surface interferes with the ability of the disinfectant to penetrate the biofilm and inactivate the bacteria. Improved corrosion controls through pH control, adjusting alkalinity, and corrosion inhibitors improves biofilm disinfection. A concern exists among operators that phosphate-based corrosion inhibitors stimulates bacterial growth. Zinc orthophosphate has effectively controlled corrosion for compliance with the Lead and Copper Rule and also has been associated with improved microbial water quality. Because the corrosivity of water changes seasonally, some agencies are increasing the use of corrosion inhibitors during the warmer summer months when biofilm regrowth problems are most common.

Temperature

Water temperature has three major impacts on distribution system water quality:

1. Higher temperatures tend to speed the rate of chemical reactions and increase biological growth rates
2. Biological decomposition may be intensified by summer temperatures
3. Chlorine demand may be considerably greater in summer so residuals will not carry as far in the distribution system

Flow

Large variations in flow through a system may adversely affect water quality in three ways:

1. Changes in water velocity and flow reversals can result in sediments being stirred up and carried along until they reach the consumer
2. Low circulation and stagnant water can result in the growth of organisms, formation of sediments, corrosion products, depletion of oxygen, and increased tastes and odors
3. Turbulence can entrain air into the supply causing milky water, which is objectionable to consumers

Time in System

The age of water at a particular point in the distribution system can influence water quality. Water delivered to consumers close to the source might be only minutes old, while that water

received at remote parts of the system might have been in the system for several days or more depending on storage and demands. The longer water is in the system, the more time is available for chemical and biological changes to take place.

Age of Facility

As water mains and reservoirs become older, they require more maintenance. Gradual deterioration in protection against corrosion can lead to water quality problems. Ruptures and leaks in piping become more frequent. In older systems, it is not uncommon to find that the pipes and tanks were of poor construction when installed and have had little or no protective coatings.

Operation

Careless or poor operating procedures can also result in water quality degradation. Inadequate cross-connection control, poorly performed water quality monitoring and flushing programs, tolerance of low or negative pressures in the distribution system, insufficient surveillance to determine whether the protective features for storage facilities and mains are adequate, inadequate disinfection after repair or installation of new facilities, and disregard for the hazards of installing facilities such as sewers in close proximity to water lines and reservoirs are examples of operational problems resulting in water quality issues. The lack of trained, qualified, adequately paid operators contribute to water quality problems as well.

WATER QUALITY DEGRADATION IN WATER MAIN

Water quality deterioration can occur in water mains because of pipe characteristics, materials, construction, and location.

Large Surface Areas

Substance can be deposited, biological growths can be attached, and corrosion reactions can take place on the inside surfaces of pipe walls. The large interior surface area provides considerable space for these activities to take place. Reduced flows allow greater chemical and biological activity to take place at the interface where the pipe and water meet. This relatively quiet zone is capable of harboring considerable chemical or biological activity. Therefore, the quality conditions next to the pipe wall is quite different from those conditions in the main stream flow. In smaller mains, the ratio of surface area to volume of water is much greater, making the quality problems in the mains much more likely to be serious if chemical or biological activity occurs.

Dead Ends

The lack of circulation in a dead end creates nearly ideal conditions for degrading water quality. The velocity is very low if not zero, the time of contact of water with the pipe and any deposits,

encrustations, or slimes is long, an accumulation of organic matter containing nutrients exists, organisms grow and use the available dissolved oxygen, and oxygen may be depleted, therefore, initiating anaerobic conditions, which produce carbon dioxide, methane, and sulfide odors. Carbon dioxide may increase the corrosion potential. Chlorination may not be effective because of the increased chlorine demand by organics, biological forms, and corrosion products.

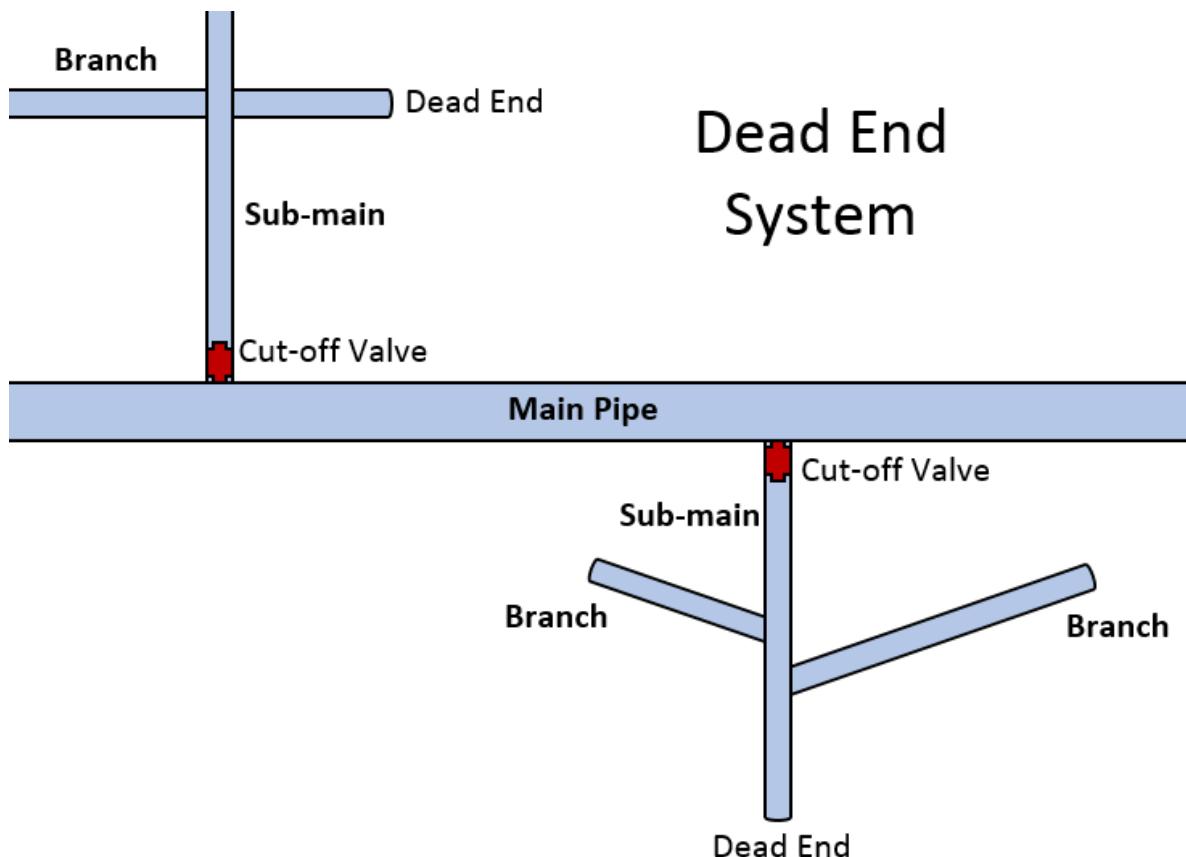


Figure 11.5: Dead end in distribution system³⁵

Pipe Material

Pipes are made of metal, asbestos-cement, or plastic. In metal and asbestos-cement pipe, corrosion can cause the release of substances from the piping materials into the water. With coal tar-lined or plastic pipe, however, the physical characteristics of the water are of minor importance. The concern is the possibility of leaching of material from the pipe or the lining by the water. To prevent corrosion, the insides of cement or metal pipes may be lined with asphalt or coal tar coatings. The potential for corrosion then relates to the integrity of the coatings.

Of special concern are systems that have considerable unlined pipe in the ground; and therefore, are more susceptible to corrosion problems. When pipes of dissimilar metals are

³⁵ Image by [COC OER](#) is licensed under [CC BY](#)

connected, an increased corrosion near the connection exists. Asbestos-cement pipe will deteriorate if aggressive water conditions exists, releasing increasing amounts of asbestos fibers.

