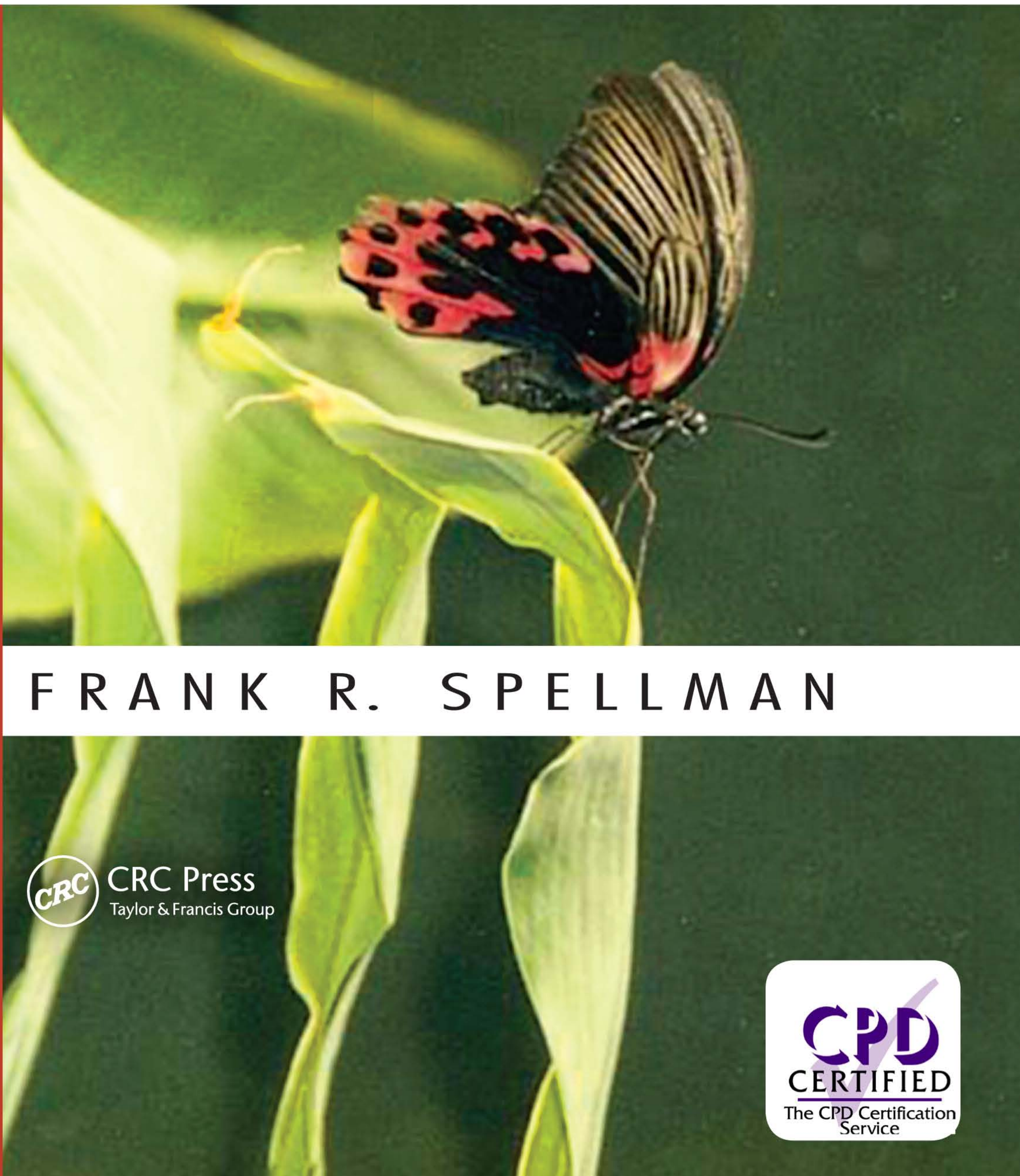
THE SCIENCE OF ENVIRONMENTAL POLLUTION

THIRD EDITION



FRANK R. SPELLMAN

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Dedication

For Kathern Welsh whose artwork inspires me … continuously.

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Preface

Hailed on its first and second publication as a masterly addition to the three-edition environmental series that includes *The Science of Water*, *The Science of Air*, and *The Science of Renewable Energy*, this new and fully updated edition of *The Science of Environmental Pollution* brings this successful series fully into the 21st century. The third edition of *The Science of Environmental Pollution* continues to be based on good science and not feel-good science. It continues to be presented in the author's conversational style. And it continues to ask the same basic questions: Environmental pollution, what is it? Environmental contamination, what is it? Environmental pollution, what is its impact, and should we be concerned? Environmental pollution, what are the causes? Environmental pollution, what are the proper mitigation procedures?

Concern for the environment and for the impact of environmental pollution grew during the last 30 years of the 20th century. Information and technological advances allowed us to monitor the Earth as never before. Moreover, as more people became aware of the environment and environmental degradation, environmental awareness, activism, and sensitivity increased to where the environment was discussed and debated. Before this awakening to the environment around us, the average person's view of the impact of environmental pollution was more superficial than a paper cut; however, this distorted view is fading. We are beginning to realize that we are responsible for much of the environmental degradation of the past and present—all of which is readily apparent today. Finally, the impact of 200 years of industrialization and surging population growth has far exceeded that of an individual's backyard bonfire when localized, isolated pockets of pollution were the main concern.

Today, pollution is much more of a global problem with potentially far-reaching consequences. Consider acid rain, for example. The belching smokestacks of the industrial complexes in the U.S. Midwest produce clouds filled with chemical cocktails that reach not only the Finger Lakes region of New York but also parts of Canada, the Appalachian forest areas, and other areas, severely damaging flora, fauna, and surface waters. Then there are the world's tropical rainforests, which are disappearing at an alarming rate, along with several species of plants and animals. We can't overlook the potable water problems, either. Literally, water is the new oil. Earth contains a finite amount of water to quench the thirst of a rapidly growing population. Potable water is not always located where it is needed the most. An example of this can be seen in the southwestern United States, where water availability is decreasing daily. Areas of the world where freshwater is readily available are encountering problems with water quality. Polluted waterways and water sources are becoming increasingly more common as a result of industrial and agricultural runoff. Diseases resulting from contaminated waste, such as cholera, are endemic in some regions. We are overexploiting our natural resources and wasting the legacy we should be leaving behind for our children and grandchildren. Some might think our future looks bleak; indeed, without a profound change in attitude toward environmental pollution and its effects, there may be no future to contemplate. Fortunately, we seem to have come to realize the obvious and perhaps anticipate the not so obvious. But, keep in mind that the complete story on this issue has yet to be written.

In addition to asking the same questions, this standard synthesis has now been completely revised and expanded for the second edition. The text still deals with the essence of our environment—that is, what maintaining the good health of our environment is all about. This edition also includes the following new sections or chapters:

- Indoor air quality
- Air monitoring procedures
- Air sampling procedures and equipment
- Mold control
- Pharmaceuticals and endocrine disruptors in drinking water

Why a text on the science of environmental pollution? Simply put, studying pollution without science is analogous to attempting to cook without being able to read a recipe or to measure ingredients correctly or to monitor the progress of that which is cooking. However, studying pollution through science affords us the opportunity to maintain a healthful, life-sustaining environment for ourselves and for all of Earth's organisms. Keep in mind that I am not striving to make the study of pollution simplistic; I am striving to make it simple. This is a tall order, because there is nothing simple about pollution or its impact on all of us. The bottom line, when you get right down to it, is that sustaining healthy life on Earth is a goal everyone should strive for.

Many of us have come to realize that a price is paid (sometimes a high price) for what is considered the "good life." Our consumption and use of the world's resources makes us all at least partially responsible for the pollution of our environment. Pollution and its ramifications are the inevitable products of the good life we all strive to attain, but obviously pollution is not something caused by any single individual nor can any one individual totally prevent its occurrence or correct the situation. To reduce pollution and its harmful effects, everyone must band together as an informed, knowledgeable group and pressure the elected decision makers to manage the problem now and in the future. Even as individuals, though, we are not impotent in the battle to preserve and repair our environment. The concepts and guidelines in this text will equip you with the scientific rationale required to make decisions that directly affect the environment around you. This is important, because the information on environmental issues that is filtered through the media frequently portends dire catastrophes. Some sources say that pollution is the direct cause of climate change; others deny that the possibility even exists. Is climate change an encroaching problem? This text helps sort through the hyperbole to allow you to make your own informed decision. Is that not what education and information are really about? That is, education and information provide humans with the intellectual tools necessary to make their own informed decisions.

Although it is impossible to ensure that personal views and perceptions are nonexistent in this text, I have deliberately avoided the intrusion of media hype and political ideology (which I consider to be thinking without thought); instead, this text attempts to relate facts. I am a firm believer in good science and detest feel-good science. Political ideology and the media work to temper perception and to fog the facts, which in turn fogs both the public perception of the issues and the scientific assessment of environmental quality.

Throughout this text, common-sense approaches and practical examples are presented. Again, because this is a science text, I have adhered to scientific principles, models, and observations, but you need not be a scientist to understand the principles and concepts presented. What is needed is an open mind, a love for the challenge of wading through all the information, an ability to decipher problems, and the patience to answer the questions relevant to each topic presented. The text follows a pattern that is nontraditional; that is, the paradigm used here is based on real-world experience, not on theoretical gobbledygook. Real-life situations are woven throughout the fabric of this text and presented in straightforward, plain English to provide the facts, knowledge, and information needed to make informed decisions.

This text is not an answer book. Instead, it is designed to stimulate thought. Although answers to specific pollution problems are not provided, the framework and principles you can use to understand the complexity of any pollution problem are provided.

Environmental issues are attracting ever-increasing attention at all levels. The problems associated with these issues are compounded and made more difficult by the sheer number of factors involved in handling any phase of any problem. Because the issues affect so many areas of society, we must hunt for strategies to solve the problems for all while maintaining a safe environment without excessive regulation and cost—Gordian knots that defy easy solutions.

The preceding statement goes to the heart of why this text is needed. Currently, only a limited number of individuals have sufficient background in the science of pollution to make informed decisions on environmental pollution issues. Although environmental problems such as pollution have resulted in the development and introduction of new environmental science programs at many universities, many of these new programs are, when it comes to a particular science major, just more of the same. Although they have rigorous science-based curriculums requiring a broad background in earth science, hydrology, geology, chemistry, physics, biology, and mathematics, they miss a critical aspect of environmental issues—the culture framework in which environmental problems exist.

Do these programs produce students equipped with the information they need to solve the pollution problems we face—and will face? Along with a strong foundation of science basics, education in environmental science should include a learning path that gives environmental science majors the ability to solve real-world problems. Dealing with environmental pollution problems involves political, cultural, and societal skills that a college scientific classroom is usually now well equipped to develop. Pollution is a real-world problem.

Finally, the third edition of *The Science of Environmental Pollution* is designed to reach a wide range of student backgrounds. The text focuses on pollution of the atmosphere, surface and groundwater, and soil (three of the four environmental media, the fourth being the biota), all critical to our very survival. Most importantly of all, however, *The Science of Environmental Pollution* aims to generate a greater awareness of the importance of preserving our environment for the benefit of the generations to come. Because pollution is a real-world problem, it logically follows that we can solve pollution problems by using real-world methods. That's what *The Science of Environmental Pollution* is all about. Critical to solving these real-world environmental problems is for all of us to remember that old saying that we should take nothing but pictures, leave nothing but footprints, and kill nothing but time.

Prologue: When the Animas River Became a Yellow Boy[*]

Day: Wednesday
Date: August 5, 2015
Place: Near Silverton, Colorado
Event: Gold King Mine spill
Surface water bodies affected: Cement Creek, Animas River, San Juan River, Colorado River
Watershed: Colorado, Utah, New Mexico, Arizona, Nevada, and California

GOLD KING MINE SPILL

On August 5, 2014, the U.S. Environmental Protection Agency (USEPA) conducted a mine site investigation of the abandoned Gold King Mine above the old adit (a mine tunnel) to

- Assess the ongoing water releases from the mine.
- Treat mine water.
- Assess the feasibility of further mine remediation.

During the excavation required for the investigation the heavy equipment disturbed loose material around a soil "plug" at the mine entrance, spilling about 3 million gallons of pressurized water stored behind the collapsed material into Cement Creek, a tributary of the Animas River. The spill volume associated with the release on August 5 was calculated to be approximately 3 million gallons based on flow rates. Discharge rates from the mine as of November 5, 2015, averaged around 600 gallons per minute. It is important to point out, for context, that multiple mines are located along the upper Animas, and historically there have been considerable discharges at each mine site. The Red and Bonita mines, just below the Gold King Mine, currently discharge about 300 gallons per minute. One of the most striking effects of the Gold King Mine spill was the color change clearly visible in Cement Creek and Animas River and to a lesser degree downstream almost to the San Juan River. The iron from the acid mine drainage precipitated out into the water as a result of the rise in pH, turning it yellow. Old-time goldpanners and other sluice miners refer to the resulting red, orange, and yellow solids as "yellow boy." Typically, as more water is mixed in (dilution is the solution to pollution, according that mythical hero Hercules, who arguably might have been the world's first environmental engineer), the iron and other metals become even more dilute or get attached to sediments, causing them to drop out of the water, sink, and settle into river bottom sediments. The water color then returns to normal. But, and this is the gist of this text, what appears normal in surface water bodies (or any environmental medium) may not actually be normal because, as in the case of the Animas River and thousands of other polluted streams, what we are able to see at the surface does not in any way certify the quality of the water contained within the water body.

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USEPA. (2017). *Frequent Questions Related to Gold King Mine Response.* Washington, DC: U.S. Environmental Protection Agency (https://www.epa.gov/goldkingmine/frequent-questions-related-gold-king-mine-response).

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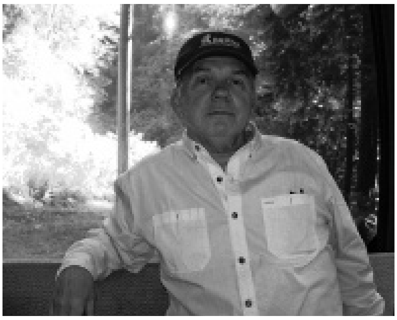
[*] Adapted from Spellman, F.R., *Contaminated Sediments in Freshwater Systems*, CRC Press, Boca Raton, FL, 2017.

Author



Frank R. Spellman, PhD, is a retired adjunct assistant professor of environmental health at Old Dominion University, Norfolk, Virginia, and the author of more than 110 books covering topics ranging from concentrated animal feeding operations (CAFOs) to all areas of environmental science and occupational health. Many of his texts are readily available online, and several have been adopted for classroom use at major universities throughout the United States, Canada, Europe, and Russia; two have been translated into Spanish for South American markets. Dr. Spellman has been cited in more than 850 publications. He serves as a professional expert witness for three law groups and as an incident/accident investigator for the U.S. Department of Justice and a northern Virginia law firm. In addition, he consults on homeland security vulnerability assessments for critical infrastructures, including water/wastewater facilities, and conducts pre-Occupational Safety and Health Administration and Environmental Protection Agency audits throughout the country. Dr. Spellman receives frequent requests to co-author with well-recognized experts in several scientific fields; for example, he is a contributing author to the prestigious text *The Engineering Handbook*, 2nd ed. Dr. Spellman lectures on wastewater treatment, water treatment, and homeland security, as well as on safety topics, throughout the country and teaches water/wastewater operator short courses at Virginia Tech in Blacksburg. In 2011, he traced and documented the ancient water distribution system at Machu Picchu, Peru, and surveyed several drinking water resources in Amazonia, Ecuador. He has also studied and surveyed two separate potable water supplies in the Galapagos Islands, in addition to studying Darwin's finches while there. Dr. Spellman earned a BA in public administration, a BS in business management, an MBA, and both an MS and a PhD in environmental engineering.

Section I

Introduction

I will show you fear in a handful of dust.

T.S. Eliot, *The Wasteland* (1922)

1 Pollution: What Is It?

Salt, meet wound. Insult, greet injury. Pollution, say hello to the environment. Modern pollution is uncontrolled and poorly regulated.

INTRODUCTION: DEEP AND GLOOMY WOODS[*]

> The mountain, and a deep and gloomy wood,
> Their colours and their forms, were then to me
> An appetite: a feeling and a love,
> That had no need of remoter charm.
>
> **William Wordsworth,** ***Lines Composed a Few Miles Above Tintern Abbey*** **(1798)**

We had not walked any part of the Appalachian Trail, with its nearly 50 mountains spanning 14 states and 8 national forests, for more than several years. Though we had never walked its entire 2160-mile length, from Springer Mountain in Georgia to Katahdin, Maine, at once, over the course of several years a long time ago we had in piecemeal fashion covered most of it, and we had hiked many of the several hundred trails that parallel and join it as well. But we had moved out of easy reach of the Trail, and for years had only our memories of it.

For us, the lure of sojourning the Appalachian Trail had always been more than just an excuse to get away from it all—whatever "it" happened to be at the time. The draw, the magnetism of the Trail, was more—much more—to us than that, though we have always found its magic difficult to define. Maybe it was a combination of elements—recollections, pleasant memories, ephemeral surprises found and never forgotten. Memories waking from the miles-deep sleep of earned exhaustion to the awareness of peace … inhaling deep draughts of cool, clean mountain air; breathing through nostrils tickled with the pungency of pure, sweet pine … eardrums soothed by the light tattoo of fresh rain pattering against taut nylon … watching darkness lifted, then suddenly replaced with cloud-filtered daylight, spellbound by the sudden, ordinary miracle of a new morning … anticipating our expected adventure and realizing the pure, unadulterated treasure of pristine wilderness we momentarily owned, with minds not weighed down by the mundane, everyday existence. That is what we took away from our Trail experiences years ago, what we remembered about living on the Trail, on our untroubled sojourn through one of the last pure wilderness areas left in the United States. Those memories were magnets. They drew us inexorably to the Trail—back again and again.

But, of course, the Trail had another drawing card—the natural world and all its glory. The Trail defined that for us. The flora that surrounds you on the Trail literally encapsulates you, as it does in any dense forest, and brings you fully into its own world, shutting out all the other worlds of your life. For a brief span of time, along the Trail, the office was gone; cities, traffic, the buzz and grind of work melted away into forest. But this forest was different, and its floral inhabitants created the difference. Not only the thickets of rhododendrons and azaleas (in memory, always in full bloom) but also the other forest growths drew us there: the magnificent trees—that wild assortment of incomparable beauty that stood as if for forever—that was the Trail.

This was how it had been no more than 25 years ago, but now things were different; things had changed for the worse. To say that we were shocked at what we found recently along the Trail—along most of its length—is true, and we can only describe it as wounding heartache, as achingly sad to us as the discovery of the physical debilitation of a long-beloved friend. Even though still lined (and, in some places, densely packed) with Fraser fir, red spruce, sugar maples, shagbark

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[*] Adapted from Spellman, F.R., *The Science of Environmental Pollution*, CRC Press, Boca Raton, FL, 1999.

hickory, northern red oak, quaking aspens, tulip poplars, white basswood, yellow buckeyes, black gums, old-growth beech, mountain laurel, and those incomparable dogwoods whose creamy-white bracts light up the woods in early spring, the world along the Trail was different. Let us paint you a picture of the differences. Walking various segments of the trail and its arteries in North Carolina, Virginia, and Maryland, we observed the following:

- Standing dead Fraser fir and red spruce
- Stands of pollution-killed trees where fallen gray tree trunks crisscrossed each other in a horrible game of giant jackstraws
- Standing dead red spruce silhouetted by polluted fog
- Understories of brambles looking up at dead sugar maples
- Foliage areas bleached by ozone
- Trees of all varieties starved to death, the necessary soil nutrients leached away by decades of acid deposition and the trees weakened until they were no longer capable of withstanding the assaults of even ordinary disease and bad weather
- Logged wasteland areas
- Branch dieback on northern red oak
- Premature leaf drop on quaking aspens
- Thinning crowns on sugar maples
- Tipped-over tulip poplars with rotted roots
- Chemically green ponds in areas where active strip mining occurs
- An orange waterfall next to an abandoned mine
- An overview where 25 years earlier we could view the surrounding landscape for 50 miles but was now veiled in thick, stagnant, polluted fog with visibility reduced to 2 or 3 miles

POLLUTION DEFINED

When asked to define pollution, most people have little trouble doing so, having witnessed some form of it firsthand. They usually come up with an answer that is a description of its obvious effects, but pollution is complicated, and it cannot be easily defined because what pollution is and isn't is a judgment call. In nature, even the most minute elements are intimately connected with every other element, and so too are pollution's effects. In this chapter, we define pollution more fully and explain the difficulty involved with defining it, beginning a process that will allow readers to create their own definitions of pollution—though each reader's definition will vary.

When we need a definition for any environmental term, the first place we look is in pertinent U.S. Environmental Protection Agency (USEPA) publications. For the term *pollution*, however, we did not find the USEPA definition to be particularly helpful or complete. USEPA (1989) has defined pollution as "generally, … the presence of matter or energy whose nature, location, or quantity produced undesired environmental effects … impurities producing an undesirable change in an ecosystem." Under the Clean Water Act (CWA), for example, the term is defined as "the man-made or man-induced alteration of the physical, biological, and radioactive integrity of water" (USEPA, 1989). Although this definition is not inaccurate, it leaves out too much to suit our needs. The USEPA does, however, provide an adequate definition of the term *pollutant*: "any substance introduced into the environment that adversely affects the usefulness of a resource." Pollution is often classified as point-source or nonpoint-source pollution; however, USEPA's definition of pollution seems so general as to be useless, perhaps because it fails to add information about what such a broadly inclusive term may cover. Definitions from other sources present similar problems. One of the problems with defining pollution is that it has many manifestations (see Figure 1.1).

Why is pollution so difficult to define? The element of personal judgment mentioned earlier contributes to the difficulty. Moreover, the manifestations of pollution shown in Figure 1.1 attempt to illustrate what pollution is but also work to confound the difficulty. The main problem with the

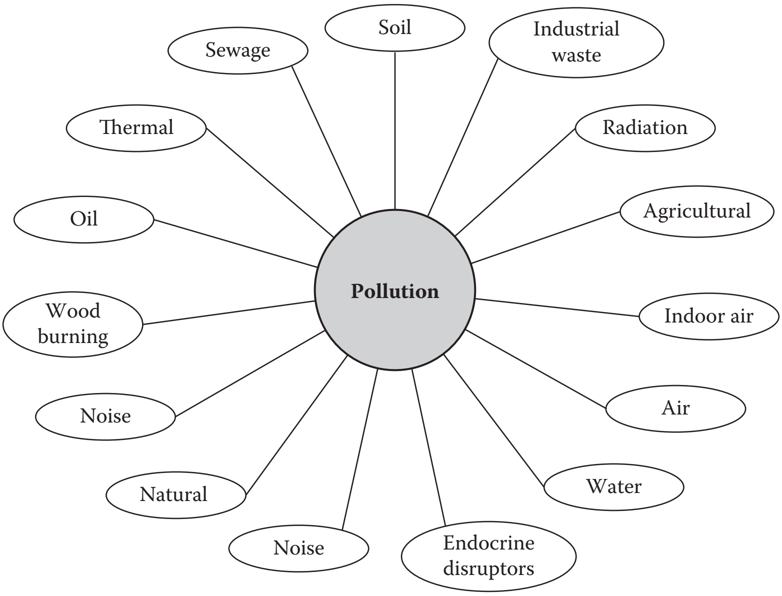

FIGURE 1.1 Pollution and its manifestations.

manifestations of pollution shown in Figure 1.1 is that they are too general. And there is that "other" problem. What might that be you ask? Well, the terms *pollution* and *contamination* are often considered to have the same meaning. What if someone pours sugar into your coffee and you can't hack sugar in just about anything? Would you refer to the sugar that was added to be pollution or contamination? I have actually heard people say that their coffee had been contaminated with sugar, but I have never heard anyone say that their coffee had been polluted with sugar. Have you? Although the terms *pollutant* and *contaminant* both refer to undesirable or unwanted substances or materials, a pollutant is a substance that pollutes the environment, and a contaminant is a substance that contaminates the environment. In this book, a *pollutant* is defined as a harmful substance found within an environmental medium (air, water, or soil); on the other hand, contamination is the presence of an unwanted impurity or constituent, which is not necessarily harmful but could be, in a material, physical body, or natural environment.