Pipe Construction and Repair

An ample opportunity exists for entry of contaminants during construction of new mains and repair of old mains. To ensure the safety of the delivered water, proper protective, cleaning, and disinfection practices must be followed. When lines are being repaired, keep the hole dewatered to prevent possible contamination of the water line. After the line has been repaired, thoroughly flush the line downstream from the repair to remove any dirt and mud that could have entered the line. Flushing is important for health reasons and to avoid consumer complaints. After flushing, the line should be disinfected before being returned to service.

Hazardous Facilities

When physical conditions or soil conditions prevent minimum separation distances from being met, water mains can be located adjacent to collection system lines, fuel lines, individual septic tanks, and disposal systems or tanks containing dangerous materials. If leakage from such hazardous facilities saturates the soil around the mains, the mains could become contaminated. When they are out of service for any reason and are not under pressure, contaminants may seep into the lines through cracked or inadequately sealed joints.

Appurtenances

Appurtenances are small (but important) parts of a water distribution system, such as valves or meters, which help control flow. Distribution system water quality can be adversely affected by improperly constructed or poorly located blowoffs or air release and vacuum relief valves. They may be located where they could become flooded and permit the entrance of contaminated water when they are open. A lack of blowoffs would make it difficult or impossible to correct a poor quality condition, or to give temporary relief. Air valves are important to relieve entrapped air and to help prevent milky water and surge problems when lines are being filled.

WATER QUALITY MONITORING

Water quality monitoring of distribution systems is important to identify when and where water quality changes occur in the system. Routine monitoring consists of collection samples at remote locations in the system and testing for chlorine residual and coliforms. The minimum number of samples per month is based on the population served. When problems or complaints develop, a more detailed monitoring program is required to identify the cause and source of the problem

OPERATION OF DISTRIBUTION SYSTEM

Operators of distribution systems can maintain water quality in distribution systems by developing and implementing an effective distribution system operation and maintenance program. The critical elements of an effective program are:

1. a comprehensive system of surveillance and monitoring;
2. developing and enforcing good water main repair and replacement procedures, especially, for disinfecting mains before placing them in service;
3. instituting a biofilm control program;
4. developing and implementing a unidirectional flushing program;
5. developing a regular schedule and program for inspecting and maintaining storage tanks, and making sure an adequate turnover of water in the tank is occurring;
6. developing and maintaining an active corrosion control program;
7. instituting an annual cleaning and lining program;
8. developing a program to eliminate as many of the dead ends as possible in the distribution system;
9. developing a valve exercise program to ensure proper setting and operation of valves;
10. developing and implementing a backflow prevention program;
11. maintaining positive pressure on the system at all times (by rule at least 20 psi); and
12. investigating and responding to all consumer complaints.

Key Terms

- **appurtenances** – small (but important) parts of a water distribution system, such as valves or meters, which help control flow
- **Community Water System** – a public water system that has at least 15 regular service connections and regularly serves at least 25 all year residents
- **cross connection** - an unprotected connection between a part of a water system used or intended to be used to supply water for drinking purposes and any source or system containing water or a substance that is not or cannot be approved as safe drinking water. It is a connection between a regulated and approved drinking source and an unregulated drinking water source.
- **Public Water System (PWS)** – any system with at least 15 connections and regularly serves an average of 25 individuals daily at least 60 days out of the year

REVIEW QUESTIONS

- 1. What is a cross-connection?**
 - 2. How can backflow occur in a drinking water distribution system?**
 - 3. Define backsiphonage.**
 - 4. Define backflow.**

5. Name the common situations that can result in a cross connection in the drinking water distribution system.

6. Describe corrosion as a process in a drinking water distribution system.

7. Describe the problems associated with dead ends in the distribution system.

CHAPTER QUIZ

1. A _____ is defined as any system that has at least 15 service connections and regularly serves an average of at least 25 individuals daily at least 60 days out of the year.
 - a. public water system (PWS)
 - b. community water system (CWS)
 - c. transient water system
 - d. non-transient non-community water system
2. A system that has at least 15 service connections used by all-year residents and regularly serves at least 25 all-year residents is defined as a _____.
 - a. public water system (PWS)
 - b. community water system (CWS)
 - c. transient water system
 - d. non-transient non-community water system
3. EPA identifies some systems as _____ if they regularly serve at least 25 of the same persons over 6 months per year.
 - a. public water system (PWS)
 - b. community water system (CWS)
 - c. transient water system
 - d. non-transient non-community systems
4. The routine monitoring frequency for community water systems is based on the _____.
 - a. past history of coliforms being present in the sampling
 - b. population served
 - c. type of treatment
 - d. raw water source being surface water or ground water
5. The MCL for coliforms is based on the presence-absence concept, such that for water systems analyzing at least 40 samples per month, no more than _____ of the samples (including routine and repeat samples) may be positive for total coliforms.
 - a. zero
 - b. one
 - c. one percent
 - d. five percent

6. The MCL for coliforms is based on the presence-absence concept, such that for water systems analyzing fewer than 40 samples per month, no more than _____ of the samples per month may be positive for total coliforms.
- zero
 - one
 - one percent
 - five percent
7. A _____ is an unprotected connection between a part of a water system used or intended to be used to supply water for drinking purposes and any source or system containing water or a substance that is not or cannot be approved as safe drinking water. It is a connection between a regulated and approved drinking source and an unregulated drinking water source.
- cross-connection
 - backflow connection
 - backsiphonage connection
 - dead end
8. A critical situation exists when a routine sample tests positive for total coliforms and for fecal coliforms or *E. coli*, and any repeat sample tests positive for total coliforms and when a routine sample tests positive for total coliforms and negative for fecal coliforms or *E. coli*, and any repeat sample tests positive for fecal coliforms or *E. coli*. These situations are considered an acute risk to health. This occurrence is a _____ violation, which requires that the state and the public be notified within 24 hours.
- Tier 1
 - Tier 2
 - Tier 3
 - sampling error
9. _____ is a form of backflow caused by a negative or below atmospheric pressure within the water supply piping. It can develop from such causes as main breaks, an inadequate source of supply capacity, undersized mains, unusual water demands, planned shutdowns for maintenance or repair, or the use of on-line booster pumps.
- A cross-connection
 - A backflow connection
 - A backsiphonage connection
 - A dead end

10. _____ is caused by back pressure can occur when the user's water system is at a higher pressure than the public water system.
- A cross-connection
 - A backflow connection
 - A backsiphonage connection
 - A dead end
11. The lack of circulation in a _____ creates ideal conditions for degrading water quality. The velocity is very low if not zero, the time of contact of water with the pipe and any deposits, encrustations, or slimes is long, an accumulation of organic matter containing nutrients exists, organisms grow and use the available dissolved oxygen, and oxygen may be depleted; therefore, initiating anaerobic conditions, which produce carbon dioxide, methane, and sulfide odors. Carbon dioxide may increase the corrosion potential. Chlorination may not be effective because of the increased chlorine demand by organics, biological forms, and corrosion products.
- cross-connection
 - backflow connection
 - backsiphonage connection
 - dead end

CHAPTER 12: WATER TREATMENT FOR CONTAMINANT REMOVAL

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Describe water quality characteristics
- Describe disinfection processes
- Describe the classes of water quality
- Explain water quality characteristics

WATER QUALITY CHARACTERISTICS

Water is the universal solvent. This means it carries all types of dissolved materials. Water also carries biological life forms that can cause diseases. Waterborne pathogenic organism can cause diseases like anthrax, bacillary dysentery, cholera, gastroenteritis, salmonella, shigellosis, typhoid fever polio, amoebic dysentery cryptosporidium and giardia.

Water can be cleaned through different processes. One of the cleansing processes in the treatment of safe water is called disinfection. Disinfection is the process designed to kill or inactivate most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria. Water can be disinfected with chlorination, which is the most common method employed because of cost, availability, and reliability. Sterilization is the complete destruction of all organisms and is expensive. Sterilization is not necessary in water treatment.

FACTORS INFLUENCING DISINFECTION

Many factors influence disinfection of water. These factors include pH, temperature, turbidity, reducing agents, and microorganisms.

pH

The pH of the water being treated can alter the efficiency of disinfection. Chlorine disinfects water much faster and better at a pH around 7.0 rather than at a pH over 8.0.

Temperature

Temperature conditions influence the effectiveness of disinfectants. The higher the temperature of water then the more efficiently it can be treated. Water near 70 to 85 °F is easier to disinfect than water at 40 to 60 °F. Longer contact times are required to disinfect water at lower temperatures. To speed up the process, operators use larger amounts of chemicals. Be aware that the higher the chlorine concentration, the greater the dissipation rate

of chlorine into the atmosphere. This fact can result in the production of odors and the process wastes chlorine.

Turbidity

Under normal operating conditions, the turbidity level of treated water is low by the time the water reaches the disinfection process. Excessive turbidity will greatly reduce the efficiency of the disinfecting chemical or process. Water treatment plants have demonstrated that when water is filtered to a turbidity of one unit or less, most of the bacteria have been removed.

Suspended matter can change the chemical nature of the water when the disinfectant is added. Some types of suspended solids can create a continuing demand for the disinfecting chemical, and change the effective germicidal properties of the disinfectant.

Organic Matter

Organics found in water can consume great amounts of disinfectants while forming unwanted compounds. Trihalomethanes (THMs) are an example of undesirable compounds formed by reactions between chlorine and certain organics. Disinfecting chemicals often react with organics and reducing agents. Then, if any of the chemical remains available after this initial reaction, it can act as an effective disinfectant. The reactions with organics and resulting agents, however, has a significant reducing effect on the amount of chemical available for disinfection.

Inorganic Matter

Inorganic compounds, such as ammonia (NH_3) in water being treated can create special problems. In the presence of ammonia, some oxidizing chemicals form side compounds causing a partial loss of disinfecting power. Silt can also create a chemical demand. It is clear that the chemical properties of water while being treated can seriously interfere with the effectiveness of disinfecting chemicals.

Reducing Agents

Chlorine combines with a wide variety of materials, especially reducing agents. Most reactions between chlorine and reducing agents occurs rapidly; however, other reactions are much slower. The side reactions complicate the use of chlorine for disinfection. The demand for chlorine by reducing agents must be satisfied before chlorine becomes available to disinfect. Examples of reducing agents in water that react with chlorine are hydrogen sulfide (H_2S), ferrous ion (Fe^{+2}), manganous ion (Mn^{+2}), ammonia (NH_3), and nitrite (NO_2^-). Organic reducing agents in water also will react with chloride and form chlorinated organic materials of potential health significance.

Microorganisms

The concentration of microorganisms is important because the higher the number of microorganisms, the greater the demand for a disinfecting chemical. The resistance of microorganisms to specific disinfectants varies. Non-spore forming bacteria are generally less resistant than spore-forming bacteria. Cysts and viruses can be resistant to certain types of disinfectants.

REMOVAL PROCESSES

Pathogenic organisms can be removed from water, killed, or inactivated by physical and chemical water treatment processes. These processes are:

1. **Coagulation** Chemical coagulation followed by sedimentation and filtration will remove 90 to 95-percent of the pathogenic organisms depending on which chemicals are used. Alum usage can increase virus removals up to 99-percent.
2. **Sedimentation** Proper design of sedimentation processes can effectively remove 20 to 70-percent of the pathogenic microorganisms. This removal is accomplished by allowing the pathogenic organisms to settle out by gravity, assisted by chemical floc.
3. **Filtration** Filtering water through granular filters is an effective means of removing pathogenic and other organisms from water. The removal rates vary from 20 to 99-percent, depending on the coarseness of the filter media and the type of effectiveness of pretreatment.

DISINFECTION PROCESS

Disinfection destroys harmful organisms. The process can be accomplished physically or chemically. Physical methods can be:

1. Physically removing the organisms from the water
2. Introducing motion that will disrupt the cells' biological activity and kill or inactivate them

Chemical methods alter the cell chemistry causing the microorganism to die. The most widely used disinfectant chemical is chlorine. Chlorine is easily obtained, relatively inexpensive, and most importantly, leaves a chlorine residual that can be measured. Other disinfects are also used. An increased interest in disinfectant other than chlorine has occurred because of the carcinogenic compound that chlorine may form (trihalomethanes or THMs).

Ultraviolet Rays

UV light is a physical means of disinfection. It is used to destroy pathogenic microorganisms. To be effective, the rays must come in contact with each microorganism. The ultraviolet energy disrupts various organic components of the cell causing a biological change that is fatal to the microorganisms.

This system does not have a measurable residual and the cost of operation is high. The use of ultraviolet rays is limited to small or local systems and industrial applications. Oceangoing ships have used these systems for their water supplies.

Advances in ultraviolet technology and concern about disinfection byproducts produced by other disinfectants has prompted a renewed interest in UV disinfection.

Heat

Heat has been used for centuries to disinfect water. Boiling water for about 5 minutes will destroy essentially all microorganisms. This method is energy intensive and expensive. The only practical application is in the event of a disaster when individual local users are required to boil their water.

Ultrasonic waves

This process is used to disinfect water on a limited scale. Sonic waves destroy microorganisms by vibration. This process is not practical and is expensive.

Chemical Disinfection

Iodine

Iodine is used as a disinfectant in water, but its use is limited to emergency situations. It is a good disinfectant, but its cost is high. The recommended dosage is two drops of iodine tincture, which is 7% available iodine, in a liter of water.

Bromine

Bromine is used on a limited basis for water treatment because of handling difficulties. Bromine causes skin burns on contact. Because bromine is a very reactive chemical residual are hard to obtain. Bromine can be purchased for swimming pool and hot tub usage.

Bases

Bases can be effective disinfectants, but the high pH values leave a bitter taste in finished water. Bases like sodium hydroxide and lime can burn when left too long in contact with skin. Bases effectively kill all microorganisms; and therefore, they can sterilize water. Bases have been used to sterilize pipes.

Ozone

Ozone is used to disinfect water along with reducing taste and odors. Drawbacks of ozone for disinfection include a high cost, big physical footprint, lack of residual, difficulty in storing, and maintenance requirements.

Although ozone is effective in disinfecting water, its use is limited by its solubility. The temperature and pressure of the water being treated regulate the amount of ozone that can be dissolved in the water. These factors tend to limit the disinfectant strength that can be made available to treat water.

Ozone destroys all microorganisms but significant residual ozone does not guarantee that water is safe to drink. Organic solids may protect organisms from the disinfection action of ozone and increase the amount of ozone needed for disinfection. In addition, an ozone residual cannot be maintained in metallic conduits for any period of time because of ozone's reactivity. The inability of ozone to provide a residual in the distribution system is a major drawback to its usage. However, the formation of THMs by chlorine has resulted in a renewed interest in ozone as an alternative means of disinfection.

CHLORINE

Chlorine is a greenish-yellow gas with a penetrating and distinctive odor. The gas is two-and-a-half times heavier than air. Chlorine has a high coefficient of expansion. One liter of chlorine liquid will expand 450 times when changing from liquid to a gas. No chlorine containers should be filled to more than 85-percent of their capacity.

Chlorine is not flammable and is non-explosive. It will support combustion. When the temperature rises, so does the vapor pressure of chlorine. When the temperature increases the pressure of chlorine gas inside a chlorine container increases. This property of chlorine is considered when feeding chlorine gas from a container or dealing with a leaking chlorine cylinder.

Disinfection Action

Chlorine exerts a direct action against the bacterial cell destroying it. When chlorine is added to water, several chemical reactions take place. These reactions involve water molecules. Some other reactions involve organic and inorganic substances suspended in the water.