Let's move along. Anyone who seriously studies pollution quickly realizes that there are five major categories of pollution, each with its own accompanying subsets; these are shown in Table 1.1 (the types of pollution listed are defined later in the chapter). The categories and types of pollution listed in Table 1.1 can also be typed or classified as to whether they are *biodegradable* (subject to decay by microorganisms) or *nonbiodegradable* (cannot be decomposed by microorganisms). Moreover, nonbiodegradable pollutants can also be classified as *primary pollutants* (emitted directly into the environment) or *secondary pollutants* (result of some action of a primary pollutant).

KEY TERMS

To understand the basic concepts of environmental pollution, it is necessary to learn the core vocabulary. Following are some of the key terms that are used in this chapter and discussed in greater detail throughout this text. Remember what Voltaire said: "If you wish to converse with me, please define your terms."

Scientists gather information and draw conclusions about the workings of the environment by applying the *scientific method*, a way of gathering and evaluating information. It involves observation, speculation (hypothesis formation), and reasoning. The science of pollution may be divided

TABLE 1.1
Categories and Types of Pollution

Pollution Categories	Type of Pollution	
Air pollution	Acid rain	Global distillation
	Chlorofluorocarbon	Particulates
	Global warming	Smog
	Global dimming	Ozone depletion
Water pollution	Eutrophication	Surface runoff
	Hypoxia	Thermal pollution
	Marine pollution	Wastewater
	Marine debris	Waterborne diseases
	Ocean acidification	Water quality
	Oil spills	Water stagnation
	Ship pollution	
Soil contamination	Bioremediation	Pesticides
	Electrical resistance heating	Soil Guideline Values (SGVs)
	Herbicides	
Radioactive contamination	Actinides in the environment	Plutonium in the environment
	Environmental radioactivity	Radiation poisoning
	Fission products	Radium in the environment
	Nuclear fallout	Uranium in the environment
Others	Invasive species	Radio spectrum pollution
	Light pollution	Visual pollution
	Noise pollution	

among the study of air pollution (atmosphere), water pollution (hydrosphere), soil pollution (geosphere), and life (biosphere). Again, the emphasis in this text is on the first three—air, water, and soil—because without any of these, life as we know it is impossible.

The *atmosphere* is the envelope of thin air around the Earth. The role of the atmosphere is multifaceted: (1) it serves as a reservoir of gases, (2) it moderates the Earth's temperature, (3) it absorbs energy and damaging ultraviolet (UV) radiation from the sun, (4) it transports energy away from equatorial regions, and (5) it serves as a pathway for vapor-phase movement of water in the hydrologic cycle. Air, the mixture of gases that constitutes the Earth's atmosphere, is by volume at sea level 78.00% nitrogen, 21.00% oxygen, 0.93% argon, and 0.03% carbon dioxide, together with very small amounts of numerous other constituents. The *hydrosphere* is the water component of the Earth, encompassing the oceans, seas, rivers, streams, swamps, lakes, groundwater, and atmospheric water vapor. *Water* (H_2O) is a liquid that when pure is without color, taste, or odor. It covers 70% of the Earth's surface and occurs as standing (oceans, lakes) and running (rivers, streams) water, rain, and vapor. It supports all forms of Earth's life. The *geosphere* consists of the solid portion of Earth, including *soil*. The *lithosphere* is the topmost layer of decomposed rock and organic matter that usually contains air, moisture, and nutrients and can therefore support life. The *biosphere* is the region of the Earth and its atmosphere in which life exists, an envelope extending from up to 6000 meters above to 10,000 meters below sea level. Living organisms and the aspects of the environment pertaining directly to them are *biotic* (biota); the other, nonliving part of the physical environment is considered to be *abiotic*.

The series of biological, chemical, and geological processes by which materials cycle through ecosystems are called *biogeochemical cycles*. We are concerned with two types: the *gaseous* and the *sedimentary*. Gaseous cycles include the carbon and nitrogen cycles. The main *sinks*—the main receiving areas for material; for example, plants are sinks for carbon dioxide—of nutrients in the gaseous cycle are the atmosphere and the ocean. The sedimentary cycles include the sulfur and phosphorus cycles. The main sink for sedimentary cycles is the soil and rocks of the Earth's crust. Formerly known as natural science, *ecology*, as it is commonly called today, is critical to the study of environmental science, as it is the study of the structure, function, and behavior of the natural systems that comprise the biosphere. The terms *ecology* and *interrelationship* are interchangeable; they mean the same thing. In fact, ecology is the scientific study of the interrelationships among organisms and between organisms and all aspects, living and nonliving, of their environment.

Ecology is normally approached from two viewpoints: (1) the environment and the demands it places on the organisms in it, or (2) organisms and how they adapt to their environmental conditions. *Sensory ecology*, a relatively new field of study, is the examination of how organisms acquire, process, and respond to information from their environment (Dusenbery, 1992). It is important to point out that members of our environment include much more than just us (self-centered humans). The environment also includes all other living and non-living participants and components. This is where sensory ecology not only comes into play but also becomes an important topic of discussion in this new edition of the text. Ecology generally focuses on the exchanges of matter and energy involved with humans and their interactions with the environment.

On the other hand, sensory interactions generally examine influences on behavior and functions of certain sense organs (physiological systems). Sensory ecology covers topics ranging from the neurobiological mechanisms of sensory systems to the behavior patterns employed in the acquisition of sensory information. Human perception relies primarily on the visual sense; however, other species rely more heavily on the different senses (Dusenbery, 1992, 2001; Van Dyck, 2012). Thus, the question becomes, if humans change, modify, and/or destroy a particular environment for their own self-centered needs, what is the impact on the other species that would typically share the previously undisturbed environment?

An *ecosystem*, a cyclic mechanism, describes the interdependence of species in the living world (the biome or community) with one another and with their nonliving (abiotic) environment. An ecosystem has physical, chemical, and biological components, as well as energy sources and pathways. An ecosystem can be analyzed from a functional viewpoint in terms of several factors. The factors important in this discussion include *biogeochemical cycles*, *energy*, and *food chains*. Each ecosystem is bound together by biogeochemical cycles through which living organisms use energy from the sun to obtain or "fix" nonliving inorganic elements such as carbon, oxygen, and hydrogen from the environment and transform them into vital food, which is then used and recycled. The environment in which a particular organism lives is a *habitat*. The role of an organism in a habitat is its *niche*.

It is probably easier to understand what an ecosystem is and how certain materials are constantly interchanged by referring to an illustration of one of Nature's basic (but critical) ecosystems. To clarify our understanding of various important terms, Figure 1.2 depicts an ecosystem where biotic and abiotic materials are constantly exchanged. (Remember that nature is dynamic. Nothing—absolutely nothing—is static in nature.) *Producers* construct organic substances through photosynthesis and chemosynthesis. *Consumers* and *decomposers* use organic matter as their food and convert it into abiotic components—that is, they dissipate energy fixed by producers through food chains. The abiotic part of the pond in Figure 1.2 is formed of inorganic and organic compounds, including carbon, oxygen, nitrogen, sulfur, calcium, hydrogen, and humic acids. Producers—rooted plants and phytoplankton—represent the biotic part. Fish, crustaceans, and insect larvae make up the consumers. Mayfly nymphs, for example, are detrivores, feeding on organic detritus. Decomposers (aquatic bacteria and fungi) make up the final biotic element.

One major goal for environmentalists and ecologists alike is the goal of achieving a *sustainable society*. A society that manages its economy and population without harming the environment by regulating population growth, uses renewable resources at a rate at which they can be replenished, and encourages Earth-sustaining forms of economic development is considered to be a sustainable society (Miller, 2004).

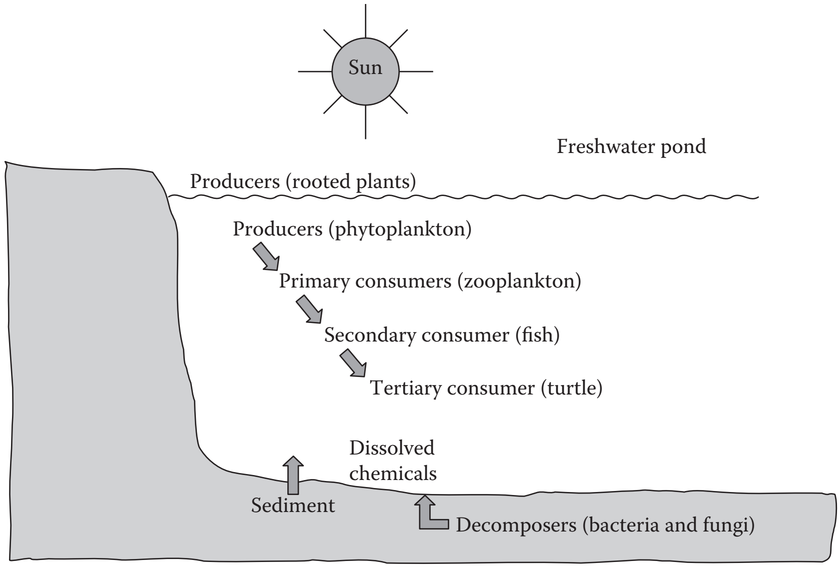

FIGURE 1.2 Major components of a freshwater pond ecosystem. (Adapted from Spellman, F.R., *Stream Ecology and Self-Purification: An Introduction for Wastewater and Water Specialists*, Technomic, Lancaster, PA, 1996.)

Note: Although many branches of science help us understand the physical, chemical, and biological processes of our environment, ecology concentrates on the way these processes interact as systems. A well-grounded knowledge of ecology is fundamental to gaining knowledge of environmental pollution.

Key terms, many listed in Table 1.1, are defined below:

- *Acid rain*—Any form of precipitation made more acidic from falling though air pollutants (primarily sulfur dioxide) and dissolving them.
- *Actinides in the environment*—The sources, environmental behavior, and effects of radioactive actinides in the environment.
- *Air Quality Index*—A standardized indicator of the air quality in a given location.
- *Atmospheric dispersion modeling*—The mathematical simulation of how air pollutants disperse in the ambient atmosphere.
- *Bioremediation*—Any process that uses microorganisms, fungi, green plants, or their enzymes to return the natural environment altered by contaminants to its original condition.
- *Chlorofluorocarbons (CFCs)*—Synthetic chemicals that are odorless, nontoxic, nonflammable, and chemically inert.
- *Electrical resistance heating remediation*—An *in situ* environmental remediation method that uses the flow of alternating current electricity to heat soil and groundwater and evaporate contaminants.
- *Emerging pollutants (contaminants, such as PPCPs)*—Any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment but has the potential to enter the environment and cause known or suspected adverse ecological and/or human health effects. Pharmaceuticals and personal care products (PPCPs) comprise a very broad, diverse collection of thousands of chemical substances, including prescription and over-the-counter therapeutic drugs, fragrances, cosmetics, sunscreen agents, diagnostic agents, nutrapharmaceuticals, biopharmaceuticals, and many others.
- *Environmental radioactivity*—The study of radioactive material in the human environment.

DID YOU KNOW?

An unlikely ally for buffering the carbon dioxide that acidifies seawater is fish poop. There are 2 billion tons of fish in the world's oceans, and fish poop seems to play a key role in maintaining the ocean's delicate pH balance (Brahic, 2009).

- *Eutrophication*—A natural process in which lakes receive inputs of plant nutrients as a result of natural erosion and runoff from the surrounding land basin.
- *Fission product*—The atomic fragments left after large nucleus fission.
- *Global dimming*—The gradual reduction in the amount of global direct irradiance at the Earth's surface.
- *Global distillation* (or *grasshopper effect*)—The geochemical process by which certain chemicals, most notably persistent organic pollutants (POPs), are transported from warmer to colder regions of the Earth.
- *Global warming*—The long-term increase in the average temperature of the Earth.
- *Herbicide*—Chemical substances used to kill unwanted plants.
- *Hypoxia*—A phenomenon that occurs in aquatic environments as dissolved oxygen (DO) becomes reduced in concentration to the point where it is detrimental to aquatic orgasms living in the system.
- *Indoor air quality*—A term referring to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants.
- *Invasive species*—Non-indigenous species (e.g., plants, animals) that adversely affect the habitats they invade economically, environmentally, or ecologically.
- *Light pollution*—Excessive or obtrusive artificial light (photopollution or luminous pollution).
- *Marine debris*—Human-created waste that has deliberately or accidentally become afloat in a waterway, lake, ocean, or sea.
- *Marine pollution*—Harmful, or potentially harmful, effects resulting from the entry into the ocean of chemicals, particles, or industrial, agricultural, and residential waste or from the spread of invasive organisms.
- *Noise pollution*—Unwanted sound that disrupts the activity or balance of human or animal life.
- *Nuclear fallout*—The residual radiation hazard from a nuclear explosion, so named because it "falls out" of the atmosphere into which it is spread during the explosion.
- *Ocean acidification*—The ongoing decrease in the pH of the Earth's oceans, caused by their uptake of anthropogenic carbon dioxide from the atmosphere (Caldeira and Wickett, 2003).
- *Oil spill*—The release of a liquid petroleum hydrocarbon into the environment due to human activity; a form of pollution.
- *Ozone depletion*—Ozone concentrations vary naturally with sunspots, the seasons, and latitude, but these processes are well understood and predictable. Scientists have established records spanning several decades that detail normal ozone levels during these natural cycles. Each natural reduction in ozone levels has been followed by a recovery. Recently, however, convincing scientific evidence has shown that the ozone shield is being depleted well beyond changes due to natural processes (USEPA, 2009).
- *Particulates*—Normally refers to fine dust and fume particles that travel easily through air.
- *Pesticide*—A substance or mixture of substances used to kill pests.
- *Plutonium in the environment*—A member of the actinides series in the environment.
- *Radiation poisoning*—A form of damage to organ tissue due to excessive exposure to ionizing radiation.
- *Radio spectrum pollution*—Straying of waves in the radio and electromagnetic spectrums outside their allocations that can cause problems.

- *Radium* and *radon*—Radium and its decay product, radon gas, are highly radioactive.
- *Smog*—Term used to describe visible air pollution; a dense, discolored haze containing large quantities of soot, ash, and gaseous pollutants such as sulfur dioxide and carbon dioxide.
- *Soil Guideline Values (SGVs)*—A series of measurements and values used to measure contamination of the soil.
- *Surface runoff*—The water flow that occurs when soil is infiltrated to full capacity and excess water from rain, snowmelt, or other sources flows over the land.
- *Thermal pollution*—Increase in water temperature with harmful ecological effects on aquatic ecosystems.
- *Uranium*—A naturally occurring element found in low levels within all rock, soil, and water.
- *Visual pollution*—The unattractive or unnatural (human-made) visual elements of a vista, a landscape, or any other thing that a person might not want to look at.
- *Wastewater*—The liquid wastestream primarily produced by the five major sources: human and animal waste, household wastes, industrial waste, stormwater runoff, and groundwater infiltration.
- *Water quality*—The physical, chemical, and biological characteristics of water.
- *Water stagnation*—Occurs when water is at rest, allowing the growth of pathogenic microorganisms to take place.
- *Waterborne diseases*—Diseases caused by pathogenic microorganisms directly transmitted when contaminated drinking water is consumed.

This list of key terms and definitions along with Figures 1.1 and 1.2 and Table 1.1 provide some help, but we are still trying to nail down a definitive meaning of pollution. Accordingly, to clear the fog, maybe it will help to look at a few more definitions for the term.

As defined by Keller (1988, p. 496), pollution is "a substance that is in the wrong place in the environment, in the wrong concentrations, or at the wrong time, such that it is damaging to living organisms or disrupts the normal functioning of the environment." Again, this definition seems incomplete, although it makes the important point that often pollutants are or were useful—in the right place, in the right concentrations, at the right time. Let's take a look at some of the definitions for pollution that have been used over the years:

- Pollution is the impairment of the quality of some portion of the environment by the addition of harmful impurities.
- Pollution is something people produce in large enough quantities that it interferes with our health or wellbeing.
- Pollution is any change in the physical, chemical, or biological characteristics of the air, water, or soil that can affect the health, survival, or activities of human beings or other forms of life in an undesirable way. Pollution does not have to produce physical harm; pollutants such as noise and heat may cause injury but more often cause psychological distress, and aesthetic pollution such as foul odors and unpleasant sights affects the senses.

Pollution that initially affects one medium frequently migrates into the other mediums; air pollution falls to Earth, contaminating the soil and water; soil pollutants migrate into groundwater; and acid precipitation, carried by air, falls to Earth as rain or snow, altering the delicate ecological balance in surface waters.

In our quest for the definitive definition, the source of last resort was consulted: the common dictionary. According to one dictionary, *pollution* is a synonym for *contamination*. A contaminant is a pollutant—a substance present in greater than natural concentrations as a result of human activity and having a net detrimental effect upon its environment or upon something of value in the environment. Every pollutant originates from a source. A receptor is anything that is affected by a pollutant. A sink is a long-time repository of a pollutant. What is actually gained from the dictionary definition is that, because pollution is a synonym for contamination, contaminants are things that contaminate the three environmental mediums (air, water, soil) in some manner. The bottom line is that we have come full circle to the impact and the exactness of what we stated in the beginning of this text: "Pollution is a judgment call."

People's opinions differ in what they consider to be a pollutant on the basis of their assessment of benefits and risks to their health and economic wellbeing. For example, visible and invisible chemicals spewed into the air or water by an industrial facility might be harmful to people and other forms of life living nearby; however, if the facility is required to install expensive pollution controls, it might have to shut down or move away. Workers who would lose their jobs and merchants who would lose their livelihoods might feel that the risks from polluted air and water are minor weighed against the benefits of profitable employment. The same level of pollution can also affect two people quite differently. Some forms of air pollution, for example, might cause a slight irritation for a healthy person but life-threatening problems for someone with chronic obstructive pulmonary disease (COPD), such as emphysema. Differing priorities lead to differing perceptions of pollution (concern about the level of pesticides in foodstuffs that leads to wholesale banning of insecticides is unlikely to help the starving). No one wants to hear that cleaning up the environment is going to have a negative impact on them. The fact is that public perception lags behind reality because the reality is sometimes unbearable. This perception lag is clearly demonstrated in Case Study 1.1.

Case Study 1.1. Eau de Paper Mill

With regard to certain unbearable facets of reality, consider, for example, the residents of Franklin, Virginia, and their reeking paper mill. For those of us who live close to Franklin—it is 50 miles from Norfolk/Virginia Beach—there is no need to read the road signs. The nose knows when it's close to Franklin. The uninitiated, after a stream of phew-eees courtesy of eau de paper mill, ask that same old question: How can anyone stand to live in a town that smells like a cocktail mixture of swamp, marsh, sulfur mine, and rotten eggs? Among those who live inside the city limits and, in particular, the 1100 who work at the paper mill, few seem to appreciate the question. When the question is asked, smiles fade; attitudes get defensive. The eventual response is "What smell?" Then, waiting for that quizzical look to appear on the face of the questioner, the local's eyes will twinkle and with a chuckle he will say, "Oh, you must mean that smell of money."

So, again, what is pollution? Our best answer? Pollution is a judgment call. And preventing pollution demands continuous judgment.

DID YOU KNOW?

The distinctive odor of a whiff of marsh or swamp comes from a gas known as TRS (total reduced sulfur) that is released when plants break down. If we multiply that by the stream of trees reduced to pulp at a paper mill, you have a stench. TRS seeps out in the steam that billows from a mill's stacks. It smells like rotten eggs, boiling cabbage, or burned matches. With regard to the health effects of TRS, most authorities say it is not hazardous, at least not in the concentrations emitted by a paper mill. When the odor gets strong enough, however, some people complain of nausea and headaches. TRS has been cited as a threat to the environment. It is one of the culprits behind acid rain (Kimberlin, 2009).

POLLUTION: EFFECTS OFTEN EASY TO SEE, FEEL, TASTE, OR SMELL

Although pollution is difficult to define, its adverse effects are often relatively easy to see; for example, some rivers are visibly polluted or have an unpleasant odor or apparent biotic population problems (such as fish kill). The infamous Cuyahoga River in Ohio became so polluted it twice caught on fire from oil floating on its surface. Air pollution from automobiles and unregulated industrial facilities is obvious. In industrial cities, soot often drifts onto buildings and clothing and into homes. Air pollution episodes can increase hospital admissions and kill people sensitive to the toxins. Fish and birds are killed by unregulated pesticide use. Trash is discarded in open dumps and burned, releasing impurities into the air. Traffic fumes in city traffic plague commuters daily. Ozone levels irritate the eyes and lungs. Sulfate hazards obscure the view.

Even if you are not in a position to see pollution, you are still made aware of it through the media. How about the Bhopal incident in 1984, Chernobyl nuclear plant disaster in 1986, *Exxon Valdez* oil spill in 1989, pesticide spill into the Sacramento River in 1991, oil spill in Russia's far north in 1994, Gulf of Mexico oil spill in 2010, or the Fukushima Daiichi nuclear accident in 2011? Most of us do remember some of these, even though most of us did not directly witness any of these travesties. Events, whether manmade (e.g., Bhopal) or natural (e.g., Mount St. Helens erupting) disasters, sometimes impact us directly, but if not directly they still get our attention. Worldwide, we see constant reminders of the less dramatic, more insidious, continued, and increasing pollution of our environment. We hear reports of dead fish in stream beds, litter in national parks, decaying buildings and bridges, leaking landfills, and dying lakes and forests. On the local scale, air quality alerts may have been issued in your community.

Some people experience pollution more directly, firsthand—what we might call the "in your face," "in your nose," "in your mouth," "in your skin" type of pollution. Consider train and truck accidents that release toxic pollutants that force us to evacuate our homes (see Case Study 1.2). We become ill after drinking contaminated water or breathing contaminated air or eating contaminated (*Salmonella*-laced) peanut butter products—sometimes purposely poisoned as an act of what I call lone she-wolf terrorism (see Case Study 1.3). We can no longer swim at favorite swimming holes because of sewage contamination. We restrict fish, shellfish, and meat consumption because of the presence of harmful chemicals, cancer-causing substances, and hormone residues. We are exposed to nuclear contaminants released to the air and water from uranium-processing plants.

Case Study 1.2. Toxic Sulfuric Acid

At 6:30 p.m. on Monday, October 5, 1998, 16 railroad cars derailed on the Buffalo and Pittsburgh Railroad, at the edge of the Allegheny National Forest near the Clarion River, not far from Erie, Pennsylvania. One of the derailed cars spilled its load of toxic sulfuric acid. Emergency workers contained the spill about 8 hours after the accident occurred, and the leaking tank car was sealed about 3 hours later. Once the tank was sealed, the acid, which hung in the air in a light mist, dissipated. No injuries were reported, although 100 people were evacuated from their homes in nearby Portland Mills overnight. Route 949 was closed while workers from a remediation company finished cleaning up the spill. Emergency workers were concerned about acid contamination of the Clarion River, but the spill's flow had been contained in a ditch between the tracks and the road. None of the sulfuric acid reached the river (Associated Press, 1998). In this particular hazardous materials emergency, proper planning and emergency procedures prevented both human health and environmental damage.

Case Study 1.3. Crazy Sally[*]

After making sure that the coast was clear, that no workers were looking, that the oncoming shift was still meeting with their shift supervisor, Sally turned the heat exchanger valve wheel slowly, carefully, like the dial on a safe full of money—someone else's money. Earlier she had attached a jerry-rigged hose to the heat exchanger drain and placed the other end in the peanut butter batch. Now she was adding the contaminated water to the batch as she continued to look above her, to her left, to her right, forward, and at the wall-sized mirror in front of her, making sure no one was watching … absolutely no one. Sally was careful but she had to hurry, as the oncoming shift would soon take over the production line and its batch of contaminated peanut butter.

As the dayshift production line supervisor of Creamy Gold Peanut Butter Company, she knew exactly what she was doing, even though it was wrong, unethical, absolutely criminal. She was adding water to the peanut butter batch, creating a slurry that was wetter than necessary. Adding too much water at this stage in the peanut butter manufacturing process would create the perfect environment for her buddy in crime, the bug *Salmonella* Tennessee. *Salmonella* bacteria can cause diarrhea, fever, and stomach pain; the infection usually lasts 5 to 7 days. This particular strain of bacteria also causes nasty urinary infections. "Oh, what better way to mess up a bunch of snotty women," she thought. Occasionally, but rarely, such infections can cause death but usually only of the elderly and those with faulty immune systems. "Just collateral damage," Sally told herself. "Survival of the fittest … just another way to eliminate a society of misfits, commies, decrepit old hangers-on, a bunch of old hags."