When chlorine is added to water containing organic and inorganic materials, it will combine with these materials and form chlorine compounds. Continued addition of chlorine will reach a point where the reaction with organic and inorganic materials stops. At this point, the chlorine demand has been satisfied.

The chemical reactions between chlorine and organic and inorganic substances produce chlorine compounds. Some compounds have disinfecting properties and other compounds do not. In a similar fashion, chlorine reacts with water and produces substances with disinfection properties. The total of the compounds with disinfecting properties plus any remaining free chlorine is known as the chlorine residual. The presence of this measurable chlorine residual indicates to the operator that all possible chemical reactions with chlorine have taken place and

that a sufficient available residual chlorine is left to kill any microorganisms present in the water.

When the amount of chlorine needed to satisfy the chlorine demand and the amount of chlorine residual needed for disinfection, then the chlorine dose is calculated.

$$\text{Chlorine Dosage} = \text{Chlorine Demand} + \text{Chlorine Residual}$$

Chlorine Reactions in Water

In solutions that are dilute with low concentrations of chlorine and have a pH above 4, the formation of HOCl, hypochlorous acid, is nearly complete and leaves little free chlorine (Cl_2). Depending on the pH, some hypochlorous acid will disassociate and produce a hydrogen ion and a hypochlorite ion. Hypochlorous acid is a weak acid and is poorly dissociated at pH levels below 6. Below pH 6 the free chlorine is almost all in the HOCl form. Above pH 9, almost all of the free chlorine is in the OCl^- form and none in the HOCl form.

In water with a pH of 7.5, approximately 50-percent of the chlorine present is in the form of HOCl and 50-percent is in the form of OCl^- . This fact is important in that HOCl and OCl^- differ in disinfection ability. HOCl has a much greater disinfection potential than OCl^- .

Reactions with Substances in Water

Hydrogen sulfide and ammonia are two inorganic substances that are found in water when it reaches the disinfection stage of treatment. Their presence can complicate the use of chlorine for disinfection purposes because they exert a chlorine demand. Hydrogen sulfide and ammonia are reducing agents and they react with chlorine to remove it from the water. They lose electrons and chlorine reacts rapidly to accept these electrons.

Hydrogen sulfide produces an odor that smells like rotten eggs. It reacts with chlorine to form sulfuric acid and elemental sulfur. Elemental sulfur is objectionable because it can cause odor problems and will precipitate as finely divided white particles that are sometimes colloidal in nature.

When chlorine is added to water containing ammonia, it reacts rapidly with the ammonia and forms chloramines. This reaction reduces the chlorine that is available to act as a disinfectant. As the concentration of ammonia increases, the disinfectant power of the chlorine drops at a rapid rate because of the chlorine demand exerted by the ammonia.

When organic material are present in water, the chemical reactions that take place with chlorine can produce suspected carcinogenic compounds (THMs). The formation of these compounds can be prevented by limiting the amount of prechlorination and by removing the organic materials before chlorination of the water.

HYPOCHLORITE

The use of hypochlorite to treat potable water achieves the same result as chlorine gas. Hypochlorite can be applied in the form of calcium hypochlorite or sodium hypochlorite. The form of calcium hypochlorite that is used most frequently to disinfect water is known as High Test Hypochlorite (HTH).

CHLORINE DIOXIDE

Chlorine dioxide (ClO_2) can be used as a disinfectant. Chlorine dioxide does not form carcinogenic compounds that can be formed by other chlorine compounds. It also is not affected by ammonia, and it is a very effective disinfectant at higher pH levels. In addition, chlorine dioxide reacts with sulfide compounds helping to remove them and eliminate their characteristic odors. Phenolic tastes and odors can be controlled with chlorine dioxide.

CHLORAMINATION

Chloramination is used as an alternative disinfection process by operators to:

1. Reduce the formation of THMs and other disinfection byproducts
2. Maintain a detectable residual throughout the distribution system
3. Penetrating the biofilm and reducing the potential for coliform regrowth
4. Killing or inactivating heterotrophic plate count bacteria
5. Reducing taste and odor problems

Several factors are used to make a decision concerning the use of chloramine disinfection. These factors are the quality of the raw water, the ability of the treatment plant to meet various regulations, operational practices, and distribution system characteristics.

Three methods are used to produce chloramines for disinfection purposes. These methods include pre-ammoniation followed by chlorination, addition of chlorine and ammonia at the same time, and pre-chlorination with post-ammoniation.

Pre-ammoniation followed later by chlorination is applied at the rapid-mix unit process and chlorine is added downstream at the entrance to the flocculation basin. This approach produces lower THM levels than the post ammoniation method. Pre-ammoniation to form chloramines does not produce phenolic tastes and odors, but this method may not be as effective as post-ammoniation for controlling tastes and odors associated with diatoms and anaerobic bacteria in the source water.

Concurrent addition of chlorine and ammonia is a method that applies chlorine to the plant influent at the same time or immediately after ammonia is introduced at the rapid mix unit process. Concurrent chloramination produces the lowest THM levels of the three methods.

Prechlorination and postammoniation is a method where chlorine is applied at the head of the plant and a free chlorine residual is maintained throughout the plant processes. Ammonia is added at the plant effluent to produce chloramines. Because of the longer free chlorine contact time, this method results in the formation of more THMs, but it may be necessary to use this method to meet the disinfection requirements of the Surface Water Treatment Rule. A major limitation of using chloramine residuals is that chloramines are less effective as a disinfectant than free chlorine.

UV DISINFECTION AND TREATMENT OF WATER

Ultraviolet (UV) rays are part of the light that comes from the sun. The UV spectrum is higher in frequency than visible light and lower in frequency compared to x-rays. The UV spectrum has a larger wavelength than x-rays and a smaller wavelength than visible light and the order of energy, from low to high, is visible light, UV, and x-rays.

UV is known to be an effective disinfectant due to its strong germicidal (inactivating) ability. UV disinfects water containing bacteria and viruses and can be effective against protozoans, such as *Giardia lamblia* cysts or *Cryptosporidium* oocysts. UV is used in the pharmaceutical, cosmetic, beverage, and electronics industries. In the United States, it is used for drinking water disinfection; however, high operating costs compared to disinfection by chlorination has limited its usage.

Because of safety issues associated with the reliance of chlorination and improvements in UV technology, UV has experienced increased acceptance in municipal water systems. Two classes of disinfection systems are certified and classified by the NSF under Standard 55, Class A and Class B Units.

1. Class A These ultraviolet water treatment systems must have an intensity and saturation rating of at least 40,000 uw-sec/cm² and possess designs that will allow them to disinfect and/or remove microorganisms from contaminated water. Affected contaminants should include bacteria and viruses. Class A point-of-entry and point-of-use systems covered by this standard are designed to inactivate and/or remove microorganisms, including bacteria, viruses, and *Cryptosporidium* oocyst and *Giardia* cysts from contaminated water. Systems covered by this standard are not intended for the treatment of water that has obvious contamination or intentional source contamination, such as raw sewage, nor are these systems intended to convert wastewater to drinking water. These systems are intended to be installed on visually clear water.
2. Class B These ultraviolet water treatment systems must have an intensity and saturation rating of at least 16,000 uw-sec/cm² and possess designs that will allow them to provide supplemental bactericidal treatment of water already deemed safe, such that no elevated levels of *E. coli* or a standard plate count of less than 500 colonies per 1 ml exists. NSF Standard 55 suggests Class B UV systems are designed to operate at a minimum dosage and are intended to reduce normally occurring non-pathogenic or

nuisance microorganisms only. The Class B or similar non-rated UV systems are not intended for the disinfection of microbiologically unsafe water.