Sally, known as Crazy Sally to those who worked for and with her, was a 40-year-old plain-Jane type with no friends, no love life, nor even a pet dog, cat, pig, or jackass to kick around. Ice cubes are cold; Sally made them colder. She had worked at Creamy Gold for 22 years, having begun her employment the same day she graduated from high school. A no-nonsense, take-no-prisoners employee, Sally had climbed the promotion ladder in record time from line worker to foreperson to line manager and finally to shift supervisor. In her climb to the top, she never forgot that she deserved the best, the top position, so even though there were occasional setbacks she still plowed her way up, annihilating the glass ceiling on the way.

Sally's climb to the top position in the company had been spectacular (and bloody), to say the least. For years, the lower ranks of the company were filled with the wrecked careers of those she had backstabbed on her way to the top. Actually, most didn't even know what had hit them. When she finally reached the top, she ruled with a pudgy iron fist, not a velvet glove. Absolutely no doubt could possibly exist in any employee's mind about who was in charge. Sally was in charge—period. Sally's only pleasure, her only gratification in life, was dominating and controlling other people. At Creamy Gold, Sally was in her element.

Over the years, the women (Sally was partial to women because, in her opinion, they are so malleable and posed absolutely no threat to her) who worked for her quickly learned that it was either Sally's way or the dirty highway. You did not mess with Sally; instead, you brown-nosed her to attain that niche of individual safety and security that all employees seek and need.

If an outsider looked at Sally's all female crew, they would immediately notice that all of the workers looked pretty much the same: plain, short, and overweight. This was intentional on Sally's part, of course. Sally believed that the only way she could truly stand out among her workers was to look better than they did. Sally ensured that those she hired fit the image—unattractive, thus enhancing her own attractiveness.

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[*] Adapted from Spellman, F.R., *Food Supply Protection and Homeland Security*, 2nd ed., Bernan Press, Lanham, MD, 2017.

All of this points to the problem that Sally had with the nightshift. In particular, she had a problem with Thelma Thorn. Quite literally, Thelma had become a thorn in Sally's side. Thelma was a super attractive, blue-eyed blonde who made both men and women look at her not twice but much more. To add insult to injury, Thelma's entire nightshift crew consisted of similarly attractive young women. This situation made Sally's blood boil. The one thing that irritated Sally more than having to work for someone—to take orders from someone, anyone—was having to look at women that made her look like a plain Jane.

Over the years, Sally had learned how to get rid of the attractive ones (lookers, defined as pretty and able to wear very tight, faded blue jeans) on her shift, including a few of her plain Janes that had attractive husbands or lovers. She simply fired them. However, getting rid of attractive ladies from the other shift presented a problem—that is, until a couple years ago when Sally figured out how to get rid of the lookers from the shift she did not supervise.

When Sally decided she had to mitigate her problem with the nightshift, she figured out how to tap the contaminated water in the heat exchanger and add it to a fresh batch of peanut butter. This fresh batch was the night shift's responsibility to process, test, package, and ship. Sally knew that eventually people would get sick from the contaminated peanut butter and that the regulators would show up to investigate. Of course, this is exactly what happened. Hundreds became ill from the tainted peanut butter. When the affected batch numbers were identified, the nightshift crew was investigated and fired for gross incompetence on the job. Thus, the current nightshift crew with Thelma in charge came about because of the massive firings two years ago.

Based on her success in getting the last crew and supervisor fired, Sally decided to do the same thing again. As it turned out, Sally's plan worked to perfection. Several people ingested the tainted peanut butter, and several consumers because very ill. The bad batch was identified, and the regulators investigated. Again, the owners of Creamy Gold Peanut Butter fired the entire nightshift. Ironically, they asked Sally to help with the interviewing process to hire a new nightshift.

Sally's nefarious escapades probably would have continued on indefinitely, but there was a glitch: Mary Anne Strobe, who had been hired by Sally two years earlier. She was a prime candidate for employment because she met all of Sally's preferred criteria. Mary Anne was overweight, and Sally thought she was unattractive and dumb, as well. The problem began when Mary Anne decided to lose weight. Additionally, when Mary Anne began the slow process of sloughing off pound after pound, she looked in the mirror and decided a bit of plastic surgery was called for—just a nip and tuck here and there.

Eagle-eyed Sally noticed Mary Anne's weight loss early on, but paid little attention because she still thought Mary Anne was unattractive. It was when Mary Anne had cosmetic surgery that Sally did a double take and became concerned about Mary Anne's radical makeover. The plotting for Mary Anne's demise began immediately.

Two months after the night crew had been fired and replaced, Sally fired Mary Anne based on trumped up charges of insubordination and failure to use proper personal hygiene practices before assuming her position on the peanut butter process line. Turns out that the firing of Mary Anne was the beginning of the end of Sally. Mary Anne did not take her forced outing from Creamy Gold lightly. No, sir. She took her firing seriously, with a coldness that would frost a hot tamale. Mary Anne was not a proponent of the school of thought that revenge is best served cold. In fact, as a matter of record, one week from the day she was fired, Mary Anne walked into the Creamy Gold factory with a fully loaded, double-barrel, 12-gauge shotgun loaded with triple-ought buckshot. She quickly found Sally and immediately unloaded both barrels into her face, leaving less than a head on her shoulders. Mary Anne then pulled a handgun from her back pocket and shot herself dead. Beyond the obvious implications of homegrown terrorism, this tale highlights the very real and ongoing problem with violence in the workplace.

The Message

This incident points to one of the main purposes of this text—namely, to emphasize that pollution and contamination can manifest themselves in several different ways and forms; they can emanate from natural, accidental, or intentional human-caused events. It is important to recognize that the potential for pollution and contamination events is ubiquitous in all that we do and that terrorism is real and can be initiated domestically. Since September 11, the nation's attention has been focused on possible threats from Islamic terrorists and foreigners who simply do not like Americans and are willing to go to any length to totally destroy us and what we stand for—freedom. But the Crazy Sallys of the world, the homegrown terrorists, have been steadily plotting and carrying out attacks all across the United States.

Preventing Pollution

An awareness of the potential for the occurrence of hazardous materials incidents, such as the one described in Case Study 1.2, and deliberate acts of terrorism, as described in Case Study 1.3, offers many benefits. Proper hazardous materials emergency preplanning and responder training, as well as training in preventing acts of terrorism, combined with the development of well-thought-out emergency response procedures, can lessen the impact of, for example, chemical spills on the environment and malicious, malevolent, wicked employee acts. Gross environmental pollution or poisoning can be averted.

Most of our effort to prevent environmental pollution has focused on preplanning and dry-run practice exercises; the results of such efforts are clearly demonstrated in the event described in Case Study 1.2. It is important to point out, however, that we are more reactive than proactive in preventing or mitigating such events. We tend not to be very proactive in our pollution control planning techniques. Instead, reactive, after-the-fact responses to such incidents are quite common. As clearly demonstrated in Case 1.2, not all pollution events can be prevented or even prepared for. Consider, for example, the tragic events of 9/11. Because we cannot get into the minds of terrorists (and other cold-blooded murderers or anyone else, for that matter), we have difficulty imagining the deliberate crashing of perfectly good airplanes, full of fuel and passengers, into buildings and a farm field. We all recognize that this tragic event occurred; however, there might be some people out there wondering what those tragic incidents have to do with environmental pollution.

If you were not present in New York City or the Pentagon or in that Pennsylvania farm field and thus not up close and personal with any of these events, then you might not be aware of the catastrophic unleashing of various contaminants into the environment because of the crashes. Or, maybe you did not have access to television coverage clearly showing the massive cloud of dust, smoke, and other ground-level debris engulfing New York City. Maybe you have not had a chance to speak with any of the emergency response personnel who climbed through the contaminated wreckage looking for survivors, These responders were exposed to chemicals and various hazardous materials, many of which we still are not certain of their exact nature. Days later, when rescue turned to recovery, you may not have noticed personnel garbed in moon suits (Level A hazmat response suits) and using instruments to sample and monitor the area for harmful contaminants. If you had not witnessed or known about any of the reactions after the 9/11 event, then it might be reasonable to assume that you might not be aware that these were indeed pollution-emitting events.

In addition to terrorism, vandalism, and other deliberate acts, we pollute our environment with apparent abandon. The Crazy Sallys of the world love doing just that. Many of us who teach various environmental science and health subjects to undergraduate and graduate students often hear students complain that the human race must have a death wish. Students quickly adopt this view based on their research and intern work with various environment-based service entities. During their exposure to all facets of pollution—air, water, and soil contamination—they come to understand that everything we do on Earth contributes pollution of some sort or another to one or all three environmental mediums.

Science and technology notwithstanding, we damage the environment through use, misuse, and abuse of technology. Frequently, we take advantage of technological advances before we fully understand their long-term effects on the environment. We weigh the advantages that a technological advance can give us against the environment and discount the importance of the environment due to greed, *hubris*, lack of knowledge, or stupidity. We often only examine short-term plans without fully developing how problems may be handled years later. We assume that, when the situation becomes critical, technology will be there to fix it. The scientists will figure it out, we believe; thus, we ignore the immediate consequences of our technological abuse.

Consider this: Although technological advances have provided us with nuclear power, light bulbs and their energy source, plastics, internal combustion engines, air conditioning, and refrigeration (and scores of other advances that make our modern lives pleasant and comfortable), these advances have affected the Earth's environment in ways we did not expect, in ways we deplore, and in ways we may not be able to live with. In this text, the argument is made that the same science and technology that created or exacerbated pollution events can, in turn, be used to mitigate the misuse of science and technology.

POLLUTION AND ENVIRONMENTAL SCIENCE/HEALTH

In order to prevent or mitigate pollution events, highly trained interdisciplinary practitioners are needed to monitor air, water, and soil quality. Generally, professionals responsible for environmental pollution monitoring, prevention, or control are thoroughly trained in environmental science or environmental health. To precisely define *environmental science* as an interdisciplinary study of how the Earth works, to determine how we are affecting the Earth's life-support systems (i.e., environment), and to figure out how to deal with the environmental problems we face, we must first break down the term and look at each word separately. The *environment* includes all living and nonliving (such as air, soil, and water) things that influence organisms. *Science* is the observation, identification, description, experimental investigation, and theoretical explanation of natural phenomena. When we combine the two, we are left with a complex interdisciplinary study that must be defined both narrowly and broadly—and then combined—to allow us an accurate definition.

The narrow definition of environmental science is the study of the human impact on the physical and biological environment of an organism. In this sense, environmental scientists are interested in determining the effects of pesticides on croplands, learning how acid rain affects vegetation, evaluating the impact of introducing an exotic species of game fish into a pond or lake, and so on. Beginning in the early 1960s, environmental science evolved out of the studies of natural science, biology, ecology, conservation, and geography. Increasing awareness of the interdependence that exists among all the disparate elements that make up our environment led to the field of study that contains aspects of all of these elements. Although environmental scientists are generalists who may have concentrated their study on a particular specialty, solidly trained environmental scientists have one thing in common: They are well grounded in biological and physical ideas that have been combined with ideas from the social sciences—sociology, economics, and political science—to form the new, interdisciplinary field of environmental science (Figure 1.3).

Environmental health practitioners, like environmental scientists, are trained in the major aspects of environmental science; however, they are also concerned with all aspects of the natural and built environment that may affect human health. Unlike the relatively new environmental science profession, the environmental health profession has its modern-day roots in the sanitary and public health movement of the United Kingdom in the 1880s. Environmental health practitioners address human-health-related aspects of both the natural and the human-made environment. Environmental health concerns are shown in Figure 1.4.

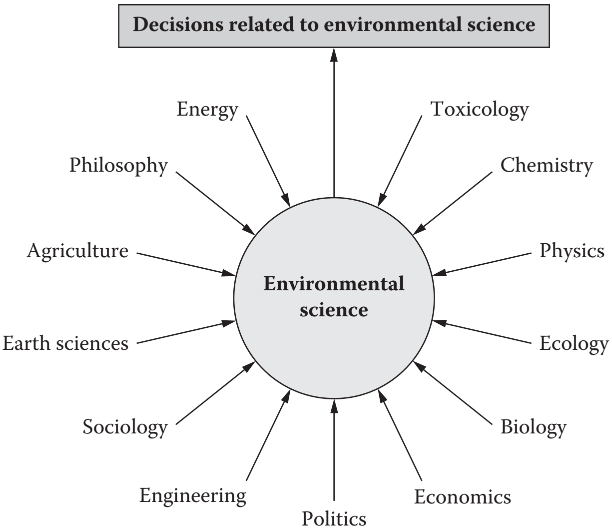

FIGURE 1.3 Major components of environmental science.

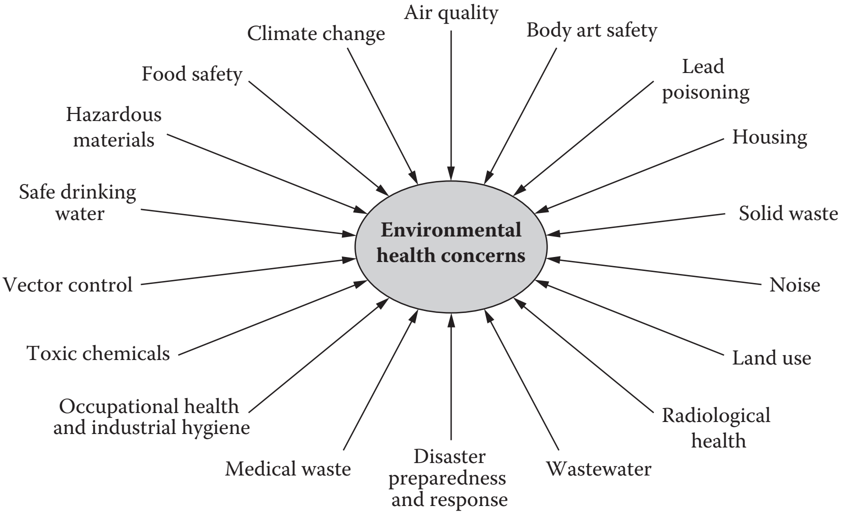

FIGURE 1.4 Environmental health concerns.

In the broadest sense, environmental science and environment health encompass the social and cultural aspects of the environment. As a mixture of several traditional sciences, political awareness, and societal values, environmental science and environmental health demand examination of more than the concrete physical aspects of the world around us, and many of those political, societal, and cultural aspects are far more slippery (with regard to the so-called "feel good" aspects) than what we can prove as scientific fact. In short, we can accurately say that environmental science and environmental health are pure sciences, because they include the study of all of the mechanisms of environmental processes: air, water, and soil. But, they are also applied sciences, because they examine problems with the goal of contributing to their solution; they involve the study of the effects of human endeavors and technology thereon. Obviously, to solve environmental problems and understand the issues, environmental scientists and environmental health practitioners need a broad base of information from which to draw. The environment in which we live has been irreversibly affected by advancements in technology—and has been affected for as long as humans have wielded tools to alter their circumstances. As a result of rapid industrialization, overpopulation, and other human activities such as deforestation for agriculture (and the practice of agriculture itself), Earth has become loaded with diverse pollutants that have been released as byproducts. We will continue to alter our environment to suit ourselves as long as we remain a viable species, but to do so wisely we need to closely examine what we do and how we do it.

A DIFFERENT APPROACH

Scientists who conduct studies to determine and understand how the *biosphere* creates and supports all life and environmental scientists who work to solve human-made environmental and public health problems strive to accomplish two very different undertakings using two different approaches. In light of their differences and to provide clarity, consider Case Study 1.4. Think about the pollution events described and see if you can identify the different approaches the variously trained professional scientists took to solve them. Also, try to identify the types of pollution therein (if any) that have not been mentioned to this point in the text. In your reading and study, it is important to remember that, like cancer, pollution can be insidious in its many manifestations and impacts. In studying pollution and its impact on our environment, good science is called for; cowboy or spaceship science is not needed, required, or wanted.

Case Study 1.4. Salmon and the Rachel River[*]

The Rachel River, a hypothetical river system in the northwestern United States, courses its way through an area that includes a Native American reservation. The river system outfalls to the Pacific Ocean, and the headwaters begin deep, remote, and high within the Cascade Range in Washington State. For untold centuries, this river system provided a natural spawning area for salmon. The salmon fry thrived in the river, eventually growing the characteristic dark blotches on their bodies and transforming from fry to parr. When the time came to make their way to the sea, the salmon, now called smolt with bodies larger and covered with silver pigment, inexorably migrated to the ocean, where they thrived until time to return to the river and spawn (about 4 years later). In spawning season, the salmon instinctively homed their way toward the odor generated by the Rachel River (their homing signal) and up the river to their home waters, as their life-cycle instincts demand.

Before non-Native Americans (settlers) arrived in this pristine wilderness region, nature, humans, and salmon lived in harmony and provided for each other. Nature gave the salmon the perfect habitat; the salmon provided Native Americans with sustenance. Native Americans gave both their natural world and the salmon the respect they deserved. After settlers came to the Rachel River Valley, changes began. The salmon still ran the river and humans still fed on the salmon, but circumstances quickly altered. The settlers wanted more land, and the Native Americans gave way; their way of life was destroyed, and they were forced to move away to reservations. The settlers did all they could to erase Native American beliefs and cultural inheritance. The salmon still ran the streams.

After the settlers drove out the Native Americans, the salmon continued to run, for a while. But, more settlers poured into the area. As the area became more crowded, the salmon still ran, but now their home, their habitat, the Rachel River, started to show the effects of modern civilization's influence. It became common practice to think that, "If I don't want it any more, it's

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[*] Adapted from Spellman, F.R. and Whiting, N., *Environmental Science and Technology: Concepts and Applications*, 2nd ed., Government Institutes, Rockville, MD, 2006.

trash and I'll throw it away." The river, unfortunately, provided a seemingly endless dump—out of the way, out of sight, out of mind. And they threw their trash away, all the mountains of trash they could manufacture, into the river. The salmon still ran.

More time passed. More people moved in, and the more people, the bigger their demands. In its natural course, sometimes the river flooded, creating problems for the settler populations. Everyone wanted power to maintain their modern lifestyles—and hydropower constantly poured down the Rachel River to the ocean. So, they built flood control systems and a dam to convert hydropower to hydroelectric power. (Funny, the Native Americans didn't have a problem with flood control. When the river rose, they broke camp and moved to higher ground. Hydroelectric power? If you don't build your life around things, you don't need electricity to make them work. With the sun, the moon, and the stars and healthy, vital land at hand, who would want hydroelectric power?)

The salmon still ran.

Building dams and flood control systems takes time, but humans, though impatient, have a way of conquering and using time (and anything else that gets in the way) to accomplish their tasks, goals, objectives—and construction projects. As the years passed, the construction moved on to completion, and finally ended. The salmon still ran—but in reduced numbers and size. Soon local inhabitants couldn't catch the quantity and quality of salmon they had in the past. When the inconvenience finally struck home, they began to ask, "Where are the salmon?"

But no one seemed to know. Obviously, the time had come to call in the scientists, the experts. The inhabitants' governing officials formed a committee and funded a study and hired some scientists to tell them what was wrong. "The scientists will know the answer. They'll know what to do," they said, and that was partly true. Notice they didn't try to ask the Native Americans, who also would have known what to do. The salmon had already told them—water is life's mother. There is no life without water.

The scientists came and studied the situation, conducted testing, tested their tests, and decided that the salmon population needed to increase. They determined that an increase in the salmon population could be achieved by building a fish hatchery, which would take the eggs from spawning salmon, raise the eggs to fingerling-sized fish, release them into specially built basins, and later release them to restock the river. A lot of science goes into the operation of a fish hatchery. It can't operate successfully on its own (although Mother Nature never has a serious problem with it when left alone) but must be run by trained scientists and technicians following a proven protocol based on biological studies of salmon life-cycles.

When the time was right, the salmon were released into the river; meanwhile, other scientists and engineers realized that some mechanism had to be installed in the dam to allow the salmon to swim downstream to the ocean and the reverse, as well. In the salmon world (because they are an anadromous species that spends its adult life at sea but returns to freshwater to spawn), what goes down must go up(stream). The salmon would eventually need some way of getting back up past the dam and into their home waters, their spawning grounds. So, the scientists and engineers devised, designed, built, and installed fish ladders in the dam, so the salmon could climb the ladders, scale the dam, and return to their native waters to spawn and die.

After a few seasons, the salmon again ran strong in the Rachel River. The scientists had temporarily—and at a high financial expenditure—solved the problem. Nothing in life or in nature is static or permanent. All things change. They shift from static to dynamic in natural cycles that defy human intervention, relatively quickly and without notice—like global climate change, a dormant volcano, or the Pacific Rim tectonic plates. In a few years, local Rachel River residents noticed an alarming trend. Studies over a 5-year period showed that no matter how many salmon were released into the river, fewer and fewer returned to spawn each season.

So, they called in the scientists again: "Don't worry. The scientists will know. They'll tell us what to do." The scientists came in, analyzed the problem, and came up with five conclusions:

1. The Rachel River was extremely polluted both from point and nonpoint sources.
2. The Rachel River dam had radically reduced the number of returning salmon to the spawning grounds.
3. Foreign fishing fleets off the Pacific Coast were depleting the salmon.
4. Native Americans were removing salmon downstream before they even got close to the fish ladder at Rachel River Dam.
5. A large percentage of water was being withdrawn each year from the river to cool machinery in local factories. Large rivers with rapid flow rates usually can dissipate heat rapidly and suffer little ecological damage unless their flow rates are sharply reduced by seasonal fluctuations. This was not the case, of course, with the Rachel River. The large release of heated water from factories in the Rachel River area back into the slow-moving Rachel River was creating an adverse effect called *thermal pollution*. Thermal pollution and salmon do not mix. In the first place, increased water temperatures lowers the dissolved oxygen (DO) content by decreasing the solubility of oxygen in the river water, and warmer river water also causes aquatic organisms to increase their respiration rates and consume oxygen faster, thus increasing their susceptibility to disease, parasites, and toxic chemicals. Although salmon can survive in heated water—to a point—many other fish (the salmon's food supply) cannot. Heated discharge water from the factories also disrupts the spawning process and kills the young fry.

The scientists prepared their written findings and presented them to city officials, who read them and were at first pleased. "Ah!" they said. "Now we know why we have fewer salmon!" But their pleasure soon faded. They could not refute the causal factors identified by the scientists—but what was the solution? The scientists looked at each other and shrugged. "That's not our job," they said. "Call in the environmental folks."

The salmon still ran, but not up the Rachel River to its headwaters.

Within days, the city officials hired an environmental engineering firm to study the salmon depletion problem. The environmentalists came up with the same causal conclusions as the scientists (which they also related to the city officials), but they also related the political, economic, and philosophical implications of the situation to the city powers. The environmentalists explained that most of the pollution constantly pouring into the Rachel River would soon be eliminated when the city's new wastewater treatment plant came on line; thus, the area's *point-source pollution* would be eliminated. They explained that the state agricultural department and their environmental staff were working with farmers along the lower river course to modify their farming practices and pesticide treatment regimes to help control the most destructive types of *nonpoint-source pollution*. The environmentalists said that the existing fish ladder at the Rachel River dam was incorrectly configured but could be modified with some minor retrofitting.

The environmentalists went on to explain that the overfishing by the foreign fishing fleets off the Pacific Coast was a problem that the federal government was working to resolve with the governments involved. The environmentalists explained that the state of Washington and the federal government were addressing the problem of Native Americans fishing the downriver locations before the salmon ever reached the dam. Both governmental entities were negotiating with the local tribes, and the local tribes had pending litigation against the state and the federal government with regard to who actually owned fishing rights to the Rachel River and the salmon.

The final problem was thermal pollution from the factories, which was making the Rachel River unfavorable for spawning, decreasing the salmon food supply, and killing off the young salmon fry. The environmentalists explained that to correct this problem the outfalls from the factories would have to be changed and relocated. The environmentalists also recommended construction of a channel basin whereby the salmon fry could be released in a favorable environment at ambient stream temperatures and would have a controlled one-way route to safe downstream locations where they could thrive until time to migrate to the sea.

After many debates and many newspaper editorials, the city officials put the matter to a vote and voted to fund the projects needed to solve the salmon problem in the Rachel River. Some short-term projects are already showing positive signs of change, long-term projects are underway, and the Rachel River is on its way to recovery.

In short, scientists are professionals who study to find “the” answer to a problem through scientific analysis and study. Their interest is in pure science. The environmental engineers and scientists can arrive at the same causal conclusions as the pure scientists, but they are also able to factor in socioeconomic, political, and cultural influences, as well.

But, wait! It’s not over yet. Concerns about disruption of the wild salmon gene pool by hatchery trout are being raised by environmentalists, conservationists, and wildlife biologists. Hatchery or farm-raised stock of any kind is susceptible to problems caused by, among other things, a lack of free genetic mixing and the spread of disease, infection, and parasites, as well as reinforcement of negative characteristics. When escaped hatchery salmon breed with wild salmon, the genetic strain is changed, diseases can be transmitted, and many problems arise, thus emphasizing that fixing an environmental problem is not always the final word on the problem.

ENVIRONMENTAL POLLUTION AND TECHNOLOGY: THE CONNECTION

As long as capitalism drives most modern economies, people will desire material things—leading to a high level of consumption. For better or for worse, the human desire to lead the good life (which Americans may interpret as a life enriched by material possessions) is a fact of life. Arguing against someone who wants to purchase a new, modern home with all the amenities or the latest, greatest automobile is difficult. Arguing against people wanting to make a better life for their children by making sure they have all they need and want to succeed in their chosen pursuit is even more difficult. How do you argue against such goals with someone who earns his or her own way and spends his or her hard-earned money at will? Look at the trade-offs, though, that often affect the environment. That new house purchased with hard-earned money may sit in a field of radon-rich soil or on formerly undeveloped land. That new SUV may get only 8 miles to the gallon. The boat they use on weekends gets even worse mileage and discharges wastes into the local lake, river, or stream. The weekend retreat on 5 wooded acres is part of the watershed of the local community, and the breeding and migration habitat for several species is disturbed.

The environmental trade-offs never enter into the average person’s mind. Most people don’t commonly think about it. In fact, most of us don’t think much about the environment until we damage it, until it becomes unsightly, until it is so fouled that it offends us. People can put up with a lot of environmental abuse, especially with our surroundings—until the surroundings no longer please us. We treat our resources the same way. How often do we think about the air we breathe, the water we drink, the soil our agribusiness conglomerates plant our vegetables in? Not often enough.

The typical attitude toward natural resources is often deliberate ignorance. Only when someone must wait in line for hours to fill the car gas tank does gasoline become a concern. Only when he can see—and smell—the air he breathes and coughs when he inhales does air become a visible resource. Water, the universal solvent, causes no concern (and very little thought) until shortages occur, or until it is so foul that nothing can live in it or drink it. Only when we lack water or the quality is poor do we think of water as a resource to worry about. Is soil a resource or is it “dirt”? Unless you farm or plant a garden, soil is only dirt. Whether you pay any heed to the soil/dirt debate depends on what you use soil for—and on how hungry you are.

Resource utilization and environmental degradation are tied together. While people depend on resources and must use them, this use impacts the environment. A *resource* is usually defined as anything obtained from the physical environment that is of use to humans—the raw materials that support life on Earth. Some resources, such as edible growing plants, water (in many places), and

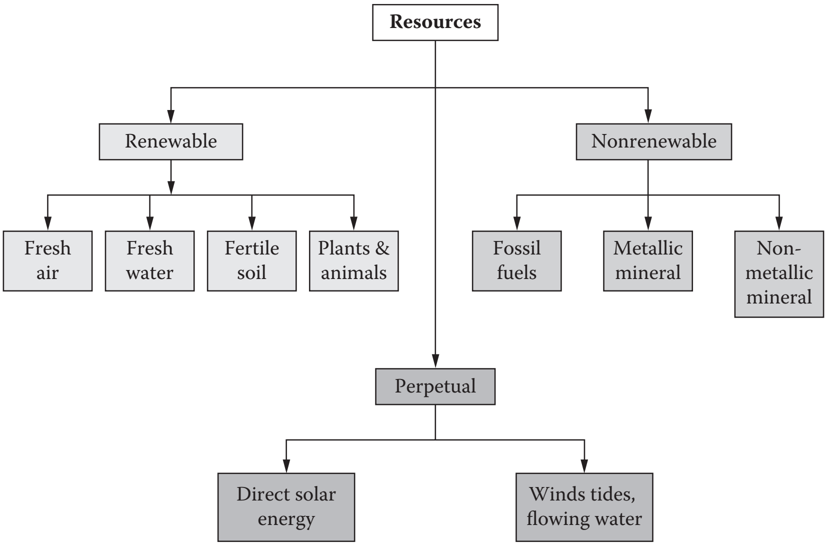

FIGURE 1.5 Major types of resources.

fresh air, are directly available to humans. But, most resources, such as coal, iron, oil, groundwater, game animals, and fish, are not. They become resources only when we use science and technology to find them, extract them, process them, and convert them, at a reasonable cost, into usable and acceptable forms. Natural gas, found deep below the Earth's surface, was not a resource until the technology for drilling a well and installing pipes to bring it to the surface became available. For centuries, humans stumbled across stinky, messy pools of petroleum and had no idea of its potential uses or benefits. When its potential was realized, we exploited petroleum by learning how to extract it and refine it into heating oil, gasoline, sulfur extract, road tar, and other products.

Earth's natural resources and processes that sustain other species and us are known as *Earth's natural capital*, which includes air, water, soil, forests, grasslands, wildlife, minerals, and natural cycles. Societies are the primary engines of resource use, converting materials and energy into wealth, delivering goods and services, and creating waste or pollution. This provision of necessities and luxuries is often conducted in ways that systematically degrade the Earth's natural capital—the ecosystems that support all life.

Excluding *perpetual resources* (solar energy, tides, wind, and flowing water), two different types of resources are available to us: renewable and nonrenewable (see Figure 1.5). *Renewable resources* (e.g., fresh air; fresh water; fertile soil, plants, and animals via genetic diversity) can be depleted in the short run if used or contaminated too rapidly but normally will be replaced through natural processes in the long run. Water is a good example. Water is a renewable resource. The amount of water on Earth is constant, although its distribution is not. Water that is not available for safe use (contaminated) is of no value to humankind. Moreover, even though impurities are left behind when water evaporates, the water cycle does not ensure that clean water is always available. Thus, water must be managed; we must sample, monitor, and test it to ensure its safety for consumption.

Because renewable resources are relatively plentiful, we often ignore, overlook, destroy, contaminate, and, in particular, mismanage them. Classifying anything as renewable is a double-edged sword. Renewable resources are renewable only to a point. Timber or grass used for grazing must be managed for *maximum sustainable yield* (the highest rate at which a renewable resource can be used without impairing or damaging its ability to be fully renewed). If timber or grass yields exceed this rate, the system gives ever-diminishing returns. Recovery is complicated by the time factor, which is life-cycle dependent. Grass can renew itself in a season or two. Timber takes decades. Any length of time is problematic when people get impatient.

Remember, one of the contributing factors of the plight of the Rachel River salmon was overfishing. When a fishery is pushed past its limit, if the catch is maintained by collecting greater and greater numbers of younger salmon, no increase is possible. If the same practices are used on a wild species, extinction can result. We have no more passenger pigeons, heath hens, Carolina parakeets, dodos, solitaires, or great auks—and many other species are at risk right now, including the Attwater prairie chicken (see Case Study 1.5).

Case Study 1.5. Attwater's Prairie Chicken[*]

Is Attwater's prairie chicken, the only coastally adapted prairie chicken left, following the passenger pigeon, heath hen, and others into extinction? A *National Geographic* article (Chadwick, 2002) detailed the problems with Attwater's chicken. With a population of over a million birds at the turn of the 20th century, by 1937 their numbers were under 9000, and only about 100 remain in the wild today. The birds live in two separate 12,400-acre grassland patches in Texas, the remnants of 6 million acres of coastal prairie and just 1% of its original range. During the late 1980s, 3 years of drought followed by three stormy breeding seasons hammered Attwater's chickens, killing 500 birds in one county. With so few birds left on tiny islands of habitat, the greatest threat now is from predators such as hawks and owls, according to biologist Mike Morrow.

Texas A&M University, four zoos, Sea World, and Fossil Rim, a private wildlife facility, have been raising Attwater's chickens in captivity and have delivered almost 100 young birds for release in the wild annually. But, just under 2% of these birds survive, largely because of the poor-quality habitat. The small islands of natural prairie left do not offer the birds—and predators—enough space. The breeding program is all that is keeping Attwater's chicken afloat.

Another problem is the lack of public knowledge about the bird which makes funding for field research and captive breeding difficult to come by. Plans to reconnect fragments of coastal grassland, which might offer the birds larger and better habitat, have gathered little momentum. The U.S. Fish and Wildlife Service and the Nature Conservancy hope to purchase more habitat for the birds, but this takes money and time—something Attwater's doesn't necessarily have much of (Taylor, 2002, pp. 209–210).

ENVIRONMENTAL DEGRADATION

Exceeding maximum sustainable yield is only the tip of the iceberg—other environmental, social, and economic problems may develop. Let's look at *overgrazing* (depleting) grass on livestock lands. The initial problem occurs when the grass and other grazing cover are depleted, but secondary problems kick in fast. Without grass, the soil erodes quickly. In very little time, so much soil is gone that the land is no longer capable of growing grass—or anything else. Productive land converted to nonproductive deserts (*desertification*) is a process of *environmental degradation* that impacts social and economic factors. Those who depend on the grasslands must move on, but moving on costs time, energy, and money—and puts more land at risk. Should the same level of poor stewardship of land resources continue on more acreage?

Environmental degradation is not limited to salmon and grass. Let's look at a few other examples. Along with overfishing and overgrazing, land can also be overcultivated. Intense overcultivation reduces soil nutrients and increases erosion to the point where agricultural productivity is reduced, leading to overfertilization, which eventually damages water supplies. If irrigation of agricultural lands proceeds without proper drainage, the excessive accumulation of water or salts in the soil

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[*] Adapted from Spellman, F.R. and Whiting, N., *Environmental Science and Technology: Concepts and Applications*, 2nd ed., Government Institutes, Rockville, MD, 2006.

decreases productivity. Environmental degradation takes place when trees are removed from large areas without adequate replanting. The results are destruction of wildlife habitat, increased soil erosion, and flooding. Habitat fragmentation is another problem related to habitat destruction. When habitat is fragmented, species that require distance from human activity are affected.

Take, for example, both greater and lesser prairie chickens in Kansas. Radiotelemetry research demonstrates that prairie chickens are extremely sensitive to human activity. The birds seldom use sand sage within a quarter mile of an inhabited house; a house built on a 1-acre site actually eliminates 160 acres of habitat for the birds. Human habitation isn't the only factor, however. Natural gas compression facilities—and southwest Kansas has a bunch—are noisy, clanging affairs, usually a couple of acres in size. The birds won't use habitat within half a mile of these areas, so that's another 640 acres down the tubes. Lesser chickens seldom venture within a mile of a coal-fired power plant, even though the sand sage habitat surrounding it may be the best on the range. A 30-acre power plant chews up 2500 additional acres of chicken habitat. In addition, lesser chickens rarely nest or raise broods in habitat blocks less than 2000 to 4000 acres in size, nor do the birds frequent habitats along well-traveled roads. Do the math, and pretty soon you see the magnitude of the problem associated with preserving or supplying large, open blocks of the right habitat for chickens (Taylor, 2002).

Poor land use and water management practices are not new. Consider the Florida Everglades, for example. Land-use and water management practices dating as far back as the late 19th century have changed the distribution and composition of plant and animal communities throughout the system. The predrainage (before 1900) Everglades were influenced primarily by seasonal rainfall and underlying topography (USGS, 2013). Overflow of water from Lake Okeechobee during the wet season produced seasonal sheet flow across the Everglades, which drained into Florida Bay and Biscayne Bay. Wetland hydroperiods and water depths and estuarine salinity were primarily a function of precipitation. Human alteration of the natural hydrologic patterns of the Everglades began in the early 20th century with construction of canals and the Hoover Dike around Lake Okeechobee (Light and Dineen, 1994). A second wave of canal and levee construction it the 1950s and 1960s significantly changed the quantity and seasonality of freshwater flow through the wetlands and fragmented the ecosystem. By the early 21st century, the spatial extent of the Everglades wetland had been reduced by approximately one half (Lodge, 2005).

These land-use changes also affected water delivery from the Everglades to adjacent marine ecosystems in Florida Bay and Biscayne Bay. Hypersalinity and resulting seagrass dieoffs in Florida Bay were of particular concern and were attributed to decreased runoff of freshwater from canal building and water management (Robblee et al., 1991). In addition, increased nutrient loading from agricultural land use may have changed estuarine ecosystems from a clear water system with abundant benthic primary production to one with high turbidity and common algal blooms (Rudnick et al., 2005).

The degradation of wetlands and associated wildlife resulted in passage of the Everglades Forever Act in 1994, which aimed to restore healthy ecosystem function to the Everglades. More recently, the recognition that the health of the greater Everglades ecosystem and the quality and availability of water affected the economy and culture of south Florida prompted the Comprehensive Everglades Restoration Plan (CERP) to restore natural hydroperiods, seasonality, and connectivity of the ecosystem through modification of existing water-control structures. Another example of environmental land degradation often occurs when a metropolitan area expands. In high-growth areas, productive land is covered with concrete, asphalt, buildings, water, or silt to such an extent that agricultural productivity declines and wildlife habitat is lost. Consider Case Study 1.6, for example.

Case Study 1.6. The Amish and Lancaster County, Pennsylvania

Lancaster County in Pennsylvania is fortunate to possess some of the best nonirrigated farmland in the country. Lancaster also receives a higher than average dewfall, and in years when counties around it are in drought Lancaster can still bring in a reasonable crop. For many years, farming was the main industry in the region, primarily accomplished by Amish farmers working with minimum technology, teams of mules, and their neighbors and families. Lancaster County still has a high Amish farmer population, which is steadily expanding. Those who farm typically raise high-profit, labor-intensive crops and garden produce for their own use, but farming is no longer the primary local industry. Today, more than 50% of the Amish work in something other than farming but not necessarily by choice. Over the last 20 years, property values around Lancaster County have risen steeply. Per-acre costs of good farmland mean that a small farm that goes on the market could sell for astronomical prices. Lancaster has become a popular tourist area, and developers watching the tourist trade grow want to increase the number of attractions the tourists can visit. Most tourists come to Lancaster County to do two things: See the Amish or shop the outlets.

This problem is compounded by local growth. Industrial growth and a heavy influx of population over the last 20 years have caused the county to expand quickly, especially in and around Lancaster City itself. With Philadelphia, Baltimore, and the Washington, DC, area within reach, Lancaster is expanding in population rapidly, and residential and commercial building is keeping pace. Many of these new residents don't want to live in the city in row houses, although hundreds of homes in the city are for sale. They want new houses with big yards and suburban schools. They don't want to shop downtown, where businesses are struggling and storefronts are empty. They want to shop at the outlet malls, at Park City, or at the strip malls in their own neighborhoods.

"What's the problem with that?" you ask. Take your pick:

- The Amish can't afford to buy land for their sons to start farming on. They now often band together and purchase what land they can cooperatively, but even though their farming methods allow them to farm incredibly profitably they cannot compete with the developers for the per-acre prices.
- Every year more acres of prime farm land are bulldozed for health campuses, outlet stores, entertainment complexes, and subdevelopments, while the tax base of Lancaster City moves to the suburbs, the city dies a slow death, and local farmlands and wildlife habitats dwindle.
- Lancaster's urban sprawl encompasses what only a few years ago were separate towns, 5 or 6 miles away. Now developments full of houses, strip malls, and car dealerships fill in those spaces, and the farmland they cover is destroyed.
- All this growth is springing up on what used to be corn and tobacco fields—farmland. After you put a strip mall on farmland, the land isn't much good for growing anything. Asphalt parking lots are hard to plow.
- The farmers who remain must use every available inch of cropland. They plow and plant to the edges of the roads and remove remaining copses and fencerows, destroying valuable agricultural edge habitat that formerly supported songbirds, pheasants, quail, and small mammals.
- People who move out into the developments built on former farms realize quickly that they don't like the smells associated with the farms still in their neighborhoods. They sometimes go so far as to take their complaints to court.
- Low-lying areas suffer from flooding. When uphill land that used to be open to the rain is covered with asphalt, runoff quickly overwhelms the creeks below, creating new floodplain in areas that were not at risk before.
- Construction fouls local creeks, releasing quantities of silt and dirt into the streams, altering habitat, and reducing habitat quality.
- The system of roads designed for the lower expected rates of growth predicted when the roads were built 40 or so years ago is clogged and congested with traffic. Driving on Route 30 from Gap to Lancaster (15 miles) can take 2 hours in tourist season, in bumper-to-bumper traffic.

- Exhaust fumes build up until the air is gray; people keep their car windows closed and air conditioners running so they don't have to breathe it while they sit in traffic with their engines running. Air pollution alert days are common, especially in the hot summer months.

People everywhere are blind to their own conditions in some respects. Lancaster County is clearly vastly changed from what it was 30 years ago, or even 10 years ago. Lancastrians allowed free growth and free expansion for years. Now, Lancaster does recognize these problems and is working to combat them. They have conservancy programs designed to keep farmland in farming, but funds are limited—and developers get the bank loans. The local residents recognize that a valuable natural resource is slipping away, but the problem is complicated by local economics, politics, sociology, religion, government, and business, as well as money interests outside the community. Any successful action taken to preserve farmland or wild areas in one place is immediately countered by a loss somewhere else. Is there a solution? Yes. These problems could be solved, but to solve them people who don't want to agree with one another will have to work together—people in local politics, business, and religion (Spellman and Whiting, 2006).

The Good Life

Nonrenewable resources (copper, coal, tin, and oil, among many others; see Figure 1.5) have built up or evolved in a geological time-span. They cannot be replaced at will, only over a similar time scale. In this age of advanced technology, we often hear that, for example, when high-grade tin ore runs out (when 80% of its total estimated supply has been removed and used), low-grade tin ore (the other 20%) will become economically workable. This erroneous view neglects energy resource depletion and increasing pollution with lower grade burdens. In short, to find, to extract, and to process the remaining 20% generally costs more than the result is worth. Even with unlimited supplies of energy (impossible according to the *laws of thermodynamics*, discussed later), what if we could extract that last 20%? When it is gone, nothing is going to bring it back except time, measured in centuries and millennia, paired with the elements that produce the resource.

Advances in technology have allowed us to make great strides in creating the "good life." These same technological advances have also amplified environmental degradation. But, not all of the news is bad. Technological advances have also let us (via recycling and reuse) to conserve finite resources—aluminum, copper, iron, plastics, and glass, for example. *Recycling* involves collecting household waste items (e.g., aluminum beverage cans) and reprocessing usable portions. *Reuse* involves using a resource over and over in the same form (e.g., refillable beverage bottles, water).

We discussed the so-called "good life" earlier—modern homes, luxury cars and boats, a second home in the woods. With the continuing depletion of natural resources, prices must be forced upward until attaining the good life, or even gaining a foothold toward it, becomes difficult or impossible—and maintaining it becomes precarious. Ruthless exploitation of natural resources and the environment—overfishing a diminishing species (look at countless marine species populations, for example), intense exploitation of energy and mineral resources, cultivation of marginal land without proper conservation practices, degradation of habitat by unbalanced populations or introduced species, and the problems posed by further technological advances—will result in environmental degradation that will turn the good life into something we don't want to even think about. Our prevailing attitude of fly now and pay later is, along with cowboy science, not pertinent here.

So—what's the answer? Are we looking for the bluebird? What are we to do? What should we do? Can we do anything? Should we even care or think about it? Well, as is pointed out in Case Study 1.7, to preserve our natural resources and prevent environmental pollution, there are those, such as Garrett Hardin, for example, who would have us privatize the "commons," so to speak.

Case Study 1.7. Tragedy of the Commons Revisited

Garrett Hardin's influential article, "The Tragedy of the Commons," published in *Science* in 1968, describes a dilemma in which multiple individuals acting independently in their own self-interests (sounds so American, does it not?) can ultimately, through overexploitation, destroy a shared limited resource even when it is clear that it is not in anyone's long-term interest for this to happen. With regard to environmental pollution, Hardin pointed out that the term *tragedy of the commons*, in a reverse way, is not taking something from the commons but rather putting something into it (e.g., sewage or chemical, radioactive, and heat wastes in water; noxious and dangerous contaminants into the atmosphere; various forms of visual pollution in line of sight). We can't readily fence the air, water, and soil we depend on; thus, the tragedy of the commons must be prevented by coercive laws or taxing devices that make it less expensive for the polluter to treat his pollutants than discharge them untreated. Hardin considered the pollution problem to be a consequence of population.

To avoid the pollution problems Hardin alludes to, we must seek means or ways to "prevent fouling our own nest" (Hardin, 1968). In light of this view, some would have us all return to nature. Those people suggest returning to Thoreau's Walden Pond on a large scale, to give up the good life to which we have become accustomed. They think that giving up the cars, boats, fancy homes, the bulldozers that make construction and farming easier, the pesticides that protect our crops, the medicines that improve our health and save our lives—the myriad material improvements that make our lives comfortable and productive—will solve the problem. Is this approach the answer or even realistic? To a small (vocal and impractical) minority, it is, although for those who realize how urban Walden Pond was, the idea is amusing.

For the rest of us? Get real! This is a pipe dream founded in romance, not logic. It cannot, should not, and will not happen. We can't abandon ship—we must prevent the need to abandon our society from ever happening. Properly managed, technological development is a boon to civilization and will continue to be. Technological development is not the problem—improper use of technology is. Using technology in ways that degrade our environment by introducing undesirable change in our ecosystems is absolutely untenable. We must prevent this from occurring. But, at the same time, we must continue to make advances in technology, we must find further uses for technology, and we must learn to use technology for the benefit of mankind and the environment. Technology and the environment must work hand in hand, not stand opposed. We must also foster respect for, and care for, what we have left.

Just how bad are the problems of technology's influence on environment?

Major advances in technology have resulted in enormous transformation and pollution of the environment. While transformation is generally glaringly obvious (e.g., damming a river system), as mentioned, polluting or pollution is not always as clear. Remember that to *pollute* means to impair the purity of some substance or environment. *Air pollution* and *water pollution* refer to alteration of the normal compositions of air and water (their environmental quality) by the addition of foreign matter (e.g., gasoline, sewage).

Technological practices that have contributed to environmental transformation and pollution include the following:

- Extraction, production, and processing of raw natural resources, such as minerals, with accompanying environmental disruption
- Manufacturing enormous quantities of industrial products that consume huge amounts of natural resources and produce large quantities of hazardous waste and water/air pollutants
- Agricultural practices resulting in intensive cultivation of land, irrigation of arid lands, drainage of wetlands, and application of chemicals

- Energy production and use accompanied by disruption and contamination of soil by strip mining, emission of air pollutants, and pollution of water by release of contaminants from petroleum production and the effects of acid rain
- Transportation practices (particularly reliance on the airplane) that cause scarring of land surfaces from airport construction, emission of air pollutants, and greatly increased demands for fuel (energy) resources
- Transportation practices (particularly reliance on automobiles) that cause loss of land by road and storage construction, emission of air pollutants, and increased demand for fuel (energy) resources

Throughout this text, we discuss the important aspects of the impact of technology on the environment.

SCIENCE AND TECHNOLOGY OFFER SOLUTIONS

When technology is based on a sound foundation of environmental science and common sense, it can be used in solving environmental problems. In short, the goal is to produce manufacturing processes with minimum environmental impact. This procedure has already been aptly demonstrated in the redesign of standard manufacturing processes. In these new environmentally friendly designs, the production practices focus on minimizing raw material usage, energy consumption, waste production, and environmental pollution. In this redesign process, one technique is to construct a manufacturing process to use raw materials and energy sources in ways that minimize environmental impact. When processing chemicals, the process can modify reactions in such a way that the process is much more environmentally friendly. Another key change is in raw material and water usage. An environmentally friendly manufacturing process is designed so raw materials and water are recycled. State-of-the-art technologies should be employed to minimize air, water, and solid waste emissions. A few of the ways in which technology can be applied to minimize environmental impact include the following:

- Use of waste heat recovery systems to achieve maximum energy use, increase efficiency, and maximum utilization of fuel
- Use of precision machining and processing systems (e.g., lasers) to minimize waste production
- Process optimization operations to increase efficiency
- Use of materials that minimize pollution
- Use of computerized control systems to achieve maximum energy efficiency, maximum utilization of raw materials, and minimum production of pollutants
- Application of processes that enable maximum materials recycling and minimum waste production
- Application of advanced technologies to treat waste products efficiently

Advancements in technology are evolutionary. Every advance builds on its predecessor to produce a technology that improves on its predecessors; however, for environmental improvements to occur, the technologies must be used.

THE BOTTOM LINE

When you throw a stone into a pool of quiet water, the ensuing ripples move out in concentric circles from the point of impact. Eventually, those ripples, much dissipated, reach the edge of the pond, where they break, disturbing the shore environment. When we alter our environment, similar repercussions affect the world around us, and some of these actions can or will be felt across the world. We use technology to alter our environment to suit our needs. That same technology can be put to use so our environment is protected from unrecoverable losses. Environmental scientists must maintain an acute sense of awareness concerning the global repercussions of problems we create for the environment—to extend the boundaries of the problem beyond our own backyard.