The type of unit depends on the situation for use, source of water, and water quality. Transmitted UV light dosage is affected by water clarity. Water treatment devices are dependent on the quality of the raw water. When turbidity is 5 NTU or greater and/or total suspended solids are greater than 10 ppm, pre-filtration of the water is highly recommended. Normally, it is advisable to install a 5 to 20 micron filter prior to a UV disinfection system.

UV disinfection is based on the principles associated with wave lengths of light that damage the nucleic acids of water borne pathogens. UV radiation has three wavelength zones, UV-A, UV-B, and UV-C, and it is the last region, the shortwave UV-C, that has germicidal properties for disinfection. A low-pressure mercury arc lamp resembling a fluorescent lamp produces the UV light in the range of 254 nanometers (nm). These lamps contain elemental mercury and an inert gas, such as argon, in a UV-transmitting tube, usually quartz. Traditionally, most mercury arc UV lamps have been the low pressure type, because they operate at a relatively low partial pressure of mercury, low overall vapor pressure (about 2 mbar), low external temperature (50-100° C), and low power. These lamps emit nearly monochromatic UV radiation at a wavelength of 254 nm, which is in the optimum range for UV energy absorption by nucleic acids (about 240-280 nm).

In recent years, medium pressure UV lamps that operate at much higher pressures, temperatures, and power levels have been installed. They emit a broad spectrum of higher UV energy between 200 and 320 nm.

An essential requirement for UV disinfection with lamp systems is an available and reliable source of electricity. While the power requirements of low-pressure mercury UV lamp disinfection systems are modest, they are essential for lamp operation to disinfect water. Since most microorganisms are affected by radiation around 260 nm, UV radiation is in the appropriate range for germicidal activity. UV lamps are available that produce radiation in the range of 185 nm, and they are effective in reducing microorganisms as well. They will also reduce the total organic carbon (TOC) content of the water.

For typical UV systems, approximately 95-percent of the radiation passes through a quartz glass sleeve and into the untreated water. The water is flowing as a thin film over the lamp. The glass sleeve is designed to keep the lamp at an ideal temperature of approximately 104° F.

UV radiation affects microorganisms by altering the DNA in the cells and impeding reproduction. UV treatment does not remove organisms from the water. It inactivates them. The effectiveness of this process is related to exposure time and lamp intensity, as well as general water quality parameters.

The exposure time is reported as microwatt-seconds per square centimeter (uwatt-sec/cm²), and the U.S. Department of Health and Human Services has established a minimum exposure of

16,000 μ watt-sec/cm² for UV disinfection systems. Most manufacturers provide a lamp intensity of 30,000-50,000 μ watt-sec/cm². In general, coliform bacteria are destroyed at 7,000 μ watt-sec/cm².

Since lamp intensity decreases over time with use, lamp replacement and proper pretreatment are key to the success of UV disinfection. In addition, UV systems should be equipped with a warning device to alert operators when lamp intensity falls below the germicidal range.

Used alone, UV radiation does not improve the taste, odor, or clarity of water. UV light is a very effective disinfectant, although the disinfection can only occur inside the unit. No residual disinfection in the water exists to inactivate bacteria that may survive or may be introduced after the water passes by the light source. The percentage of microorganisms destroyed depends on the intensity of the UV light, the contact time, raw water quality, and proper maintenance of the equipment.

If material builds up on the glass sleeve or the particle load is high, the light intensity and the effectiveness of treatment are reduced. At sufficiently high doses, all waterborne enteric pathogens are inactivated by UV radiation. The general order of microbial resistance (from least to most) and corresponding UV doses for extensive (>99.9%) inactivation are: vegetative bacteria and the protozoan parasites *Cryptosporidium parvum* and *Giardia lamblia* at low doses (1-10 mJ/cm²) and enteric viruses and bacterial spores at high doses (30-150 mJ/cm²).

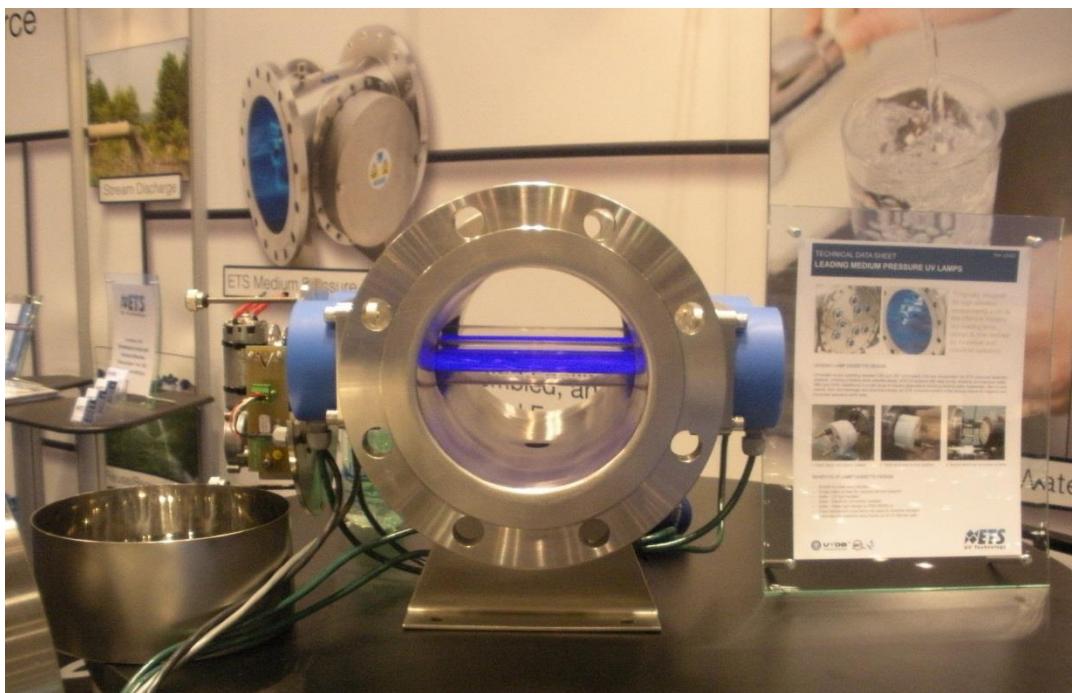


Figure 12.1: UV light used for disinfection in water treatment³⁶

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Most low-pressure mercury lamp UV disinfection systems can readily achieve UV radiation doses of 50-150 mJ/cm² in high quality water; and therefore, efficiently disinfect waterborne pathogens. However, dissolved organic matter, such as natural organic matter, certain inorganic solutes such as iron, sulfites and nitrites, and suspended matter (particulates or turbidity) will absorb UV radiation or shield microbes from UV radiation, resulting in lower delivered UV doses and reduced microbial disinfection. Another concern surrounding disinfecting microbes with lower doses of UV radiation is the ability of bacteria and other cellular microbes to repair UV-induced damage and restore pathogenicity, which is a phenomenon known as reactivation.

UV inactivates microbes primarily by chemically altering nucleic acids. However, the UV-induced chemical lesions can be repaired by cellular enzymatic mechanisms, some enzymes act independent of light (dark repair) and other enzymes require visible light (photo-repair or photo-reactivation). Therefore, achieving optimum UV disinfection of water requires delivering a sufficient UV dose to induce greater levels of nucleic acid damage; and thereby, overcome DNA repair mechanisms.

UV units have a maximum flowrate capacity and some equipment have minimum flowrates. If the flow is too high, water will pass through without enough UV exposure. If the flow is too low, heat may build up which can damage the UV lamp. A UV unit with minimum flow requirements should not be placed on the water line supplying pressure stations in a non-recirculating system. UV units are most often used in constant flow systems.

UV lamps do not burn out as normal fluorescent lamps do. Instead, the UV lamps will solarize, which reduce their intensity to about 60% of a new lamp after about one year of continuous use. When lamps are new, they will generate a dosage level near 60,000 µW-s/cm². When the dosage drops to 30,000 µW-s/cm², the minimum dosage needed to effectively kill bacteria, lamps should be replaced. Lamp life will be shortened significantly if the lamp is turned on and off more frequently than once every eight hours.