Historically, as long as human population numbers remained small, human pollutants could be adequately processed by the environment. But, as population numbers increased, human waste began to overwhelm natural systems. As societies become technologically sophisticated, humans begin producing large numbers and volumes of new substances each year. The environment's ability to absorb and process these substances (to clean itself) has natural limitations. Our environment can only handle so much. Complicating the situation even further, consumption of resources per person in the developed world increases daily—sometimes dramatically. A prevailing tendency toward consumerism in a throw-away society leads to resource abuse, resulting in ever-increasing amounts of pollution released to the environment. Consequently, pollution has become an increasing source of environmental problems.

Human progress has led inexorably to the soiling of air, water, and soil. Is this trend likely to continue? Maybe, maybe not. We do not know the answer to this vital question. Does anyone? We hope so, but some things we do know for sure. We know that the total deindustrialization of the developed world is improbable and, barring some major catastrophic event, unlikely and out of the question. A more practical view of pollution is required, one that allows sustainable development of healthy and vigorous industrial activity to provide the goods and services required by modern civilization.

We also know that we must do all this with a sense of balance. What kind of balance? Another good question. The balance we are referring to is actually the trade-off we are willing to accept for those things that we do. More specifically, suppose we want to build a new factory to produce widgets, but the production of these widgets will contribute an unreasonable level of pollutants to our air, water, and soil. We have to ask ourselves the question is it worth it? Is the trade-off between creating jobs and enhancing the material livelihood of several individuals worth the potential damage to the environment?

We need to find a middle ground. We must balance our desires against possible or potential results. Thus, what we really have is a balancing act, a delicate balance that we must work hard to maintain.

So, what is the bottom line on pollution and its effects on us? That is what this text is all about—explaining and illustrating the bottom line. Throughout this book, we consistently refer back to two overriding and connected themes. First, when it comes to pollution and its potential harmful effects on our lives, one thing is certain: We do not know the extent of the problem; we do not know what we do not know (scary, when you think about it). Second, the tragedy that underlies the politics involved in the "pollution thing" (remember, in the real world everything evolves around politics) can be summed up by the words of philosopher Gerog Hegel: "The nature of tragedy is not the conflict between right and wrong but between right and right."

For now, read this text with a mind open to the facts. Make your own choices, your own decisions, your own judgments, because the real bottom line is that when it comes to defining pollution you are required to make a judgment.

DISCUSSION QUESTIONS

1. What pollution problems might be causing the environmental damage along the Appalachian Trail?
2. Write your own definitions of *pollution*, *contaminant*, *pollutant*, and *environment*. Include in these definitions a list of the elements you consider to be of particular concern.
3. Discuss the perception of pollution as individual judgment.
4. Discuss the idea of balance and trade-off for environmental pollution control.
5. Discuss how environmental pollution remediation can be affected by politics.

6. Discuss how environmental pollutants and remediation are affected by scientific and technical levels of certainty and uncertainty.
7. Look at environmental pollution from a historical perspective. What has changed in how we view environmental pollution, and what has changed in our levels of concern and action?
8. Define *science* and *environmental science*. How do they differ? Name and discuss the pertinent aspects of two local, two regional or national, and two global environmental problems. Explain your answer.
9. Why is finding a solution to an environmental conflict so complex? Explain your answer.
10. Describe the relationship between land use in Lancaster County and environmental problems in the county.
11. Discuss extinction as it relates to habitat, maximum sustainable yield, and natural capital.
12. What's the future of Attwater's prairie chicken? Why?
13. What lies ahead for the Amish in Lancaster County? Why?
14. When solving local, regional, or national environmental problems, which of these problems can be solved by scientists alone? Please explain. If scientists alone cannot solve them, what kind of knowledge (from the social and behavioral sciences, arts and humanities, or other source) is needed to develop culturally acceptable solutions?
15. Do you believe the society you live in is on an unsustainable path? Explain.
16. Explain why you agree or disagree with the following proposition: The world will run out of renewable resources because we *cannot* use technology to find substitutes.
17. The importance of pollution prevention cannot be argued, and a relevant pollution axiom could be stated as *preventing pollution from occurring in the first place is much preferred to the alternative*. Is this possible? Explain.

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2 Pollution Science Fundamentals

> Thither were brought the dead dogs and cats, the kitchen garbage and the like, and duly dumped. The festering, rotten mess was picked over by rag pickers and wallowed over by pigs, pigs and humans contesting for a living from it, and as the heaps increased, the odors increased also, and the mass lay corrupting under a tropical sun, dispersing the pestilential fumes where the winds carried them.
>
> **—Minister describing the New Orleans dump to the American Public Health Association (1879)**

> When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely … advanced to the state of science.
>
> **—Lord Kelvin (1891)**

INTRODUCTION

In this chapter, fundamental concepts foundational to more complex material presented in subsequent chapters of the text are discussed. Note that the fundamental concepts presented herein are just that: the basics. Complex mathematics and science concepts are beyond the scope of this text and are therefore avoided where possible to make for easier understanding and a smoother read. The intention of this text is to give the student as well as the average person a clear presentation of what the science of pollution is all about and what we can do to mitigate the detrimental results of environmental contamination. The first area discussed covers the basics involved with the circulation of matter through the ecosystem—the *biogeochemical cycles*. Because biogeochemical cycles (and most other processes on Earth) are driven by energy from the sun, we next present energy and energy transfer. The final section deals with units and measurement commonly used in the science of environmental pollution.

BIOGEOCHEMICAL CYCLES

To live, grow, and reproduce, the nutrient atoms, ions, and molecules that organisms need are continuously cycled from the nonliving (abiotic—lithosphere, atmosphere, and hydrosphere) environment to living (biotic—biosphere) organisms, then back again. This takes place in what are called *biogeochemical cycles* (nutrient cycles), which are literally life–earth–chemical cycles. Each element is recycled, although in some cycles there may be reservoirs where the element accumulates or is held for long periods of time.

To understand our physical world, you must understand the natural biogeochemical cycles that take place in our environment. *Biogeochemical cycles* are categorized into two types: the *gaseous* and the *sedimentary*. Gaseous cycles include the carbon and nitrogen cycles. The atmosphere and the ocean are the main sinks of nutrients in the gaseous cycle. The sedimentary cycles include the sulfur and phosphorus cycles. Soil and the rocks of the Earth's crust are the main sinks for sedimentary cycles. These cycles are ultimately powered by the sun and fine-tuned and directed by energy expended by organisms. Another important cycle, the *hydrological cycle* (or water cycle, which is discussed later) is also solar powered and acts like a continuous conveyor system that moves materials essential for life through the ecosystem.

DID YOU KNOW?

The nutrients carbon, nitrogen, oxygen, and phosphorus are used in ecosystems by living organisms and operate on a closed system, which refers to the fact that these chemicals are recycled instead of being lost and replenished constantly such as occurs in an open system. In an open system, the energy of an ecosystem comes from the sun, which constantly provides energy in the form of light, which is eventually used and lost in the form of heat throughout the trophic levels of a food web.

Between 20 and 40 elements of the Earth's 92 naturally occurring elements are ingredients that make up living organisms. The chemical elements carbon, hydrogen, oxygen, nitrogen, and phosphorus are critical in maintaining life as we know it on Earth. Of the elements needed by living organisms to survive, oxygen, hydrogen, carbon, and nitrogen are needed in larger quantities than are some of the other elements. The point is that, no matter what elements are needed to sustain life, these elements exhibit definite biogeochemical cycles. For now, let's cover the life-sustaining elements in greater detail.

The elements needed to sustain life are products of the global environment. The global environment consists of three main subdivisions:

1. *Hydrosphere*, which includes all of the water bodies on the Earth's surface
2. *Lithosphere*, which is comprised of the solid components, such as rocks
3. *Atmosphere*, which is the gaseous mantle that envelops the hydrosphere and lithosphere

To survive, organisms require inorganic metabolites from all three parts of the biosphere. The hydrosphere, for example, supplies water, which is the exclusive source of needed hydrogen. The lithosphere provides essential elements such as calcium, sulfur, and phosphorus. Finally, the atmosphere provides oxygen, nitrogen, and carbon dioxide.

Within the biogeochemical cycles, all of the essential elements circulate from the environment to organisms and back to the environment. Because these elements are critically important for sustaining life, you can easily understand why the biogeochemical cycles are realistically labeled *nutrient cycles*. Through these biogeochemical (or nutrient) cycles, nature processes and reprocesses the critical life-sustaining elements in definite inorganic–organic phases. Some cycles (the carbon cycle, for example) are more perfect than others; that is, the cycle loses no material in the process for long periods of time. Others are less perfect, but one essential point to keep in mind is that energy flows through an ecosystem (we will explain how later), but nutrients are cycled and recycled.

Because humans need almost all of the elements in our complex culture, we have sped up the movement of many materials so the cycles tend to become imperfect, or what Odum (1971) called *acyclic*. One example of a somewhat imperfect (acyclic) cycle is demonstrated by our use of phosphate, which, of course, affects the phosphorus cycle. Phosphate rock is mined and processed with careless abandon, which leads to severe local pollution near mines and phosphate mills. We also increase the input of phosphate fertilizers in agricultural systems without controlling in any way the inevitable increase in runoff output that severely stresses our waterways and reduces water quality through *eutrophication*, the natural aging of a landlocked body of water.

In agricultural ecosystems, we often supply necessary nutrients in the form of fertilizer to increase plant growth and yield. In natural ecosystems, however, these nutrients are recycled naturally through each trophic level (feeding level). Plants take up elemental forms. The consumers ingest these elements in the form of organic plant material. They cycle through the food chain from producer to consumer, and eventually the nutrients are degraded back to the inorganic form again.

The following sections present and discuss the nutrient cycles for carbon, nitrogen, phosphorus, and sulfur.

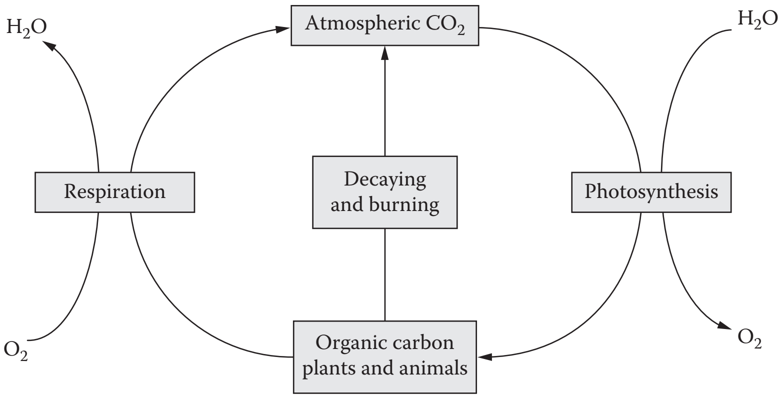

FIGURE 2.1 Carbon cycle.

CARBON CYCLE

Carbon is an essential ingredient for all living things and is the basic building block of the large organic molecules necessary for life (carbohydrates, fats, proteins, DNA, and others). It is cycled into food webs (biosphere) from the atmosphere (see Figure 2.1). In addition, in the carbon cycle, carbon is exchanged among the pedosphere (soil), geosphere, hydrosphere, and the atmosphere. Green plants obtain carbon dioxide (CO_2) from the air (Figure 2.1) and through photosynthesis—probably the most important chemical process on Earth—produce the food and oxygen upon which all organisms depend. Carbon plays an important role in the structure, biochemistry, and nutrition of all living cells. Part of the carbon produced remains in living matter; the other part is released as CO_2 during cellular respiration and is returned to the atmosphere. Some carbon is contained in buried dead animal and plant materials. Over the course of eons, many of these buried plant and animal materials were transformed into fossil fuels (coal, oil, and natural gas), which contain large amounts of carbon. When fossil fuels are burned, stored carbon combines with oxygen in the air to form carbon dioxide, which enters the atmosphere.

Although it is a small percentage of the atmosphere (approximately 0.04%), carbon dioxide acts as a beneficial heat screen that inhibits the radiation of Earth's heat into space. This balance is important. As more carbon dioxide is released into the atmosphere, that balance can be and is altered. Massive increases of carbon dioxide into the atmosphere tend to increase the possibility of global warming. The consequences of global warning might be catastrophic, and the resulting climate change may be irreversible. We will discuss carbon dioxide and global warming more fully later in this text.

NITROGEN CYCLE

The nitrogen cycle is the biogeochemical cycle that describes the transformations of nitrogen and nitrogen-containing compounds in nature. Nitrogen comprises 78% by volume of the atmosphere, making the atmosphere the largest pool of nitrogen. Nitrogen, an essential element for all living matter, constitutes 1 to 3% of the dry weight of cells, yet nitrogen is not a common element on Earth. Although it is an essential ingredient for plant growth, nitrogen is chemically very inactive; before

DID YOU KNOW?

Carbon dioxide is released into the atmosphere during the production of cement when limestone (calcium carbonate) is heated to produce lime (calcium oxide), a component of cement.

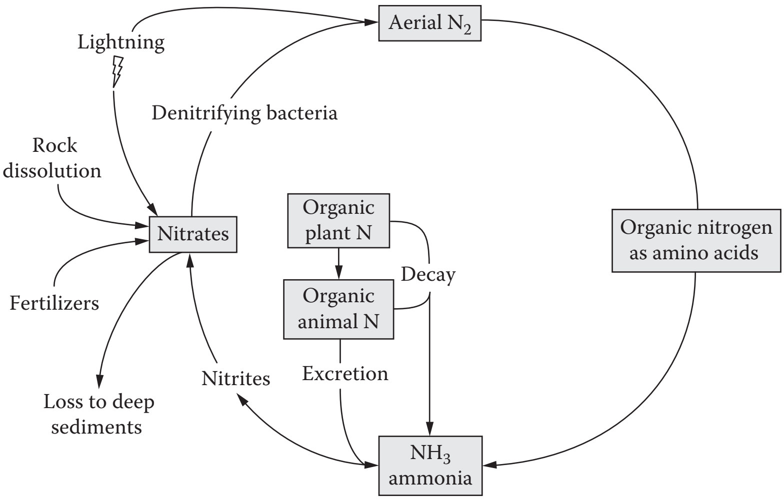

FIGURE 2.2 Nitrogen cycle.

the vast majority of the biomass can incorporate it, it must be fixed (processed). Nitrogen gas in the Earth's atmosphere is useless to most plants and animals. Fortunately, nitrogen gas is converted into compounds containing nitrate ions, which are taken up by plant roots as part of the nitrogen cycle (shown in simplified form in Figure 2.2).

Aerial nitrogen is converted into nitrates mainly by microorganisms, bacteria, and blue–green algae. Lightning also converts some aerial nitrogen gas into forms that return to the Earth as nitrate ions in rainfall and other types of precipitation. Ammonia plays a major role in the nitrogen cycle (see Figure 2.2). Excretion by animals and aerobic decomposition of dead organic matter by bacteria produce ammonia. Ammonia, in turn, is converted by bacteria into nitrites, then into nitrates. This process is known as *nitrification*. Nitrification bacteria are *aerobic*. *Nitrosococcus* and *Nitrosomonas* bacteria convert ammonia into nitrites and are known as *nitrite bacteria*; *Nitrobacter* converts nitrites into nitrates. During low oxygen (anaerobic) conditions, *denitrification* by bacteria occurs. This results in nitrates being converted to nitrogen gases and returned to the atmosphere.

Because nitrogen is often a limiting factor in naturally occurring soil, its absence can inhibit plant growth. Nitrogen is removed from topsoil when we harvest nitrogen-rich crops, irrigate crops, and burn or clear grasslands and forests before planting crops. To increase yields, farmers often provide extra sources of nitrogen by applying inorganic fertilizers or by spreading manure on the field and relying on the soil bacteria to decompose the organic matter and release the nitrogen for plant use.

PHOSPHORUS CYCLE

The phosphorus cycle is the biogeochemical cycle that describes the movement of phosphorus through the lithosphere, hydrosphere, and biosphere. Phosphorus is another element common in the structure of living organisms. Phosphorus circulates through water, the Earth's crust, and living

DID YOU KNOW?

As a result of extensive cultivation of soy, alfalfa, and clover (legumes); growing use of the Haber–Bosch process in the creation of chemical fertilizers; and pollution emitted by vehicles and industrial plants, human activities have more than doubled the annual transfer of nitrogen into biologically available forms (Vitousek et al., 1997).

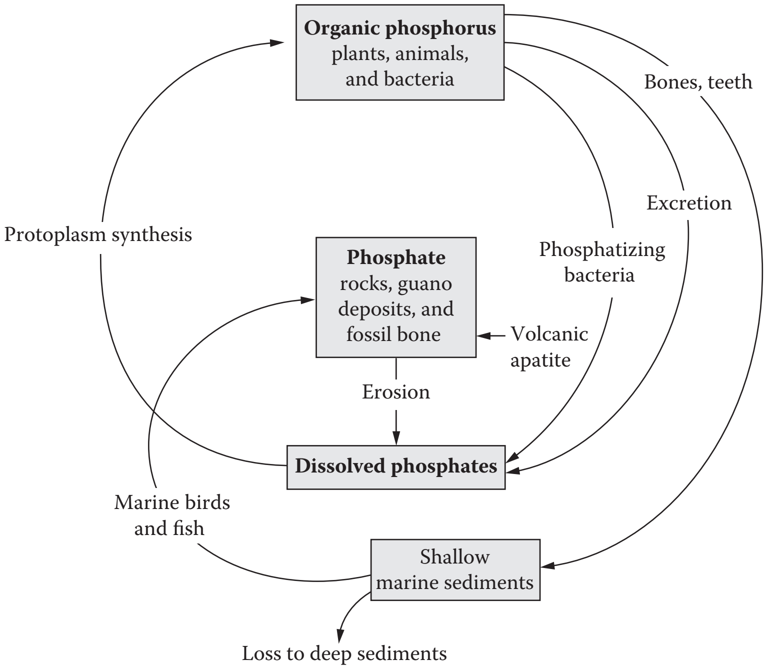

FIGURE 2.3 Phosphorus cycle.

DID YOU KNOW?

Phosphates move quickly through plants and animals; however, the processes that move them through the soil or ocean are very slow, making the phosphorus cycle overall one of the slowest biogeochemical cycles.

organisms in the phosphorus cycle; however, the atmosphere does not play a significant role in its movements (see Figure 2.3). Unlike other cycles of matter compounds, phosphorus is not found in air as a gas. The ultimate source of phosphorus is rock (a solid) (Figure 2.3). Phosphorus occurs as phosphate or other minerals formed in past geological ages. These massive deposits are gradually eroding, adding phosphorus to various ecosystems. A large amount of eroded phosphorus ends up in deep sediments in the oceans and in lesser amounts in shallow sediments. Some phosphorus reaches land when marine animals are brought out. Birds also play a role in phosphorus recovery. The great guano (bird excreta) deposit of the Peruvian coast is an example. Humans have hastened the rate of phosphorus loss through mining and the production of fertilizers that are washed away and lost.

Phosphorus has become very important in water quality studies, as it is often a limiting factor. Phosphates, upon entering a stream, act as a fertilizer and promote the growth of undesirable algal blooms. As the organic matter decays, dissolved oxygen levels decrease, and fish and other aquatic species die, limiting producer populations in freshwater systems.

SULFUR CYCLE

Sulfur, like nitrogen, is characteristic of organic compounds; it is one of the constituents of many proteins, vitamins, and hormones. The sulfur cycle (see Figure 2.4) is both sedimentary and gaseous. Bacteria play a major role in the conversion of sulfur from one form to another. In an *anaerobic*

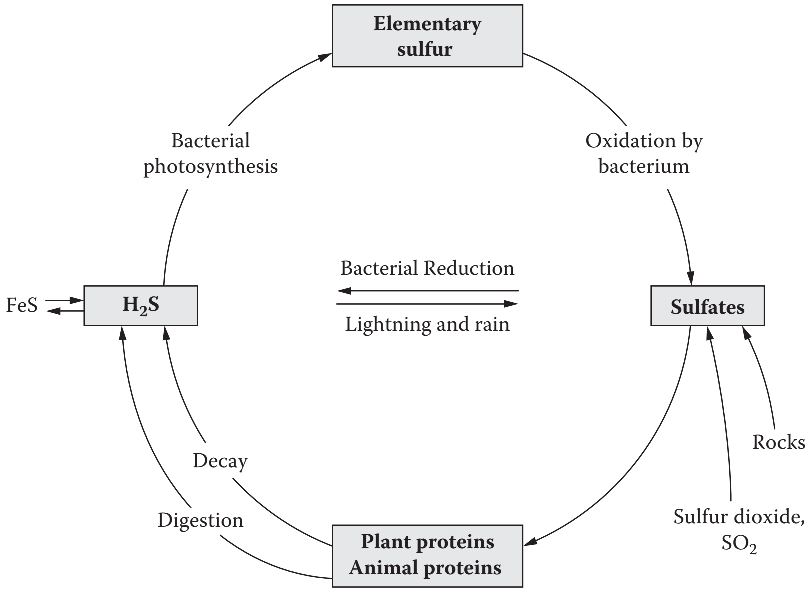

FIGURE 2.4 Sulfur cycle.

environment, bacteria break down organic matter, thereby producing hydrogen sulfide with its characteristic rotten-egg odor. *Beggiatoa* bacteria convert hydrogen sulfide into elemental sulfur. The aerobic sulfur bacterium *Thiobacillus thiooxidans* converts sulfur into sulfates. Other sulfates are contributed by the dissolving of rocks and some sulfur dioxide. Sulfur is incorporated by plants into proteins. Some of these plants are then consumed by organisms. Sulfur from proteins is liberated by many heterotrophic anaerobic bacteria as hydrogen sulfide.

ENERGY FLOW THROUGH AN ECOSYSTEM AND THE BIOSPHERE

We often take energy for granted due to our deceptive familiarity with it; we think of it in so many different ways: atomic energy, food energy, cheap energy, expensive energy, abundant energy, and so on. This presents a huge double irony, because, on the one hand, most people know that without energy our energy-dependent industrialized society would grind to a halt. On the other hand, energy is more than just the force that powers our machines, our civilization—it powers hurricanes, the movement of the planets, the entire universe. Despite its pervasiveness and its familiarity, energy is a complex and puzzling concept. It cannot be seen, tasted, smelled, or touched. What is it? To answer this question, we must first gain an understanding of *materials balance*.

DID YOU KNOW?

The sulfur cycle is primarily impacted by humans in the production of sulfur dioxide (SO_2) from industry (e.g., burning coal) and the internal combustion engine. Sulfur dioxide can precipitate onto surfaces where it can be oxidized to sulfate in the soil, reduced to sulfide in the atmosphere, or oxidized to sulfate in the atmosphere as sulfuric acid, a principal component of acid rain.

MATERIALS BALANCE

Probably the simplest way to express materials balance, one of the most important and fundamental scientific principles, is to point out that *everything has to go somewhere; moreover, material inputs to every process must balance with the outputs*. According to the *law of conservation of mass*, when chemical reactions take place, matter is neither created nor destroyed (an exception is a nuclear reaction, when mass can be converted to energy). The importance of this concept in environmental science is that it allows us to track pollutants from one location to another using the *mass balance equation*.

To perform mass balance analysis, we must first define the particular region to be analyzed. The region you select could include anything—a lake, a stretch of river or stream, an air basin above a city or factory, a chemical mixing vat, a coal-fired power plant, or the Earth itself. Whatever region you select for analysis, you must confine the region with an imaginary boundary (see Figure 2.5). From such a region we can begin to identify the flow of materials across the boundary as well as the accumulation of materials within the region.

When a material enters the region, it has three possible fates: Some of it may enter and slip through the region unchanged, some of it may accumulate within the boundary, and some of it may be converted to some other material—for example, CO to CO_2. If we use Figure 2.5 as a guide, a materials balance equation can be written as

$$\text{Input rate} = \text{Output rate} + \text{Decay rate} + \text{Accumulation rate} \tag{2.1}$$

The decay rate in Equation 2.1 does not imply a violation of the law of conservation of mass. No constraints occur on the change of one substance to another (chemical reactions), but atoms are conserved.

Note: In practice, Equation 2.1 can be (and often is) simplified by assuming steady-state equilibrium conditions (that is, nothing changes with time); discussion of this practice is beyond the scope of this text, but it is presented in many environmental engineering studies.

Let's get back to our discussion of energy. First of all, what is energy? Energy is often defined as the capacity for doing work, and work is often described as the product of force and the displacement of some object caused by that force. Along with understanding and analyzing the flow of materials through a particular region, we can also determine and analyze the flow of energy. Using the *first law of thermodynamics*, we can write *energy balance equations*. The first law of thermodynamics states that energy can be neither created nor destroyed. In short, energy may change forms

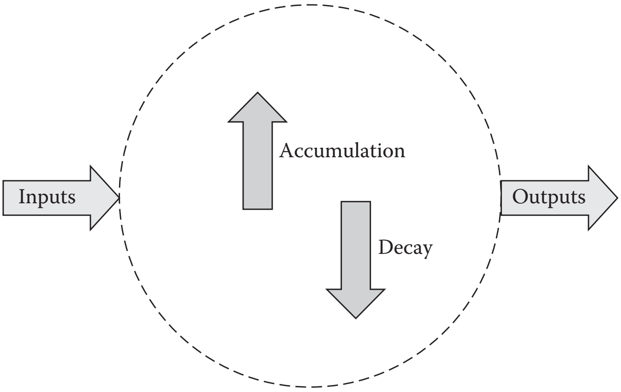

FIGURE 2.5 Materials balance diagram.

in a given process, but we should be able to account for every bit of energy during the process. In simplified form, this relationship is

$$\text{Energy in} = \text{Energy out} \tag{2.2}$$

Equation 2.2 may give you the false impression that the transfer of energy in a process is 100% efficient. This, of course, is not the case. In a coal-fired electrical power generating plant, for example, only a portion of the energy from the burned coal is converted directly into electricity. A large portion of the coal-fired energy ends up as waste heat given off to the environment because of the *second law of thermodynamics*, which states that every process generates some waste heat; devising a process or machine that can convert heat to work with 100% efficiency is impossible.

Heat can be transferred in three ways: conduction, convection, or radiation. When direct contact between two physical objects at different temperatures occurs, heat is transferred via conduction from the hotter object to the colder one. When a gas or liquid is placed between two solid objects, heat is transferred by convection. Heat is also transferred when no physical medium exists by radiation (for example, radiant energy from the sun).

Energy Flow in the Biosphere

Energy flow in the biosphere all starts with the sun. The sun's radiant energy sustains all life on Earth. The sun not only lights and warms the Earth but also provides energy used by green plants to synthesize the compounds that keep them alive. These compounds serve as food for almost all other organisms. The sun's solar energy also powers the biochemical cycles and drives climate systems that distribute heat and fresh water over the Earth's surface. Figure 2.6 illustrates an important point: Not all solar radiant energy reaches the Earth. Approximately 34% of incoming solar radiation is reflected back to space by clouds, dust, and chemicals in the atmosphere and by the Earth's surface. Most of the remaining 66% warms the atmosphere and land, evaporates water, cycles water through the biosphere, and generates winds. Surprisingly, only a small percentage (about 0.022%) is captured by green plants and used to make the glucose essential to life.

Most of the incoming solar radiation not reflected away is degraded (or wasted) into longer wavelength heat (in accordance with the second law of thermodynamics) and flows into space. The actual amount of energy that returns to space is affected by the presence of molecules of water, methane, carbon dioxide, and ozone and by various forms of particulate matter in the atmosphere. Many of these barriers are created by human activities and might affect global climate patterns by disrupting the rate at which incoming solar energy flows through the biosphere and returns to space. We will discuss the possible effects of human activities on climate in a later chapter.

Energy Flow in the Ecosystem

For an ecosystem to exist and to maintain itself, it must have energy. All activities of living organisms involve work—the expending of energy, the degradation of a higher state of energy to a lower state. The flow of energy through an ecosystem is governed by the two laws mentioned earlier: the first and second laws of thermodynamics. Remembering that the first law (sometimes called the *conservation law*) states that energy may not be created nor destroyed and that the second law states that no energy transformation is 100% efficient sets the stage for a discussion of energy flow in the ecosystem. Hand in hand with the second law (some energy is always lost, dissipated as heat) is another critically important concept—*entropy*. Used as a measure of the nonavailability of energy to a system, entropy increases with an increase in heat dissipation. Because of entropy, input of energy into any system is higher than the output or work done; the resultant efficiency is less than 100%.

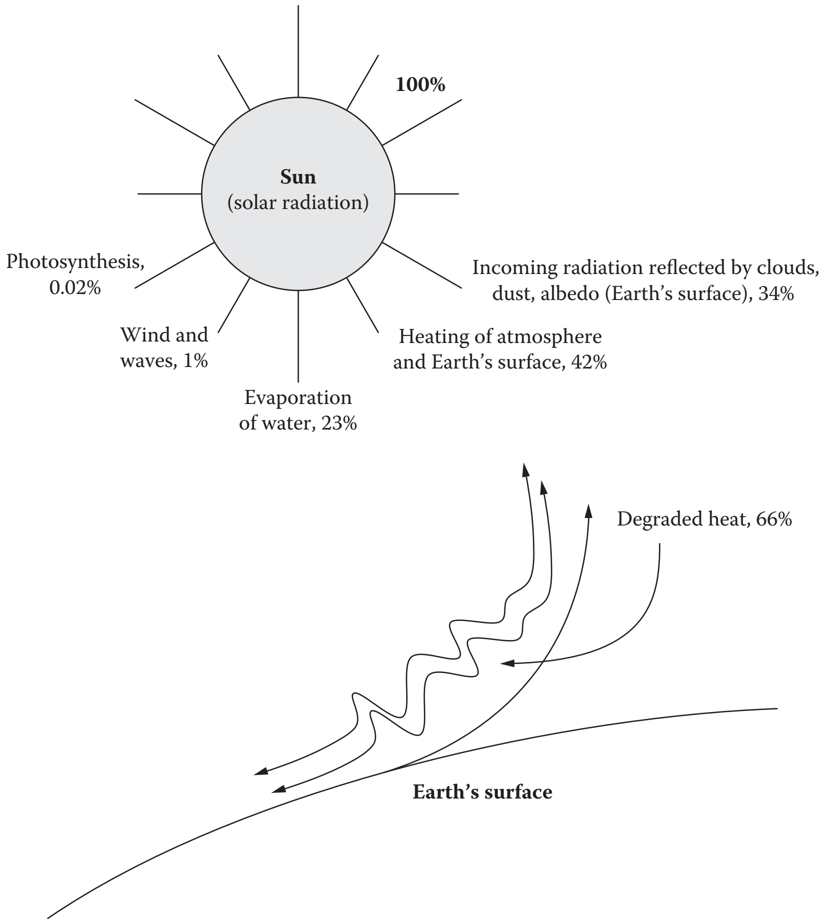

FIGURE 2.6 Flow of energy to and from the Earth.

Pollution scientists and technicians are primarily concerned with the interaction of energy and materials in the ecosystem. Earlier we discussed biogeochemical (nutrient) cycles and pointed out that the flow of energy drives these cycles. Energy does not cycle as nutrients do in biogeochemical cycles. For example, when food passes from one organism to another, energy contained in the food is reduced step by step until all the energy in the system is dissipated as heat. This process has been referred to as a *unidirectional flow* of energy through the system, with no possibility for recycling of energy. When water or nutrients are recycled, energy is required. The energy expended in the recycling is not recyclable. As Odum (1975) pointed out, this is a "fact not understood by those who think that artificial recycling of man's resources is somehow an instant and free solution to shortages" (p. 61).

The principal source of energy for any ecosystem is sunlight. *Producers* (green plants, such as flowers, trees, ferns, mosses, and algae), through the process of *photosynthesis*, transform the sun's energy into carbohydrates, which are consumed by animals. This transfer of energy, as stated earlier, is unidirectional—from producers to consumers. Often, the transfer of energy to different organisms is referred to as a *food chain*. Figure 2.7 shows a simple aquatic food chain.

All organisms, alive and dead, are potential sources of food for other organisms. All organisms that share the same general type of food in a food chain are said to be at the same *trophic level* (feeding level). Because green plants use sunlight to produce food for animals, they are considered

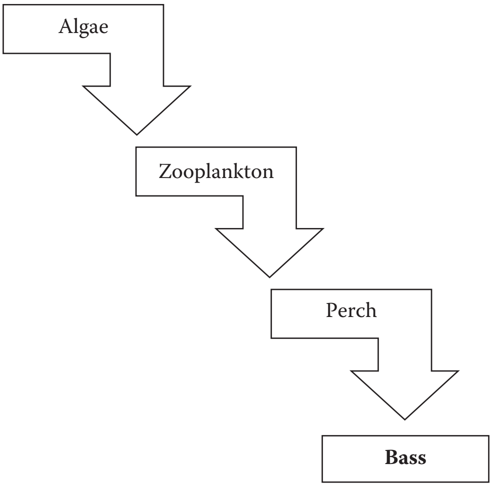

FIGURE 2.7 Aquatic food chain.

to be producers at the first trophic level. The herbivores, *primary consumers*, eat plants directly and belong in the second trophic level. The carnivores are flesh-eating consumers; they include several trophic levels from the third on up (see Figure 2.8). At each transfer, a large amount of energy (about 80 to 90%) is lost as heat and waste. Nature normally limits food chains to four or five links. Note, however, that in aquatic food chains the links are commonly longer than they are on land, because several predatory fish may be feeding on the plant consumers. Even so, the built-in inefficiency of the energy transfer process prevents development of extremely long food chains.

Only a few simple food chains are found in nature and most are interlocked. This interlocking of food chains forms a *food web*—a map that shows what eats what. An organism in a food web may occupy one or more trophic levels. Food chains and webs help to explain how energy moves through the ecosystem.

Another important trophic level of the food web is comprised of *decomposers*. The decomposers feed on dead plants or animals and play an important role in recycling nutrients in the ecosystem. Healthy ecosystems produce no wastes. All organisms, alive or dead, are potential sources of food (and energy) for other organisms.

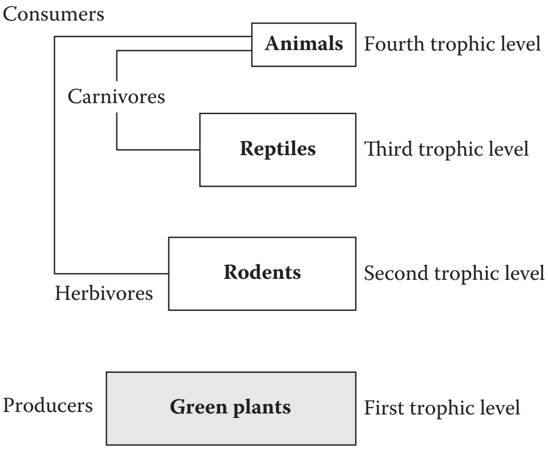

FIGURE 2.8 Energy flow through an ecosystem.

TABLE 2.1
Commonly Used Units and Conversion Factors

Quantity	SI Units	SI Symbol	×	Conversion Factor	=	USCS Units
Length	Meter	m		3.2808		ft
Mass	Kilogram	kg		2.2046		lb
Temperature	Celsius	C		1.8 (C) + 32		F
Area	Square meter	m^2		10.7639		ft^2
Volume	Cubic meter	m^3		35.3147		ft^3
Energy	Kilojoule	kJ		0.9478		Btu
Power	Watt	W		3.4121		Btu/hr
Velocity	Meter/second	m/s		2.2369		mi/hr

UNITS OF MEASUREMENT

A basic knowledge of units of measurement and how to use them is essential for students of pollution science. Pollution science students and practitioners should be familiar with both the *U.S. Customary System* (USCS), or *English system*, and the *International System of Units* (SI). We summarize some of the important units here to enable better understanding of material covered later in the text. Table 2.1 gives conversion factors for SI and USCS systems for some of the most basic units encountered. In the study of pollution science, you will commonly encounter both extremely large quantities and extremely small ones; for example, the concentration of some toxic substance may be measured in parts per million or billion (ppm or ppb). One part per million can be roughly described as the volume of liquid contained in a shot glass compared to the volume of water contained in a swimming pool. To describe quantities that may take on such large or small values, a system of prefixes for the units is useful. We present some of the more important prefixes in Table 2.2.

Units of Mass

Simply defined, *mass* is a quantity of matter and measurement of the amount of inertia that a body possesses. Mass expresses the degree to which an object resists a change in its state of rest or motion and is proportional to the amount of matter in the object. Another, simpler way to understand mass is to think of it as the quantity of matter an object contains.

Beginning science students often confuse *mass* with *weight*. They are different. Weight, for example, is the gravitational force acting upon an object and is proportional to mass. In the SI system (a modernized metric system), the fundamental unit of mass is the *gram* (g). How does mass stack up against weight? To show the relationship between mass and weight, consider that a pound contains 452.6 grams. In laboratory-scale operations, the gram is a convenient unit of measurement; however, in real-world applications the gram is usually prefixed with one of the prefixes shown in Table 2.2. For example, human body mass can be expressed in *kilograms* (1 kg = 2.2 pounds). In

TABLE 2.2
Common Prefixes

Quantity	Prefix	Symbol	Quantity	Prefix	Symbol
10^{-12}	Pico-	p	10^{-1}	Deci-	d
10^{-9}	Nano-	n	10	Deca-	da
10^{-6}	Micro-	μ	10^2	Hecto-	h
10^{-3}	Milli-	m	10^3	Kilo-	k
10^{-2}	Centi-	c	10^6	Mega-	M

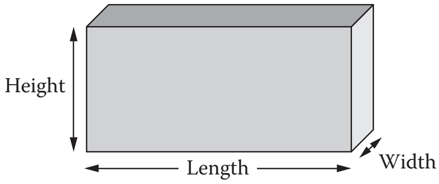

FIGURE 2.9 Units of length measurement.

everyday terms, a kilogram is the mass of 1 liter of water. When dealing with units of measurement pertaining to environmental conditions such as air pollutants and toxic water pollutants, they may be measured in teragrams (1×10^{12} grams) and micrograms (1×10^{-6} grams), respectively. When dealing with large-scale industrial commodities, the mass units may be measured in units of megagrams (Mg), also known as a metric ton.

Often mass and *density* are mistaken as signifying the same thing—they do not. Whereas mass is the quantity of matter and a measurement of the amount of inertia that a body contains, density refers to how compacted a substance is with matter; that is, density is the mass per unit volume of an object, and its formula can be written as

$$\text{Density} = \text{Mass/Volume} \tag{2.3}$$

Something with a mass of 25 kg that occupies a volume of 5 m^3 would have a density of 25 kg/5 m^3 = 5 kg/m^3. In this example, the mass was measured in kilograms and the volume in cubic meters.

UNITS OF LENGTH

When measuring locations and sizes, we use the fundamental property of *length*, defined as the measurement of space in any direction. Space has three dimensions, each of which can be measured by length. This can be easily seen by considering the rectangular object shown in Figure 2.9. It has length, width, and height, but each of these dimensions is a length.

In the metric system, length is expressed in units based on the *meter* (m), which is 39.37 inches long. A kilometer (km) is equal to 1000 m and is used to measure relatively great distances. In practical laboratory applications, the centimeter (cm = 0.01 m) is often used. The centimeter is employed to express lengths that would be given in inches in the English system; there are 2.540 cm per inch. The micrometer (μm) is also commonly used to express measurements of bacterial cells and wavelengths of infrared radiation by which Earth reradiates solar energy back to outer space. For measuring visible light (400 to 800 nm), the nanometer (nm) (10^{-9}) is often used.

UNITS OF VOLUME

The easiest way to approach measurements involving *volume* is to remember that volume is surface area multiplied by a third dimension. The *liter* is the basic metric unit of volume and is the volume of a decimeter cubed (1 L = 1 dm^3). A milliliter (mL) is the same volume as a cubic centimeter (cm^3).

UNITS OF TEMPERATURE

Temperature is a measure of how "hot" something is—how much thermal energy it contains. Temperature is a fundamental measurement in pollution science, especially in most pollution work. The temperature of a stack gas plume, for example, determines its buoyancy and how far the plume of effluent will rise before attaining the temperature of its surroundings. This in turn determines how much it will be diluted before traces of the pollutant reach ground level.

Temperature is measured on several scales; for example, the *centigrade* (or *Celsius*) and *Fahrenheit* scales are both measured from a reference point—the freezing point of water—which is taken as 0°C or 32°F. The boiling point of water is taken as 100°C or 212°F. Thermodynamic devices usually work in terms of absolute, or thermodynamic, temperature, where the reference point is absolute zero, the lowest possible temperature attainable. Absolute temperature measurement uses the thermodynamic *Kelvin* (K) scale, for which 0 (–273.15°C) is the lowest attainable temperature. A unit of temperature on this scale is equal to a Celsius degree; however, the unit is referred to as a Kelvin rather than a degree and is designated as K, not °K. Because the value of absolute zero on the Kelvin scale is –273.15°C, the Kelvin temperature is always 273 (rounded) higher than the Celsius temperature. Thus, water boils at 373 K and freezes at 273 K.

To convert from the Celsius scale to the Kelvin scale, simply add 273 to the Celsius temperature:

$$K = {}^\circ C + 273 \tag{2.4}$$

where K is the temperature on the Kelvin scale, and °C is the temperature on the Celsius scale.

Converting from Fahrenheit to Celsius or *vice versa* is not so easy:

$$^\circ C = 5/9(^\circ F - 32) \tag{2.5}$$

and

$$^\circ F = 9/5^\circ C + 32 \tag{2.6}$$

where °C is the temperature on the Celsius scale, and °F is the temperature on the Fahrenheit scale. As examples, 15°C = 59°F and 68°F = 20°C. Of course, °F or °C can be negative numbers.

UNITS OF PRESSURE

Pressure is force per unit area and can be expressed in a number of different units, including the *atmosphere* (atm), the average pressure exerted by air at sea level, or the *pascal* (Pa), usually expressed in kilopascal (1 kPa = 1000 Pa, and 101.3 kPa = 1 atm). Pressure can also be given as millimeters of mercury (mmHg), based on the amount of pressure required to hold up a column of mercury in a mercury barometer. 1 mm of mercury is a unit called the *torr*, and 760 torr equal 1 atm.

UNITS OFTEN USED IN ENVIRONMENTAL POLLUTION STUDIES

In environmental pollution studies, often the concentration of some substance (foreign or otherwise) in air or water is of interest. In either medium, concentrations may be based on volume or weight, or a combination of the two (which may lead to some confusion). To understand how weight and volume are used to determine concentrations when studying liquids or gases or vapors, consider the following explanations.

Liquids

Concentrations of substances dissolved in water are usually expressed in terms of weight of substance per unit volume of mixture. In environmental science, a good practical example of this weight per unit volume is best observed when a contaminant is dispersed in the atmosphere in solid or liquid form as a mist, dust, or fume. When this occurs, its concentration is usually expressed on a weight-per-volume basis. Outdoor air contaminants and stack effluents are frequently expressed as grams, milligrams, or micrograms per cubic meter; ounces per thousand cubic feet; pounds per thousand pounds of air; and grains per cubic foot. Most measurements are expressed in metric units; however, the use of standard U.S. units is justified for purposes of comparison with existing data, especially those relative to the specifications for air-moving equipment. Alternatively, concentrations in liquids are expressed as weight of substance per weight of mixture, with the most common units being parts per million (ppm) or parts per billion (ppb). Because most concentrations of pollutants are very small, one liter of mixture weighs essentially 1000 g, so for all practical purposes we can write

$$1 \text{ mg/L} = 1 \text{ g/m}^3 = 1 \text{ ppm (by weight)} \tag{2.7}$$

$$1 \text{ mg/L} = 1 \text{ g/m}^3 = 1 \text{ ppb (by weight)} \tag{2.8}$$

The pollution science practitioner may also be involved with concentrations of liquid wastes that may be so high that the *specific gravity* (the ratio of an object's or substance's weight to that of an equal volume of water) of the mixture is affected, in which case a correction to 2.7 and 2.8 may be required:

$$\text{mg/L} = \text{ppm (by weight)} \times \text{Specific gravity} \tag{2.9}$$

Gases or Vapors

For most air pollution work, by custom, we express pollutant concentrations in volumetric terms. For example, the concentration of a gaseous pollutant in parts per million (ppm) is the volume of pollutant per million volumes of the air mixture:

$$\text{ppm} = \text{Parts of contaminant/Million parts of air} \tag{2.10}$$

Calculations for gas and vapor concentrations are based on the gas laws:

- The volume of gas under constant temperature is inversely proportional to the pressure.
- The volume of a gas under constant pressure is directly proportional to the Kelvin temperature. The Kelvin temperature scale is based on absolute zero (0°C = 372 K).
- The pressure of a gas of a constant volume is directly proportional to the Kelvin temperature.

When measuring contaminant concentrations, we must know the atmospheric temperature and pressure under which the samples were taken. At standard temperature and pressure (STP), 1 gram-mole (g-mol) of an ideal gas occupies 22.4 L. The STP are 0°C and 760 mmHg. If the temperature is increased to 25°C (room temperature) and the pressure remains the same, 1 g-mol of gas occupies 24.45 L.

Sometimes we need to convert milligrams per cubic meter (mg/m^3), which is a weight-per-volume ratio, into a volume-per-unit-volume ratio. If 1 g-mol of an ideal gas at 25°C occupies 24.45 L, the following relationships can be calculated:

$$\text{ppm} = (24.45 \text{ mg/m}^3)/\text{Molecular weight} \tag{2.11}$$

$$\text{mg/m}^3 = (\text{Molecular weight}/24.45) \times \text{ppm} \tag{2.12}$$

THE BOTTOM LINE

Environmental pollution, like any other true science, has a foundation in observation and numerical analysis. The biogeochemical cycles that allow and sustain life on our planet operate on levels beyond ordinary observation, a common enough problem in scientific analysis. Without the fundamental knowledge of the foundational biogeochemical cycles, energy's position and importance in all life cycles, and the basics of how to quantify information gathered from the environments studied, you have not "advanced to the state of science."

DISCUSSION QUESTIONS

1. Distinguish between work and energy.
2. How can we best conserve our energy resources?
3. Define environment.
4. What is a biogeochemical cycle? How do such cycles connect past, present, and future forms of life?
5. Describe several advantages for animals that can occupy more than one trophic level.
6. Trace the route carbon might follow as it cycles through a terrestrial ecosystem. Include at least four organisms in the cycle.
7. How does biological fixation of nitrogen differ from atmospheric fixation?
8. Using the second law of thermodynamics, explain why such a sharp decrease in high-quality energy occurs along each step of the food chain. Doesn't energy loss at each step violate the first law of thermodynamics? Explain.
9. Suggest ways in which the transportation systems can be modified that will result in environmental improvement compared to present practices.
10. Explain the difference between ecosystem, niche, and habitat. Give examples of each.

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3 Global Pollution: The Problem

One of the marvels of early Wisconsin was the Round River, a river that flowed into itself, and thus sped around and around in a never-ending circuit. Paul Bunyan discovered it, and the Bunyan saga tells how he floated many a log down its restless waters. No one has suspected Paul of speaking in parables, yet in this instance he did. Wisconsin not only *had* a round river, Wisconsin *is* one. The current is the stream of energy which flows out of the soil and into the plants, thence into the animals, thence back into the soil in a never ending circuit of life.

Leopold (1970)

Whenever the Dragon advances, the world darkens. It belches clouds of soot and smoke, engulfing all that is living in its burning breath.

—Folke Isaksson, Swedish writer

… the changes represented by melting glaciers, acidifying oceans, and migrating species are—on a planetary timescale—breaking all known speed limits.

Flavin and Engelman (2009)

Appropriate places for [refuse] are becoming scarcer year by year, and the question as to some other method of disposal … must soon confront us. Already the inhabitants in proximity to the public dumps are beginning to complain.

—Health Officer's report, Washington, DC, 1889

INTRODUCTION

For millions of years, human beings inhabited the planet Earth without having any perceptible impact on the quality of the global environment that accounts for the planet's uniquely habitable conditions. (*Note:* Unless we otherwise stipulate, "global environment" refers to the three main mediums of soil, air, and water—the focus of this text.) The situation began to change several millennia ago when anthropocentric (i.e., human-generated) agricultural practices transformed land cover over large areas. These small-scale practices had perceptible impact primarily on regional (local) environments. More substantial changes to the global environment have come about as a result of the greatly expanded human use of soil, water, and air as the convenient sinks for a myriad of waste products and materials (pollutants). The advent of the Industrial Revolution in the 18th century led to great increases in the use of natural resources such as fossil fuels. The human assault on the global environment has quickened ever more dramatically since World War II. An exploding world population, an exponential rise in industrial activity, the massive spread of agriculture, and the wholesale clearing of forests have dramatically altered our planet's condition—its environmental health.