Water should be sampled and tested for bacteria counts regularly. Sample before and after the UV unit to test its performance. Water should also be sampled in the distribution since bacterial regrowth can occur downstream of the UV unit.

As water passes through the UV unit, minerals, debris and other material in the water will deposit onto the quartz or Teflon sleeve. This activity will limit the penetration of UV rays through the sleeve and into the water. To maintain high clarity, the glass around the lamp must be cleaned regularly. Cleaning frequency depends on the water quality and will be minimal with RO treatment upstream.

UV light intensity meters are available which indicate the penetration of UV light through the glass sleeve and the water. Low intensity means the UV dose is too low to provide adequate disinfection. This meter will indicate when cleaning or lamp replacement is needed.

OZONE

Ozone is one of the most powerful water treatment compounds available to system managers today. It is a technology that has been in continual commercial use for over 100 years and has distinct properties that allow disinfection of even heavily compromised water streams. With the 1996 reauthorization of the Safe Drinking Water Act, ozone was named as among the best available technologies for water system compliance with National Primary Drinking water Regulations as overseen by the US Environmental Protection Agency.

Ozone (O_3) is formed when oxygen molecules are exposed to electron flow. Ozone molecules are unstable and will lose the third oxygen atom over time. Ozone is formation characterization:

1. Ozone generators provide an electron flow between dielectric and SS tubes.
2. Oxygen is passed through the gap between dielectrics resulting in ozone generation.
3. Oxygen feed gas must be dry and free of particles.
4. Ozone generators must be cooled, and cooling water removes .90 percent of the heat that is generated.

Ozone is a powerful oxidant with high disinfectant capacity. Ozone residuals between 0.3 to 2.0 mg/L inactivate viruses. Inactivation rates range from $>3.9\text{-log}$ to $>6\text{-log}$, and occur within very short contact periods, 5 seconds. Microorganisms in natural waters are very sensitive to ozone. *Giardia* and enteric viruses are inactivated by ozone, as a primary disinfectant, with 5 minutes of contact time. Ozone residuals of 0.5 to 0.6 mg/L result in 3-log and 4-log removals, respectively. When ozone is used as a primary treatment, the criteria for its use is based on ozone residuals, competing ozone demands, and a minimum contact time to meet the required cyst and viral inactivation requirements.

Ozone is the strongest oxidant and strongest disinfectant available for potable water treatment. This unique material can be utilized for a number of specific water treatment applications, including disinfection, taste and odor control, color removal, iron and manganese oxidation, hydrogen sulfide removal, nitrite and cyanide destruction, oxidation of organics such as phenols, pesticides, and some detergents, algae destruction and removal, and as a coagulant aid. Even though ozone is the strongest chemical disinfectant available for water treatment, some refractory organics are not oxidized, or oxidize too slowly. In such cases, ozone can be combined with UV radiation and/or hydrogen peroxide to produce hydroxyl free radicals, HO^- , which is a stronger oxidant than molecular ozone, O_3 . Deliberate production of hydroxyl free radicals starting with ozone has been termed ozone advanced oxidation. Groundwater that is contaminated with chlorinated organic solvents and some refractory hydrocarbons are being treated successfully with ozone advanced oxidation techniques.

At ambient temperatures, ozone is an unstable gas, partially soluble in water; generally, more soluble than oxygen. Due to its instability, ozone quickly reverts to oxygen. Ozone cannot be produced at a central manufacturing site, bottled, shipped, and stored prior to use. It must be generated and applied on-site. The installation of an ozone production plant requires storage of

pure oxygen on-site as the feed gas. Ozone is generated for commercial uses using corona discharge or ultraviolet radiation. The UV technique produces low concentrations of ozone, whereas corona discharge produces ozone concentrations in the range of 1 – 4.5 % when dry air is fed to the ozone generator. When concentrated oxygen is used as the feed gas, gas phase ozone concentrations of up to 14 to 18% can be produced. Since ozone is only partially soluble in water, once it has been generated it must be contacted with the water to be treated in such a manner as to maximize the transfer of ozone from the gas phase into water. For this purpose, many types of ozone contactors have been developed. However, as higher concentrations of ozone gas are employed, contacting system designs become more critical because of the lower gas to liquid ratios.

The use of oxygen as the feed gas can result in oxygen super saturation of the treated water causing operational problems and corrosion in the distribution system. Ozone contacting system options include atmospheric tall towers or pressurized gas to liquid mass transfer processes. Fine bubble diffusers, static mixers, or venturi injectors can be used to mix the gas with the water to be treated in full flow or side stream configurations. Once dissolved in water, ozone is available to act on water contaminants to accomplish its intended purposes of disinfection and/or oxidation. At pH levels of 3-6, ozone is present primarily in its molecular form (O_3). However, as the pH rises, the decomposition of ozone to produce the hydroxyl free radical (HO^-) becomes increasingly rapid. At pH 7 about 50% of the ozone transferred into water produces HO^- . At pH >10, the conversion of molecular O_3 to HO^- is virtually instantaneous.

Because ozone is such a powerful oxidant/disinfectant, the trick to applying it to solve water treatment problems is to do so in a manner that is effective for water treatment, yet at the same safe for the people in the vicinity. Ozone safety issues are handled easily by using proper ambient ozone monitoring, tank venting, and ozone destruction. In the case of systems driven solely by a pumping/injector system, ozone may be produced under vacuum, which ensures no leakage of ozone into the operating environment.

The five basic components of an ozone system include:

1. Gas preparation—either drying gas to a suitable dew point or using oxygen concentrators
2. A suitable electrical power supply
3. A properly sized ozone generator(s)
4. An ozone contacting system
5. Ozone off-gas destruction or suitable venting system

Moisture in the feed gas causes two operating problems:

1. The amount of ozone produced by application of a given electrical energy level is lowered as relative humidity rises. Consequently, it is usually cost-effective to dry the air to a recommended dew point of minus 65°C (-65°C or -76°F) or lower.
2. Ozone generated using air in the presence of moisture allows small amounts of nitrogen oxides to react with the moisture to produce nitric acid. In this instance, gas condensation at the cooling/heat transfer surfaces produces a corrosive compound

which can cause corrosion problems in the ozone generation equipment with concomitant increases in equipment maintenance requirements.

Because of the high oxidative qualities of gas-phase ozone and the chance of moisture from a failing feed gas unit, system managers must take extra care to make certain that all components in the ozone generator, ozone supply line, ozone gas to liquid mass transfer equipment and the contact vessel are ozone-compatible.

For large scale ozone systems, the equipment for cleaning and drying feed gases can become quite complex. For example, effective air drying can involve multiple treatment steps including air filtration, compression, cooling, desiccation, and final filtration prior to passage into an operating corona discharge ozone generator.

A need exists for efficient ozone contacting and destruction of excess ozone in contactor off-gases. Absent an effective ozone off-gas destruct unit, excess ozone would be present for people in the vicinity to breathe, which is not recommended because of its strong oxidizing nature. Additionally, ozone is heavier than ambient air, and can settle in the vicinity, and attack oxidizable materials. Destruction of contactor off-gas ozone is readily accomplished thermally (370°C), catalytically, thermal-catalytically, and by passing the off-gas through granular activated carbon. Care should be exercised in selecting an ozone destruct method whenever very high concentrations of ozone will be encountered.

Ozone is a critical process for non-reverse osmosis purification. It is usually coupled with biologic activated carbon filtration. The process reduces TOC and trace chemical pollutants, removes protozoans, kills viruses, and is a flocculation aid. Ozone treatment is an oxidation process used as a disinfection and oxidant prior to biologic activated carbon filtration.

Instrumentation and controls for ensuring effective and safe operation of ozone systems are concerned with applying ozone effectively and affordably. System processes control ozone generation, oxygen usage, drying, ozone injection and diffusing, and ozone destruction. The instrumentation monitors each step, and each step has an alarm associated with the process.

Key Terms

- **Coagulation** – a process that followed by sedimentation and filtration will remove 90 to 95-percent of the pathogenic organisms depending on which chemicals are used; alum usage in coagulation can increase virus removals up to 99-percent.
- **Disinfection** – a process that destroys harmful organisms physically or chemically
Filtration – a process through granular filters is an effective means of removing pathogenic and other organisms from water; removal rates vary from 20 to 99-percent, depending on the coarseness of the filter media and the type of effectiveness of pretreatment.
- **Sedimentation** – a process through which pathogenic organisms settle out by gravity, assisted by chemical floc; proper design of sedimentation processes can effectively remove 20 to 70-percent of the pathogenic microorganisms

REVIEW QUESTIONS

1. List the factors that affect chlorination of drinking water?
 2. Describe disinfection as a process in drinking water treatment.
 3. What is the purpose of chloramination in drinking water?
 4. What is ozonation of drinking water?

5. How does UV light effect microorganisms?

6. Describe the primary reason that chlorine may not be used for drinking water disinfection at a particular drinking water facility.

CHAPTER QUIZ

1. _____ is the process designed to kill or inactivate most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria.
 - a. Sterilization
 - b. UV treatment
 - c. Application of chlorine
 - d. Disinfection

2. Which of the diseases listed is not caused by a waterborne pathogenic organism?
 - a. Gastrointestinal anthrax
 - b. Shigellosis
 - c. Polio
 - d. All of these are water borne diseases

3. The chemical reactions between chlorine and organic and inorganic substances produce chlorine compounds. Chlorine reacts with water and produces substances with disinfection properties. The total of the compounds with disinfecting properties plus any remaining chlorine is known as the _____.
 - a. chlorine dose
 - b. chlorine demand
 - c. free chlorine
 - d. chlorine residual

4. _____ is a gas that does not form carcinogenic compounds like those compounds formed by chlorine disinfection. It also is not affected by ammonia, and it is a very effective disinfectant at higher pH levels. It is also used to diminish taste and odor problems in the distribution system. It is especially useful in inhibiting *Legionella*.
 - a. Chloramination
 - b. Chlorine dioxide
 - c. Hydrogen peroxide
 - d. Potassium permanganate

5. Because of safety issues associated with the reliance of chlorination and improvements in _____ technology, it has experienced increased acceptance in municipal water systems. Two systems are certified and classified by the NSF under Standard 55. The type of unit depends on the situation for use, source of water, and water quality. The dosage is affected by water clarity. When turbidity is 5 NTU or greater and/or total suspended solids are greater than 10 ppm, pre-filtration of the water is highly recommended. It is advisable to install a 5 to 20 micron filter prior to the disinfection system.
- a. ozone
 - b. chloramination
 - c. ultraviolet light
 - d. chlorine dioxide
6. _____ is the strongest oxidant and strongest disinfectant available for potable water treatment. This unique material can be utilized for specific water treatment applications, including disinfection, taste and odor control, color removal, iron and manganese oxidation, hydrogen sulfide removal, nitrite and cyanide destruction, oxidation of organics such as phenols, pesticides, and some detergents, algae destruction and removal, and as a coagulant aid.
- a. Ozone
 - b. Chloramination
 - c. Ultraviolet light
 - d. Chlorine dioxide
7. A major problem with disinfection using _____ is that bacterial regrowth can occur downstream of the application site in the distribution.
- a. Ozone
 - b. Chloramination
 - c. Ultraviolet light
 - d. b and c are correct
8. Several factors are used to make a decision concerning the use of _____ disinfection. These factors are the quality of the raw water, the ability of the treatment plant to meet various regulations, operational practices, and distribution system characteristics.
- a. Ozone
 - b. Chloramination
 - c. Ultraviolet light
 - d. Chlorine dioxide

9. _____ is a critical process for non-reverse osmosis purification. It is usually coupled with biologic activated carbon filtration. The process reduces TOC and trace chemical pollutants, removes protozoans, kills viruses, and is a flocculation aid. It is an oxidation process used as a disinfection and oxidant prior to biologic activated carbon filtration.

- a. Ozone
- b. Chloramination
- c. Ultraviolet light
- d. Chlorine dioxide

10. Which of the listed factors does not have an influence on the disinfection of water with chlorine?

- a. pH,
- b. Reducing agents
- c. Hardness
- d. Temperature

CHAPTER 13: CUSTOMER QUESTIONS, COMPLAINTS, & INVESTIGATION

LEARNING OBJECTIVES

After reading this section, you should be able to:

- Outline common customer questions and complaints
- Explain recording keeping
- Explain response process to customer inquiries and complaints

QUESTIONS AND ISSUES

Your water customers are a source of information concerning water quality. Customer complaints or concerns may indicate problems with the water delivered to their homes and businesses or problems within their homes or businesses themselves. Often customer complaints stem from problems in the water distribution system or their own homes, and not the treatment plant. However, treatment plant operations, such as changes in supply and pH, chlorine, and copper residual levels, may prompt some consumers to contact their water supply agency to report problems or call simply with questions. Most customer questions are regarding secondary or aesthetic concerns:

- Why does my water look this way?
- Why does it taste this way?
- Why does it have this smell?

Many of these questions can be answered without launching a full investigation as shown below. For example, during the last drought, many water agencies relied heavily on groundwater. This also meant that sometimes the pumps were bringing water to the surface with entrained air (bubbles). While there is nothing harmful about entrained air, it does make the water look initially milky. Customer service departments could advise customers that this was a result of the drought, air was trapped in the water, and if the customer poured a glass of water and left it on the counter for five minutes, the water would be clear.

For most customer service departments, the process for dealing with a customer complaint is:

1. **Collect Data** Collect as much information from the customer as possible, including the customer's contact information, description of the problem, and dates that it started (and ended, if it did)
2. **Investigate** Direct the complaint to the proper department or person for evaluation, if necessary. Then the relevant department should initiate an investigation, consider potential causes, gather additional data from sources, such as operations records of the plant or distributions system, laboratory, or field testing results on water samples, and distribution system inspection results, such as cross connections and proper valve

operation. Determine the cause of the problem. If the problem is caused by the public water system, initiate necessary corrective action. Document the problem, cause, and solution for future reference.

3. **Circle Back** Inform the customer of the conclusion and any necessary corrective action taken or underway or future plans for corrective action

Each employee of a utility is responsible for customer relations and for positive customer communication. System operators are often the most visible of the system's employees and at such times they can be considered as being on the frontline of public relations. Some operators come into contact with the public incidentally, while other operators have direct intentional contact, such as when dealing with consumer complaints. The system operator must be aware of and take into account the responsibilities of public relations. Some water suppliers have recognized this fact and call their meter readers "water service representatives." Some water suppliers have deliberately trained operators in customer service and public relations, while other water suppliers have not.

The responsibility of representing the water supplier to the public means the operator must be careful to present a neat, efficient, knowledgeable, and cooperative image.



Figure 13.1³⁷

Remember that you represent not only your own water agency, but often serve as a representative unofficially for all government. It's a big responsibility! Work habits should not encourage public criticism so be aware that when you are in public, residents are watching to

³⁷ Image used with permission of [SCV Water](#)

make sure you are diligent, efficient and helpful. One way to frame this is to ask yourself how it would look if what you said or did ended up on the front page of the newspaper. Would you feel okay? Would you be embarrassed? If so, you need to change your attitude and behavior.

Any encounter with the public, regulatory agencies, or municipal officials should be viewed as an opportunity to provide valid information and to correct misunderstandings. All operators working for a water agency should have a basic knowledge of the system facilities and the system's operation. The public normally expects operators to have this knowledge. Operators appear to be uninformed and disinterested if simple questions about the agency cannot be answered.