Prior to the 20th century, significant environmental pollution was almost exclusively a localized problem in the vicinity of the emission sources, particularly the large cities and industrial zones of North America, the British Isles, and Western Europe. Even today, pollution is often still a localized problem; however, not only are its global implications now being recognized but they are also being felt. In this chapter (and throughout this text), we discuss pollution in the context of its global impact.

GLOBAL INTERDEPENDENCE

Evidence of the growing trend toward global interdependence, international commitment, and awareness of the global impact of pollution can be found in notes generated from an economic summit meeting in Paris in 1989. At this meeting, the leaders of the seven major democracies released a communiqué covering virtually every environmental issue and calling for immediate awareness and a plan of action, one designed to remediate, monitor, measure, and correct anthropogenic emissions (UNEP, 1989).

We are in the midst of what can be called a global awakening; the long-term consequences of this increasing interdependence are still unclear but will certainly include history-making change in the structures of societies and governments, in levels of multilateral commitment and involvement, in patterns and directions of economic activity, and in the lifestyles, rights, and responsibilities of individuals. Obviously, this is good news for the environment; however, the road to reducing the environmental impact of pollution worldwide is strewn with many boulders. Addressing global pollution issues in a world forum has obvious advantages. Shifting the focus from pollution at the local level is a major step in international progress toward solving worldwide pollution problems. (*Note:* For our purposes, “local” refers to a town, a neighborhood, and, extending to smaller scales, home and work.)

Shifting the focus from a local to global scale is a hard sell, though. Local and regional pollution issues are familiar to most of us—we encounter many of them daily. They include smog; toxic effects of locally generated air pollutants, such as eye irritants, organic vapors, particulate matter, and persistent environmental toxins; indoor air pollution, including radon, formaldehyde, tobacco smoke, and biogenic pollutants; indoor water pollution; and acid rain and acid fog. These local and regional pollution issues are real—and obvious. On the global scale, however, the threat of worldwide pollution and its terrible consequences are not so clear.

How do local pollution concerns shift to larger problems with worldwide impact potential that are encountered on a global scale? In reality, the immediate human impacts of pollution reach a global level in a patchwork and cumulative fashion. Changes that are local in domain but which are widely replicated in sum constitute changes in the whole human environment (Brookfield, 1989). In other words, individual localized pollution events pose issues in less than global domains but they add up to a global effect. More significantly, they also connect with much longer chains of environmental consequences (explained below), some of them reaching global environmental systems—climate, for example.

Case Study 3.1. Persistent Organic Pollutants

Pesticide Action Network North America (PANNA)
Updates Service
July 17, 1998

Global Meeting on Persistent Organic Pollutants

Global representatives from 92 countries concluded their first round of talks on how to reduce and eliminate worldwide use and emissions of persistent organic pollutants (POPs), highly toxic chemicals such as DDT, and dioxins that remain in the environment for years. The meeting, held in Montreal, June 29 to July 3, 1998, focused on a list of 12 persistent chemicals, including 9 pesticides. Eight of these nine pesticides are on Pesticide Action Network’s Dirty Dozen list: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, and toxaphen. The remaining chemicals on the list are dioxins, furans, mirex, and PCBs.

“These substances travel readily across international borders to even the most remote region, making this a global problem that requires a global solution,” said Klaus Toepfer, executive director of the United Nations Environment Program (UNEP), which sponsored the meetings.

A growing body of scientific evidence indicates that exposure to very low doses of certain POPs can lead to cancer, damage to the central and peripheral nervous systems, diseases of the immune system, reproductive disorders, and interference with normal infant and child development. POPs can travel through the atmosphere thousands of miles from their source. In addition, these substances concentrate in living organisms and are found in people and animals worldwide.

GLOBAL POLLUTION PROBLEMS: CAUSAL FACTORS

Before beginning a brief overview of global pollution problems, let us point out that many nations (with regard to environmental degradation attributed to pollution) lack the ability to measure environmental change, to monitor change brought about by pollution, and to anticipate the impact of interaction among factors such as population size, availability of natural resources (energy), supplies of food and water, and environmental quality. Let us also point out that the United States and most other nations fail to link the results of any existing projections to current decision making. It is also important to point out that, when discussing or explaining causal factors, there are two levels of causation: proximate and ultimate causation. *Proximate causation* (closest cause) answers the question “How?” (e.g., “How did the local stream become polluted with raw sewage?”). This factor is causal at the immediate, direct level. But, underlying that, there is a second, deeper cause. This level is referred to as the *ultimate causation* (distal cause) which answers the question “Why?” (e.g., “Why was the stream vulnerable to sewage pollution?”).

FRONTIER MENTALITY

It was one of the most famous trails ever, and it was the longest overland trail in North America. In 1843, Americans were encouraged by the U.S. government to travel the 2000 miles from Independence, Missouri, to their final destination in the Oregon territory to homestead the land. By settling the land with more Americans than British, Oregon would belong to the United States.

The 2000-mile trek to the Oregon territory was no walk in the park; it was a great migration of hordes of people traveling in covered wagons over mostly uncharted lands and trails (or so was the case early on). The seemingly endless lines of prairie schooners snaked their way along the trail for more than half a year before they arrived at their destinations.

The pioneers took whatever they could carry in their wagons. It was not unusual for each wagon to be loaded with food that included yeast for baking, crackers, cornmeal, bacon, eggs, dried meat, potatoes, rice, beans, and a big barrel of water. They also brought along a cow if they had one. Pioneers made their own clothing, so they brought cloth to sew, needles, thread, pins, and scissors, as well as leather to fix worn-out shoes. They had to make their own repairs so they brought saws, hammers, axes, nails, string, and knives.

DID YOU KNOW?

Humans first impacted the environment when they sparked that first fire into life. Later, when tools came into being, stone and metal grinding on a small scale resulted in minor accumulations of discarded material that probably dispersed with little impact on the surroundings. Human wastes would have polluted rivers and streams to some degree; however, these effects could be expected to be dwarfed by the natural world. Moreover, humans’ contributions to global pollution today dwarf those of the ancient past.

FIGURE 3.1 Casting off personal treasures to lighten the load along the old Oregon Trail. (Illustration by F.R. Spellman and Kathern Welsh.)

Occasionally, and against the advice of the wagonmaster, pioneers would also pack away personal treasures—heirlooms such as pianos, family trunks and furniture, mirrors, assorted chinaware, silver, paintings, and other decorative household goods of the day. These items not only took up a lot of space within the wagon but also were clumsy to handle and added extra weight to the wagon.

They usually had not traveled too many miles before many of those who had packed too much started to drop off or discard various personal treasures along the trail (Figure 3.1). So many personal property items were discarded along the trail that by the late 1840s it was no longer necessary to follow the tracks of the wagons that had preceded them to stay on the trail. All anyone had to do was follow the strewn and rotting personal treasures (and assorted gravesites) that marked the trail.

So many personal items were cast off during the great migration that those living in towns nearby often waited for the wagon trains to pass by so that they could confiscate the cast-off items. Unfortunately, word got out to the pioneers about the scavengers, some of whom not only cast off their treasures but also destroyed many of them so that they were of little use to anyone. This added to the pollution problem along the trail because items destroyed by the pioneers became nothing more than discarded trash.

Parting with their personal treasures must have been heartbreaking to many of the pioneers as they made the difficult trek along the Oregon Trail to their new homesteads in the West. For decades many have asked what it was that drove or enticed these people to undertake such a perilous adventure into lands unknown. The main draw, of course, was the promise of free land. For others, it was freedom from the squalor of city life or the drudgery of farm life spent trying to eke out a living on worn-out soils as tenet farmers that drove them to undertake the arduous Western adventure. For others, the draw of wide-open, untamed spaces and the quest for adventure were the drawing cards.

This burning desire to conquer new lands, exploit them, and become rich was a powerful magnet attracting and aligning the metal filings of their mentalities. This mode of thought that drove the pioneers to trek across barren, rugged, unforgiving wilderness is commonly referred to as a *frontier* *mentality*. That is, we live as though we cannot effectively harm the natural world in a significant way because it is so big and we are so little, and if we damage one place there will always be a new frontier to move to. The reality is that this mode of thought, this frontier mentality, can be summed up today by simply stating that in the United States there has always been a Western frontier, a place to go and start over that offered riches for the taking for hardy spirits and determined workers.

Let's get back to the pioneers trekking along the Oregon Trail, which they have marked with ruts carved by their wagon wheels and signposts provided by their discarded personal goods. Again, through the many years of traversing the Oregon Trail, wagon train after wagon train discarded goods that dotted the prairie areas for miles. Humans have this tendency; that is, when some object they own is no longer needed or no longer pleases them or has outlived its usefulness, they simply discard it—out of sight, out of mind. Because of their frontier mentality with regard to the West, that it was an expanse of wide-open, untamed space, the pioneers had no qualms about leaving their personal goods to rot along the trail, no qualms about polluting the landscape.

This same frontier mentality ("I no longer want or need it, so I'll throw it away") did not disappear when the pioneers reached their destinations. The mindset altered a bit, perhaps, but it persisted. It began with settlements that were almost exclusively built along rivers. The rivers provided a convenient means of disposing of the unwanted. What began with simple discards such as coffee grounds advanced through the years to more complex items such as white goods (washers, dryers, refrigerators, etc.) and even more complex and persistent chemical compounds and mixtures. The rivers became the repositories of choice for all of it. The thinking was, of course, that no matter what was thrown into a river the running water would purify itself every 10 miles or so. But, with several settlements with hundreds or thousands of people up and down the length of a river, the purification capacity of the running water was exhausted. Even though today we are running out of pristine areas to pollute, our throw-away society continues to be strongly influenced by our consumerism and excessive disposal of short-lived items.

POPULATION GROWTH

A contributing factor to degradation of the world's environment is overpopulation. How serious is the impact of overpopulation on Earth's environment? With our population increasing rapidly, pollution is a problem of increasing proportions. To gain perspective on the overpopulation problem, let's take a look at the record. From about 2 billion in 1960 and around 3 billion in 1995, the world's population has rapidly grown to its current level of approximately 7.5 billion—and counting. The world's population increases by more than 80 to 90 million each year and is projected to reach 10 billion by the year 2050, unless significant increases in the use of birth control occur worldwide.

The opinion that population is the fundamental cause of environmental pollution is arguable. There are those, however, who hold that this opinion has merit. Garrett Harden, for example, writing in his article "Tragedy of the Commons" (Hardin, 1968), argued that we would not have large problems with air pollution and land degradation if there were not so many people. To illustrate his point, he used the example of a "commons"—a resource (such as air) owned by no one but utilized by many (a pasture, in the case of his example). He argued that, in a commons, there is no incentive to be conserving of resources, for he who is conserving "loses." He extended the analogy to people's right to have as many children as they wish (Hardin, 1986).

In contrast to Hardin's view, the biologist Barry Commoner (1971) proposed that, rather than blaming environmental pollution on too many people, the real root cause of our environmental pollution problems is the inappropriate use of technology. He suggested that if we used resources more efficiently and cleanly there would be no problems, even though today there are over 7 billion of us.

Whenever we discuss differing opinions on any topic it is not too long before we run across an even more extreme position than those previously encountered. In this discussion about population being a possible contributor to environmental pollution, one such extreme opinion was expressed by the noted economist Julian Simon, who suggested that there are not too many people and that the quality of life will only improve as the human population increases (Simon, 1980). He believed that our supply of resources is virtually infinite, by virtue of an infinite capacity to substitute one resource for another. Simon said that it was only human ingenuity that limited our use of available resources as substitutes for exhausted resources. Hence, he argued that our condition will only improve as population increases because there will be more clever people who will be able to arrive at innovative solutions.

Along with the rapidly increasing population growth is a trend associated with population pressure: *population concentrations*. These population concentrations tend to exacerbate the pollution problem by increasing the level of pollution and the accompanying environmental degradation—increased deforestation, desertification, and soil erosion. Not only do population concentrations increase pollution but they also change the nature of the pollutants by producing pollutants that become hazardous because of the sheer quantities involved, as is the case with all types of municipal wastes.

In recent decades, population concentrations within different regions of the world have demonstrated a certain dynamism—a trend toward increasingly rapid change. This problem is most apparent in developing countries, those that not only have rapid increases in overall population (compared to developed countries) but also have large populations that have been lured by economic opportunities to more congested areas. These congested areas typically are responsible for consuming more natural resources than rural areas and produce mountains of waste products. More waste is produced per capita in urban areas than in rural areas, and this waste is more hazardous. It places strains on a city's infrastructure by increasing demand on the city's ability to absorb and handle wastes. Pressure is also increased on the non-urban residents (the agrarian sector) to produce more food on less land, thus straining soil productivity and aggravating the agricultural pollution problem. The level of urbanization in developing countries increased at a rate of 4 to 1 as compared to the level of urbanization in developed countries from 1970 to 1995.

Another pollution-related problem associated with overpopulation and the unprecedented rush toward urbanization by developed and undeveloped countries can be seen in the differing views on the pollution problem itself. Many industrialized countries have experienced industrialization for more than a century and, more importantly, have also felt the effects of pollution for a longer period of time than undeveloped countries. Developed countries have been modifying their polluting activities for several years, working to clean up existing pollution. Developing countries, though, where populations are growing and economic resources are limited, are escalating the very activities that lead to pollution. Pollution and its effects take a back seat to more pressing concerns—namely, the daily struggle to survive. The problem, however, is more than attitudinal—it is not just a free-will expression of the view that survival is number one so pollution is not a concern. Historically, pollution problems have generally been exacerbated by lack of financial resources and other economic problems. One measure of the impact of the global population is the fraction of the basic energy supply of all terrestrial animals directly consumed, co-opted, or eliminated by human activity. By 1986, this figure had already reached 40% (Vitousek et al., 1986). This level of exploitation was expected to double as population growth meets expectations.

So, what is the bottom line on the impact of a growing population on environmental pollution (and the environment in general)? Using science and mathematics, we can resort to a well-known equation, $I = PAT$, to help us answer this question. The impact (I) of any population can be expressed as a product of three characteristics: the population's size (P), its affluence or per-capita consumption (A), and the environmental damage (T) inflicted by the technologies used to extract resources and supply each unit of consumption (Daily and Ehrlich, 1992). Thus, human impact on the environment is a function of the population size, the level of resource use, and the environmental impacts associated with obtaining and using those resources. This formulation suggests that no one factor alone is responsible for our environmental problems. The relative important of the various factors will differ depending on the particular problem (Daily and Ehrlich, 1992).

DEVELOPMENT

Increasing worldwide population without a corresponding growth in development is virtually impossible—although the development is not always as we would envision it. As a case in point, consider the following comment by Reid et al. (1988, p. 1): "The Third World is littered with the rusting good intentions of projects that did not achieve social and economic success; environmental problems are now building even more impressive monuments to failure in the form of sediment-choked reservoirs and desertified landscapes." One thing is certain: Economic development cannot proceed without natural resources. The environmental degradation problem develops when natural resources are mismanaged, misused, wasted, and then exhausted. When this occurs, development leads to degradation—not only of the economic well-being of the inhabitants but of the environment, as well. Soil, water, and air are all, in one way or another, degraded.

Case Study 3.2. Transnational Corporations and Environmental Pollution

Transnational corporations drive the global economy and marketplace. These massive corporations, while providing the monetary base for industry, mining, distribution, technical knowledge, agriculture, and trade, are also heavily involved in most of the world's serious environmental crises. Considering the record of corporate-generated pollution problems in the United States and what environmentalists have had to do to prevent contamination, pollution, and ecological abuse, this single issue, with its potential thousands of incarnations, may be the biggest environmental problem of the new century.

Globalization expands environmentally hazardous activities around the world. Corporations commonly shift industrial practices that draw heavy environmental focus in the United States to Third World countries, dumping into these environments the wastes they are prohibited from releasing into their own country's environment. International trade and investment undermine environmentalists' attempts to curb abuse; cases supported in the United States can be overturned by global organizations for financial reasons. Global economics and industry have helped turn environmental pollution into a global problem—one that must necessarily be solved globally as well. Environmentalists will not be able to fight this battle alone. A global community, with members as diverse as scientists, artists, unions, elected officials, lawyers, consumers, and environmental activists, as well as the everyday people in the affected countries, must work to solve this issue across borders and divisions, both physical and social ones (Karliner, 1998).

Development and Soil Degradation

Soil degradation takes on many forms. Serious soil erosion, which commonly occurs in most of the world's important agricultural regions (from, for example, the overgrazing of animals, planting of a monoculture, row cropping, tilling or plowing, crop removal, and land-use conversion), is one form of degradation. Another form, just as serious as erosion, develops from our waste disposal practices. In the past, throw-away societies were able to dispose of unwanted materials and wastes with little

DID YOU KNOW?

The primary reasons for desertification are overgrazing, overcultivation, increased fire frequency, water impoundment, deforestation, overdrafting of groundwater, increased soil salinity, and global climate change (Wilson, 2001).

DID YOU KNOW?

Everything must go somewhere (Commoner, 1971). There is no "waste" in nature and there is no "away" to which things can be thrown.

impact on the environment. Most of the waste products of the past were biodegradable, and Earth's natural systems were able to self-purify environmental mediums, including soil to an extent. The problem today is that we are introducing thousands of substances into our environment that are not biodegradable; instead, they are quite persistent and hang around for a very long time.

Development and Freshwater Degradation

Poor management, lack of adequate conservation, pollution, and rapid local increases in demand create localized shortages of potable water worldwide. In developing nations, the problem is even worse; only about half of the people have access to safe drinking water. In the Western world, we have come to believe that the waterborne intestinal diseases that killed so many in the past are a problem of the past. This is not the case, however. In developing nations, an estimated 10 million deaths each year result from waterborne intestinal diseases. Even in the United States, recent localized outbreaks of illness and death from *Cryptosporidium*- and *Escherichia coli*-contaminated water supplies have forced communities to recognize that we all are at risk at times. These problems are not limited to developing nations. Surface and underground water supplies in industrial nations are being polluted by industrial and municipal wastes and by surface runoff from urban and agricultural areas. Heavy demands for water by industry, agriculture, and municipalities are rapidly depleting groundwater supplies.

Development and Atmospheric Air Degradation

We have all read news accounts about El Niño, El Niña, global climate change due to global warming, the greenhouse effect, acid rain, and damage to the ozone layer. These terms have become part of our common vocabulary; however, no consensus on what these issues will really mean to us has yet been reached. Think about two typical opinions usually voiced during arguments related to atmospheric degradation. One side argues that "the sky is falling" or "the world as we know it is doomed by pollution" or uses some other scare tactic to grab our attention and to provide lead-in to some political statement. The other side disputes the doom-and-gloom reports and states that all such statements are simply hyperbole and worse—that the real truth of the matter is that our environment is doing just fine, thank you very much. What is the truth? Are we destroying our environment? Or not? We briefly discuss the effects of global pollution in the next section.

POLLUTION AND GLOBAL ENVIRONMENTAL DEGRADATION

The truth lies somewhere in the middle, of course. We are affecting our environment—of this there is and can be little doubt. Doomed? Not exactly. Every problem has a solution. What we need is the motivation to find solutions to environmental degradation problems and then apply them on a global scale. Sounds simple enough, doesn't it? A piece of cake. It's not rocket science; we simply need to do it—do whatever it is that is needed to prevent pollution and protect the global environment. Again, simply, we need to do something.

In response to the alarmists—the producers of needless warnings—we warn about shooting from the hip. Easy, feel-good science (vs. real science) and bandage solutions are not the answer. We should be wary of the heavily inflated pronouncements of gloom and doom as well as proponents of the "nothing's wrong" camp, but we should also think twice about any quick fixes we may be tempted to implement to take care of the problem. Too often quick fixes simply slap a coat of paint over the layers of rust—allowing us to walk away with the warm fuzzy glow of accomplishment but without correcting the underlying problems. All remediation or mitigation should be accomplished based on the sound principles of science and an ounce of common sense.

Extremists, who in the past have sounded the warning calls of environmental degradation so stridently (even to the point of spiking trees, monkey-wrenching equipment, or burning the forest to the ground), may inadvertently create problems in addition to serving the useful purpose of drawing national attention to environmental problems. Informed practitioners of science learn to quiet the strident and radical alarmist by simply listening to their views and then ignoring them completely, quelling conflict or confrontation. These perceptive people of science have found the magic off switch; when you ignore the argument, there is no argument.

The alarmists are correct when they state that humankind and their practices are adversely affecting our environment. You don't need an Einstein mentality to see the proverbial writing on the wall. Every day, many toxic gases and fine particles enter the air we breathe and pose hazards to our health; some of these air pollutants cause cancer, genetic defects, and respiratory disease, in addition to exacerbating existing medical problems such as heart and lung disease.

Gaseous chemical substances such as nitrogen and sulfur oxides, ozone, and other air pollutants from fossil fuels inflict damage in many countries throughout the world. Ozone and acids of nitrogen and sulfur are damaging forests, crops, soils, lakes, streams, coastal waters, and manmade structures.

The Earth's protective ozone layer is being depleted by chlorofluorocarbons (CFCs) and other pollutants. In some regions, this depletion is beginning to increase the amount of harmful ultraviolet (UV) radiation that reaches the Earth's surface which can cause skin cancers and cataracts, damage immune systems, disrupt marine food chains, reduce crop yields, and cause significant climate change.

The amount of carbon dioxide entering the Earth's atmosphere is increasing. Combustion of fossil fuels is the primary culprit, but other heat-absorbing atmospheric gases are raising global temperatures. This, in turn, could alter weather patterns, worsen storms, disrupt agriculture, and destroy natural systems. Another problem with global warming is sea-level rise. Glacier and ice-cap melting may release large quantities of water that could lead to the flooding of many low-lying regions.

These changes have become so widespread, and the individual pieces of the problem so complex and interwoven, that the only way to approach the problem is on a global scale. Some sort of accord is needed to uniformly deal with these issues in both industrial and developing nations; otherwise, solving the problem will only be postponed, increasing the risk to all.

SO, WHAT IS THE ANSWER?

Awareness is the answer—or at least a good place to start. One thing is certain: We cannot live without soil, water, and air. Likewise, we cannot live if these media are polluted beyond use. We must take steps to ensure that we have a future to look forward to. Consider this quote on the subject of the future (Richardson, 1982): "When it comes to the future, there are three kinds of people: those who let it happen, those who make it happen, and those who wonder what happened." When it comes to pollution and its impact on the future and on people, this text is designed to provide the information required by the reader to be one of those who make it happen.

DID YOU KNOW?

The costs of pollution to society are of two kinds: the costs that arise if *no* action is taken to address pollution and the costs that arise if action *is* taken (Myers, 1998). The costs that arise if *no* action is taken are generally costs resulting from the effects of pollution on human health and the environment. The costs that arise if action *is* taken are those resulting from efforts made to reduce or eliminate the pollution source.

DISCUSSION QUESTIONS

1. Discuss pollution as both a local and a global problem.
2. Discuss the causal factors for global pollution problems.
3. Why do pollution issues require worldwide cooperation and planning to combat?
4. Discuss the most prevalent problems of pollution in industrial societies.
5. Discuss the problems of pollution prevalent in developing nations.
6. Discuss the problems that Third World countries face from pollution.
7. What environmental problems appear on a global scale? Why?
8. What are the long-term effects of population growth on pollution?
9. What does development mean in terms of environmental pollution?
10. What is the frontier mentality?

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4 Sources of Pollution

In the end we will conserve only what we love; we will love only what we understand; we will understand only what we are taught.

—Baba Dioum, forestry engineer

The means resorted to by a large number of citizens to get rid of their garbage and avoid paying for its collection would be very amusing were in not such a menace to public health. Some burn it, while others wrap it up in paper and carry it on their way to work and drop in when unobserved, or throw it into vacant lots or into the river.

—Boston Sanitary Committee (1893)

A HISTORICAL PERSPECTIVE[*]

The time is 15,543 BC. A large natural cave is set deep under a solid outcropping. The colossal sheet of ice is in retreat, and a small steady stream of meltwater courses almost in a straight line past one side of the cave down toward that valley where it will join and feed the river.

On the other side is a sloping field of young grass, brush, and flowers. Up close, we see the stark remnants of the terminal moraine that formed this abrupt slope. However, a closer look reveals a dark heap at the base of the slope—a heap of trash: skin, sinew, bone, decaying animal corpses, burned remnants of past hunts and feasts. We know only too well the refuse, filth, and discards that people leave behind as their foulest signature; somebody, maybe many people, must live close by. Where? Of course—in the cave. Let's take a look inside (Figure 4.1).