Pin It! Misconception Alert

It's easy to dismiss customer concerns, particularly if they are vocalized loudly or rudely. All complaints should be treated as legitimate.

All complaints should be treated as legitimate and investigated as soon as possible. If the person with the complaint is loud and abusive, the operator should not retaliate in kind. Instead, the operator should show concern, listen carefully, and calmly offer to look into the complaint. Help correct any problems that are found and answer questions or obtain answers to questions. Residents appreciate it when people return to "close the loop" and inform them of the answer or solution to their problem.

Sometimes, it is through complaints from consumers that a water utility learns the service being provided is not satisfactory. Complaint records should be reviewed periodically by responsible operators. These operators need to look especially at the complaint logs when numerous complaints are coming into the utility. If complaints are displayed on a map with the use of colored pins, a pattern might be detected that could indicate the area affected and where the investigation should be centered. By doing this activity routinely, the utility may be able to catch a problem at an early stage and mitigate the effect.

RECORDS

Written records should be kept on all facilities in the distribution system. These records should describe the facility, its construction, date installed, repairs and maintenance work completed, manufacture, and condition during the latest inspection.

As new facilities are installed, they should be included in the existing record system. Records should also note those facilities retired from service. Other types of records that should be kept are:

1. Results of water quality monitoring
2. Cross-connection control
3. Main flushing

4. Main cleaning
5. Consumer questions, complaints and conservation programs participated in
6. Disinfection
7. Pressure surveys
8. Leaks
9. Engineering reports
10. Any operations done in compliance with the request of the health department
11. A daily log kept on any and all unusual events occurring, such as equipment malfunction, unusual weather conditions, and natural or manmade disasters

Each public water system is required by the primary Drinking Water Regulations to maintain records of water quality analyses, written reports, variances or exemptions, and actions taken to correct violations of the regulations.

COMPLAINTS

At times, a customer's complaint is a result of a problem that is originating on the customer's premises. A customer may complain about a lack of water pressure which often results from deficiencies in the customer's plumbing. Pressure readings should be taken in the house, first without any flow so as to obtain a reading that should be close to the pressure in the system main. Then a pressure test is made with other taps in the house flowing to show the pressure drop was due to some obstruction or inadequate plumbing. Often this process may be due to the shutoff valve on the house water line being turned off or partially off. If this situation is not the cause of the failure, then the owner must usually make corrections to the plumbing. Replacing the service line from the meter to the house is often sufficient, however, occasionally repairs to the plumbing in the house may also be necessary.

Another problem that is common within the United States is red or dirty water, which could also be due to deficiencies in the consumer's plumbing lines. The cause of the problem can be demonstrated by taking samples from the customer's tap and comparing them with samples of water collected from the utility's service line just upstream of the consumer's system. Another indication of the source is that if no other home in the area has, or has recently had, the problem, then it is almost certainly coming from the consumer's water lines.

Customer complaints may vary based on geographic region. Within the southwestern United States, complaints about hard water are very common. Customers may complain about the water containing "floating objects," which are often calcium or magnesium. These are minerals that are naturally occurring in groundwater, but may cause customers to think the water is not safe to drink.

Operators may also receive complaints that some persons in a home are becoming ill, with this emphatically attributed to the water they are drinking. These complaints should be thoroughly investigated by the utility and also referred to the health department. Sometimes, the consumer's doctor says that the water supply is at fault or as the consumer claims. If this

situation takes place, the doctor should be referred to the public health officer at the county or city. Often, a bacteriological sample is collected directly from the consumer's home. If water quality tests results are negative and the customer's neighbors and the rest of the community have no problems, it is very doubtful that the utility's water supply is the culprit.

SURVEYS

Most utilities go directly to their customers to find out how the customers feel about the system and its operations. The process is part of an overall plan by a utility to self-evaluate and collect customer opinions. Follow-up after a survey with consumers, and develop an improvement program to address the issues that were uncovered in the questionnaire. The questionnaires should be designed to ask questions that a layperson could understand, and it may be advantageous to field test the survey before wide distribution. Problems can be identified and priorities can be designated as to which problems can be solved soon and which must wait solutions at some later date.

When customers or stakeholders complain about an aspect of the drinking water or service, document the complaints. Maintain a data file of all complaints that are received and use it to monitor underlying symptoms of problems that are larger than the immediate issue raised. The data file should be such that it can be searched for any patterns that could surface from the complaints. Importantly, the utility should use the complaints as a tool for early detection of potential problems.

REVIEW QUESTIONS

1. Outline the steps that should be implemented when responding to customer complaints concerning drinking water quality.
 2. What is a common consumer complaint that is received by the drinking water treatment plant?
 3. Why should complaint logs and responses to customer complaints be reviewed periodically?

CHAPTER QUIZ

1. The _____ of a utility are responsible for customer relations and for positive customer communication.
 - a. customer service personnel
 - b. employees (all)
 - c. public relations officer
 - d. operators

2. Which of the following is not included in the process of dealing with a consumer complaint?
 - a. Collect as much information from the consumer as possible
 - b. Direct the complaint to the proper department or person for evaluation, if necessary
 - c. Consider different potential causes of the problem and methods of testing
 - d. Correcting the complaint and having as little public contact as possible is the goal

3. When presented with a complaint, _____ should show concern, listen carefully, and calmly offer to look into the complaint. Help correct any problems that are found within the system and answer questions or obtain answers to questions.
 - a. customer service personnel
 - b. employees (all)
 - c. public relations officer
 - d. operators

4. Sometimes, it is through _____ that a water utility learns the service being provided is not satisfactory.
 - a. complaints
 - b. award applications
 - c. records
 - d. surveys

5. The most common problem is _____, which could be due to deficiencies in the consumer's plumbing lines. The cause of the problem can be demonstrated by taking samples from the customer's tap and comparing them with samples of water collected from the utility's service line just upstream of the consumer's system. Another indication of the source is that if no other home in the area has, or has recently had, the problem, then it is almost certainly coming from the consumer's water lines.
- pressure
 - red water or dirty water
 - illness resulting from drinking water
 - too much chlorine
6. A customer may complain about a lack of _____ which often results from deficiencies in the customer's plumbing. Investigating and testing the consumer's plumbing is the first step in determining the cause of the problem. If the problem is found in the customer's plumbing, then the owner must usually make corrections to the plumbing.
- pressure
 - red water or dirty water
 - illness resulting from drinking water
 - too much chlorine
7. Operators may also receive complaints concerning _____ in the home, with this emphatically attributed to the water they are drinking. These complaints should be thoroughly investigated by the utility and also referred to the health department. Often, a sample is collected directly from the consumer's home and water quality tests are performed. If the results are negative and the customer's neighbors and the rest of the community have no problems, it is very doubtful that the utility's water supply is the culprit.
- pressure
 - red water or dirty water
 - illness resulting from the drinking water
 - too much chlorine

8. When customers or stakeholders _____ about an aspect of the drinking water or service, document the complaints. Maintain a data file of all that are received and use it to monitor underlying symptoms of problems that are larger than the immediate issue raised. The data file should be such that it can be searched for any patterns that could surface. Importantly, the utility should use theme as a tool for early detection of potential problems in the system.
- a. complaints
 - b. award applications
 - c. regulatory agencies
 - d. surveys
9. Some utilities go directly to their customers using _____ to find out how the customers feel about the system and its operations. The process is part of an overall plan by a utility to self-evaluate and collect customer opinions.
- a. complaints
 - b. award applications
 - c. records
 - d. surveys
10. Public water system is required by the primary Drinking Water Regulations to maintain _____ of water quality analyses, written reports, variances or exemptions, and actions taken to correct violations of the regulations.
- a. complaints
 - b. award applications
 - c. records
 - d. surveys