We wander up to the huge hole in the rock that forms the mouth of the cave. We tread carefully so as not to disturb (startle, frighten, … anger) the occupants. Remember, we're talking about cavemen here. No language in common, no culture in common. Could we have *anything* in common with such primitive people? If each of us could momentarily confront each other and catch the other's gaze, which of us, caveman (troglodyte) or modern man (spelunker), would be judged as strange looking, uncivilized, dangerous? As the Abominable Snowman, Yeti, or Bigfoot (Sasquatch)? Ah, relax! All is quiet on this day. With no overt threat present, curiosity overcomes caution, and we walk right into the mouth of the cave.

Something reaches out and grabs us—no, not a caveman, but a stench too horrible to describe. With our fingers clamped tightly to our noses, we move on, too interested despite the reek to retreat. The walls of the cave are covered with black soot. A pit near the cave wall is under attack by millions of flies and other insects and provides much of the stench—the latrine. A heap of detritus similar to the dump outside contributes the rest of the reek. That this cave is abandoned dawns on us. We have no doubt as to why. The largest byproduct of mankind has taken over—the cave is a garbage dump.

Outside, a few hundred feet from the smelly cave and within sight of the garbage heap, we stop to contemplate what we've seen. Seventeen thousand years from now, archeologists will find this cave and explore it thoroughly, learning information that will give us insights into the world of these people. But the remains the archaeologists will find will be altered by 17,000 years of history. The picture they see will be incomplete, scattered by the natural interferences of life, giving mystery to the short and brutal lives of our ancestors.

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[*] This section is adapted from Spellman, F.R. and Whiting, N.E., *Environmental Science and Technology: Concepts and Applications*, 2nd ed., Government Institutes, Rockville, MD, 2006.

FIGURE 4.1 The cave. (Illustration by F.R. Spellman and Kathern Welsh.)

As different as their life was, there are some similarities to the present. We foul our environment in the same ways and in more ways. Cavemen, however, had a huge advantage over modern humans in that respect. When their living quarters became too foul for comfort, they could pick up and move on. A fresh site was always just around the next bend in the river. The pollution they created was (eventually) completely naturally biodegradable; in a few years, this cave could and would house humans again.

Although we have our similarities with those far-off noble ancestors, one stark difference is plain: Modern humans cannot destroy and pollute our environment with impunity. We can no longer simply pick up stakes and move on. What we do to our environment has ramifications on a scale that we cannot ignore or avoid or move away from.

INTRODUCTION

Earlier, we asked the question "Could we have *anything* in common with such primitive people?" Of course we do; the roots of our culture are deep in this ancient past. From the description of the cave's condition, one similarity should be obvious to all of us: We are all members of the same throw-away society. When we do not want something any longer, we simply trash it, waste it, discard it, throw it away … sometimes under our very feet. The difference in methods is a matter of scale and perspective.

It was suggested previously that pollution is an issue of judgment—what is pollution to one person may not be pollution to another. For example, consider two people visiting a stream with a massive fish kill floating down the stream belly-up. One person may see only dead fish; that might be as far as this person's thought processes and reactions go. The other person, viewing the same dead fish, may comprehend the true scope of the pollution behind the fish kill.

One thing is certain, however, as the scene in the cave clearly demonstrates: We all share some judgments about pollution. When a substance, a material, a rotting organic mess, a pollutant reaches out and grabs our attention, few of us would have difficulty in agreeing that it is offensive to us. This is the real essence of pollution and pollutants: When it offends us, it is pollution. Let's take a closer look at what we saw in the cave. Beyond the fact that the cave was an indoor-air-quality specialist's worst nightmare (e.g., soot and air pollution from too many cave fires), the cave was extremely offensive for other reasons. First of all was the stench. Human beings will voluntarily put up with many unpleasant situations, but disgusting, overwhelming noxious odors are not one of them.

Beyond being disgusting primarily because of its odor, there was more—the in-cave latrine, for example. The question you might be asking yourself, beyond the odor, is why would primitive humans foul their living space by defecating in the same place where they lived? Actually, the answer is quite simple and more a matter of self-preservation than anything else. Picture this: You wake up in the middle of the night and you have the urgent, pressing need to relieve yourself. You have two simple choices—you can do your business right there in the relative warmth and safety of the cave, or you can step outside—outside into the cold, cruel environment beyond the confines of the cave. Outside? Into the world where *Smilodon* (saber-toothed tiger) roamed? *Smilodon* was present at the time primitive people occupied this cave and was one of the most ferocious bloodsucking, meat-eating animals of this period or any other time. Imagine an attack by its two powerful and efficient elongated scimitar-like canine teeth in a muscle-bound mouth open like an all-consuming Venus flytrap from hell. *Smilodon* stabbed, tore, and ripped the flesh to disable its victims, then consumed them, body, blood, entrails, and all. *Smilodon* was not the only risk out there, though—tenacious, ferocious cats, bears, and for-real monsters like *Panthera spelaea* (the cave lion, bigger than today's lion) roamed the land at that time. Thus, when nature called, our cave dwellers had to ask themselves a question: Do I feel lucky? No, sir. Unless they possessed a death wish, they chose the warmth and safety of the cave and its accompanying malodorous ambiance every time. Wouldn't you? The presence of "night soil" might make more sense to you now, but you still might ask, "Okay, I understand the indoor latrine, but what about all the garbage—the skins, sinews, bones, decaying corpses, burned remnants of past hunts and feasts? Why would our primitive ancestors put up living with such items—disgusting, filthy waste?"

The answer confounds us; there is no easy answer for this one, only speculation. Again, remember that pollution is a judgment. Maybe primitive humans did not consider trash to be a pollutant or pollution. Hunter societies tend to make more use of all the parts of their kill than we might imagine. Our reaction to the cave is relative to our own experience. We know that farmers become accustomed to manure smells that offend city dwellers, for example. Modern standards of cleanliness are just that—modern—and indoor plumbing and water supply are the chief reasons for our standards of cleanliness. Also, remember that when the cave became so offensive that primitive humans could no longer handle it they simply picked up their possessions and moved on to another cave. We do not know this for sure, of course, but we do know that when archeologists excavate such sites they find remnants of such items.

Throughout history, a common attitude was, "I don't want it any longer. Take it down to the river and dump it." As mentioned, this throwaway tendency has been referred to as the *frontier mentality*: We can throw anything away out here in the frontier (the prairie, ocean, mountains, outer space, …). There is so much space that this piece of trash placed in the vast, endless prairie won't hurt a thing. It's like urinating in the ocean! This line of thought, of course, ignores the effect of accumulation, which inexorably catches up with all that space eventually.

Our throwaway society does whatever is necessary to make our lives better, more tenable, more comfortable. The problem is that the world we live in is not an endless prairie. We simply cannot throw away, discard, dump, dispose, hide, or ignore the trash that we produce any longer. Instead,

DID YOU KNOW?

During the 19th century, visitors described New York City as a "nasal disaster, where some streets smell like bad eggs dissolved in ammonia."

we must recognize pollutants for what they really are—byproducts of civilization that must be properly disposed of, recycled, or not produced in the first place. If pollution is a judgment, how do we come to a consensus on what needs our attention and what doesn't?

The logical question now is what is a pollutant? A pollutant is any chemical substance or physical agent (including heat, sound, and electromagnetic radiation) introduced to the soil, air, or water in an amount that threatens human health, wildlife, plants, or the orderly functioning or human enjoyment of any aspect of the environment. Where do pollutants come from? The answer to this question is what this chapter is all about. As we discuss pollutant sources, keep in mind a statement made by Dorothy L. Sayers in 1941 on the trash–waste–pollution–pollutants issue—the obvious topic of this text: "A society in which consumption has to be artificially stimulated in order to keep production going is a society founded on trash and waste, and such a society is a house built upon sand" (Sayers, 1974, p. 64).

NATURAL POLLUTANTS

When the term "pollutant" is used, certain images often form in people's minds, dependent upon their experiences. To some, the image of a pollutant could be a spilled organic chemical (e.g., oil, PCBs, pesticides), an inorganic chemical (e.g., salt, nitrate, metals), an acid (e.g., sulfuric acid, nitric acid, hydrochloric acid), a physical pollutant (e.g., soil, trash), radiological pollutants (e.g., radon, radium, uranium), or biological pollutants (e.g., pathogenic microorganisms) (see Figure 4.2).

Differentiating pollutants from one another on the basis of whether a particular pollutant is *organic* or *inorganic* is somewhat difficult. The term "organic" is commonly used to refer to what is considered natural by individuals outside scientific circles—organic produce, for example, is produce grown without artificial fertilizers or pesticides. When we state that a chemical is organic, however, what we are really saying is that it contains at least one carbon atom (though typically more). The term "natural" comes into play when speaking about organic chemicals simply because organic chemicals are synthesized naturally by animals, microorganisms, and plants. Inorganic chemicals differ from organic chemicals simply because inorganic chemicals do not contain carbon. A common example of inorganic pollutants is the synthetic plant nutrients found in fertilizers. The best known acid pollutants are nitric acid and sulfuric acid (acids commonly found in acid rain).

Physical pollutants consist primarily of solid materials found in inappropriate locations. Trash sitting in a vacant lot is an example of a physical pollutant. Soil carried in stormwater runoff from city streets, tarmac, construction sites, and agricultural fields is another example. Other physical pollutants (not commonly recognized) come from thermal sources, such as high-temperature water released from industrial plants.

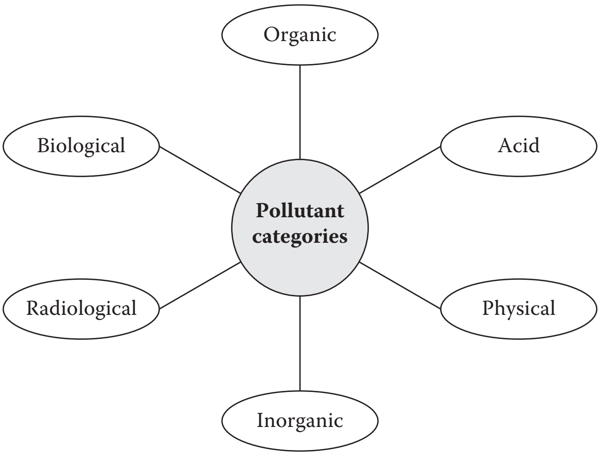


FIGURE 4.2 Pollution categories.

Radioactive chemicals found naturally in rocks, water, and soil are radioactive pollutants. Two of the better known radioactive elements are radon (a radioactive gas) and radium, both of which occur in nature. Human-generated (anthropogenic) sources of radioactive pollutants are certain hazardous waste sites (radioactive waste storage sites, for example).

Biological pollutants consist of pathogenic microorganisms (viruses, protozoa, fungi, worms, and infectious bacteria). Soil, water, and air (the focus of this text) usually contain microorganisms, some of which can be pathogenic (disease causing). Microorganisms do not have to be alive to become biological pollutants. Dead microorganisms and parts of organisms (e.g., insects) can also pollute air, water, and, to a lesser extent, soil.

What does all of this have to do with natural pollutants? Many of the categories shown in Figure 4.2 are comprised of natural pollutants. Organic pollutants and radioactive pollutants, for example, are natural pollutants. Other common natural pollutants may not be obvious and are ones we do not often think about, so we should talk about a few of these before we present a proper, balanced explanation or judgment of what pollution is, what a pollutant is, and what the sources of pollutants are.

In light of this, consider the following three natural pollutants: natural human waste products and waste products produced by other living organisms, a fallen leaf that pollutes, and a metal-laden rock (part of the Earth's crust) that pollutes. Humans and other living organisms naturally produce wastes, some of which can be categorized as pollutants. For now, let's focus on human waste products. Humans produce waste products each and every time they breathe. Each breath of air taken into the human respiratory system is chemically changed somewhat while it performs its vital function and is eventually exhaled into the environment. That exhaled air may be considered a nonpollutant type of waste product. On almost a continuous basis, human beings slough off dead skin cells and hair follicles, which represent another type of nonpollutant waste (although, if someone else's shed hair touches your clothes or skin, you may have a different view—you may feel that you have been contaminated, or polluted). Human-produced natural pollution has another manifestation, one that we are all familiar with—the production of human feces, a waste product. Human waste is a pollutant in many cases, of course, because of the presence of pathogenic microorganisms such as *Escherichia coli* (*E. coli*) and others that can contaminate our water supply, our drinking water. As a matter of fact, the major source of pathogenic bacteria is human feces, which make up approximately 34% of all feces produced on the planet.

Next, let's shift our focus to leaf pollution. Do we mean that pile of leaves covering the lawn in front of the house? That same blanket of dead leaves that is such a pain in the neck to rake up and dispose of? Or those leaves that fall on top of the car or boat or clog gutters or make their way into the internal workings of outdoor air conditioning units and eventually cause them to fail? No, not exactly. Remember, pollution and pollutants are a matter of judgment. The situations just described probably qualify more as representing nuisance items than pollutants to most people.

The type of pollution caused by fallen leaves is water pollution—stream pollution, in particular. Consider a local stream you are familiar with, one that courses through a local forested area. During spring and summer, when you walk along the stream bank surrounded by trees of myriad types with their corresponding abundance of leaves, you probably have no difficulty in recognizing Nature's architectural genius in designing them. You might, however, have difficulty in comprehending how those leaves—the palmately compound leaf of the buckeye, the pinnately compound leaf of the black walnut, the lobed leaves of a tulip poplar, the simple leaves of the dogwood, the palmately veined leaves of the maple, the globe-shaped succulent leaves of the string-of-pearls, the lobed leaves of oak trees—could possibly pollute the stream. But they can and they do.

Obviously, while the leaves remain on the trees, they pose little, if any, threat of pollution to the stream; however, during leaf fall in autumn, the dead, fallen leaves pollute the stream. Leaves are organic and biodegradable. When they fall from the tree and into the stream and remain in the stream during the degradation process, they remove dissolved oxygen (DO) by increasing biochemical oxygen demand (BOD). BOD is a widely used parameter of organic pollution applied to both wastewater and surface water; it involves measurement of the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter. Simply put, when microorganisms work to degrade the leaves in the stream, they create BOD, which in turn reduces the DO content of the stream water. The DO content can fall from its normal healthy level of approximately 8 ppm (parts per million, or ppm, is analogous to the amount of water in a full shot glass of water compared to the water in a full swimming pool) to levels as low as 2 ppm or lower (unhealthy level). At a DO level of 2 ppm or lower, the stream is considered polluted; it is unable to provide enough DO to support higher aquatic life forms.

Along with reducing dissolved oxygen content and in turn making a water body polluted, organic debris such as tree bark, branches, and trees can pollute water bodies in other ways. Consider, for example, Case Study 4.1, former U.S. Senate chaplain Peter Marshall's eloquent account of the "Keeper of the Spring," a quiet forest dweller who lived high above an Austrian village along the eastern slope of the Alps .

Case Study 4.1. Keeper of the Spring

The old gentleman had been hired many years earlier by a young town councilman to clear away the debris from the pools of water up in the mountain crevices that fed the lovely spring flowing through their town (Figure 4.3). With faithful, silent regularity, he patrolled the hills, removed the leaves and branches, and wiped away the silt that would otherwise have choked and contaminated the fresh flow of water. The village soon became a popular attraction for vacationers. Graceful swans floated along the crystal clear spring, the mill wheels of various businesses located near the water turned day and night, farmlands were naturally irrigated, and the view from restaurants was picturesque beyond description.

Years passed. One evening the town council met for its semiannual meeting. As they reviewed the budget, one man's eye caught the salary figure being paid the obscure keeper of the spring. Said the keeper of the purse, "Who is the old man? Why do we keep him on year after year? No

FIGURE 4.3 The spring. (Illustration by F.R. Spellman and Kathern Welsh.)

one ever sees him. For all we know, the strange ranger of the hills is doing us no good. He isn't necessary any longer." By a unanimous vote, they dispensed with the old man's services. For several weeks, nothing changed. By early autumn, the trees began to shed their leaves. Small branches snapped off and fell into the pools, hindering the rushing flow of sparkling water. One afternoon someone noticed a slight yellowish-brown tint in the spring. A few days later, the water was much darker. Within another week, a slimy film covered sections of the water along the banks, and a foul odor was soon detected. The mill wheels moved more slowly, some finally ground to a halt. Swans left, as did the tourists. Clammy fingers of disease and sickness reached deeply into the village.

The embarrassed council called a special meeting. Realizing their gross error in judgment, they rehired the old keeper of the spring, and within a few weeks the veritable river of life began to clear up. The wheels started to turn, and new life returned to the hamlet in the Alps.

It is important to point out that while the presence of organic debris in streams can be detrimental to the health of the stream, the stream's acquisition of organic debris is a double-edged sword, a Jekyll and Hyde situation. This situation is clearly demonstrated in Case Study 4.2, which points to the good aspects of leaf-fall into streams.

Case Study 4.2. Leaves in the Stream

Autumn leaves entering streams are nutrition poor because trees absorb most of the sugars and amino acids (nutrients) that were present in the green leaves (Suberkropp et al., 1978). Leaves falling into streams may be transported short distances but usually are caught by structures in the streambed and form leaf packs. These leaf packs are then processed in place by components of the stream communities in a series of well-documented steps (see Figure 4.4) (Peterson and Cummins, 1974).

Within 24 to 48 hours of the leaf entering a stream, many of the remaining nutrients in leaves leach into the water. After leaching, leaves are composed mostly of structural materials such as nondigestible cellulose and lignin. Within a few days, fungi (especially Hyphomycetes), protozoa, and bacteria process the leaves by microbial processing (see Figure 4.2) (Barlocher and Kendrick, 1975). Two weeks later, microbial conditioning leads to structural softening of the leaf and, among some species, fragmentation. Reduction in particle size from whole leaves, coarse particulate organic matter (CPOM), to fine particulate organic matter (FPOM) is accomplished mainly through the feeding activities of a variety of aquatic invertebrates collectively known as *shredders* (Cummins, 1974). Shredders (stoneflies, for example) help to produce fragments shredded from leaves but not ingested and fecal pellets, which reduce the particle size of organic matter. The particles are then collected (by mayflies, for example) and serve as a food

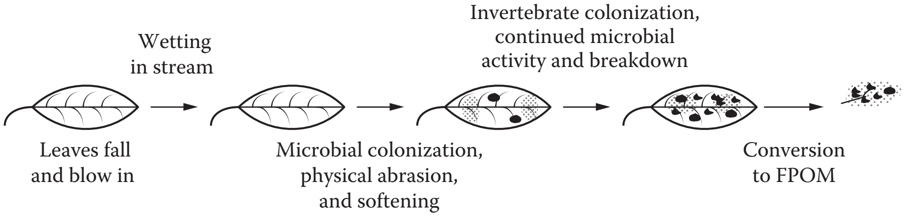


FIGURE 4.4 The processing or "conditioning" sequence for a medium-fast deciduous tree leaf in a temperate stream. (Adapted from Allen, J.D., *Stream Ecology: Structure and Functions of Running Waters*, Chapman & Hall, London, 1996, p. 114.)

resource for a variety of micro- and macroconsumers. *Collectors* eat what they want and send even smaller fragments downstream. These tiny fragments may be filtered out of the water by a true fly larva (i.e., a *filterer*). Leaves may also be fragmented by a combination of microbial activity and physical factors such as current and abrasion (Benfield et al., 1977).

Leaf-pack processing by all of the elements mentioned above (i.e., leaf species, microbial activity, physical and chemical features of the stream) is important; however, the most important point is that these integrated ecosystem processes convert whole leaves into fine particles that are then distributed downstream and used as an energy source by various consumers (Spellman, 1996).

Finally, metal- or mineral-laden soils or rocks (such as soils containing mercury) are sources of pollution. Mercury-laden soils degas volatile mercury to the atmosphere, where it is eventually washed out into water bodies. While in the water, bacteria work to transform a portion to methylmercury, which is taken up by aquatic plants and certain aquatic animals. These are eaten by successively higher orders of animals on the food chain, where the mercury builds up to progressively higher levels in animal tissues. More than 90% of human mercury exposure results from consumption of mercury-contaminated fish. Some might consider this type of exposure to be *poisoning* rather than polluting; however, poisoning is clearly a serious form of pollution. Minamata Bay in Tokyo, for example, is contaminated by mercury, which can lead to methylmercury poisoning in humans.

POLLUTANT TERMINOLOGY

So far, we have discussed the sources of pollutants and basic or fundamental pollution terms. In this section, we discuss the term *pollutant* (any substance introduced into soil, water, or air that adversely affects the usefulness of the environmental medium) and list other terms used to categorize pollutants (see Figure 4.5), providing a brief description of each.

Figure 4.5 shows that pollutants have many different but related names. Many of the following definitions were provided by the U.S. Environmental Protection Agency (USEPA, 1992). Others are from the Clean Water Act (CWA), Section 502; from the Code of Federal Regulations (CFR), Part 40, Sections 21.2, 58, 122.2, 230.3, 257.3.3, 233.3, and 401.11-91; and from the Clean Air Act (CAA), Section 302, 42 USC 7602-91. Another source is Lawrence Berkeley Laboratory's *Instrumentation for Environmental Monitoring* (LBL, 1973). The final source is the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), a regulation that deals with past hazardous materials disposal activities and occurrences. CERCLA gives the federal government authority to undertake cleanup of dangerous inactive disposal sites and emergency spill situations under a National Contingency Plan. CERCLA authorizes study investigations, testing, and disposal site monitoring, as well as implementation of remedial actions. Financial grants for such actions are provided under the Superfund program.

POLLUTANT-RELATED TERMS DEFINED

- *Air pollutants*—Any pollutant or combination of pollutants, including any physical, chemical, biological, radioactive substance, or matter, which is emitted into or otherwise enters the ambient air; any substance in air that could, if in high enough concentrations, harm humans, other animals, vegetation, or material. Pollutants may include almost any natural or artificial composition or matter capable of being airborne. They may be in the form of solid particles, liquid droplets, gases, or in combinations of these forms.
- *Compatible pollutants*—Pollutants that can be adequately treated in publicly owned treatment works without upsetting the treatment process.

FIGURE 4.5 Pollution types and sources.

- *Conservative pollutants*—A pollutant that does not decay, is persistent, and is not biodegradable (e.g., heavy metals and pesticides).
- *Conventional pollutants*—A statutorily listed pollutant understood by scientists; these pollutants include organic waste, acid, bacteria, viruses, oil and grease, heat, nutrients, and sediments.
- *Criteria pollutants*—The 1970 amendments to the Clean Air Act required the USEPA to set National Ambient Air Quality Standards for certain pollutants known to be hazardous to human health. The USEPA has identified and set standards to protect human health and welfare for six pollutants: ozone, carbon monoxide, total suspended particulates, sulfur dioxide, lead, and nitrogen oxide. The term "criteria pollutant" derives from the requirement that the USEPA must describe the characteristics and potential health and welfare effects of these pollutants. Standards are set or revised on the basis of these criteria.
- *Critical pollutants*—The pollutant with the highest sub-index during the reporting period.
- *Designated pollutants*—Any air pollutant, emissions of which are subject to a standard of performance for new stationary sources, but for which air quality criteria have not been issued and which are not included on a list published under 40 CFR 60.21–91; also, an air

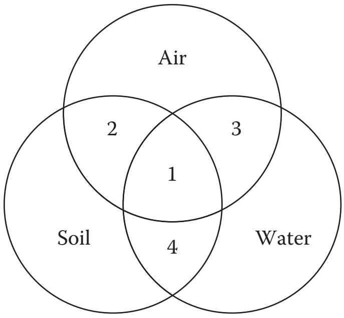
pollutant that is neither a criteria nor hazardous pollutant as described in the Clean Air Act but for which new source performance standards exist. The Clean Air Act requires states to control these pollutants, which include acid mist, total reduced sulfur (TRS), and fluorides.

- *Hazardous air pollutants*—Air pollutants not covered by ambient air quality standards but which (as defined in the Clean Air Act) may reasonably be expected to cause or contribute to irreversible illness or death. Such pollutants include asbestos, beryllium, mercury, benzene, coke oven emissions, radionuclides, and vinylchloride. A list of hazardous air pollutants is provided in Section 112.b of the Clean Air Act.
- *Incompatible pollutants*—Pollutants that would cause harm to, would adversely affect the performance of, or would be inadequately treated in publicly owned sewage treatment works.
- *No discharge of pollutants*—No net increase of any parameters designated as pollutants, to the accuracy that can be determined from the designated analytical methods.
- *Noncontact cooling water pollutants*—Pollutants present in noncontact cooling waters.
- *Nonconventional pesticide pollutants*—All pesticide active ingredients that are not toxic pollutants under 40 CFR 401.15 or conventional pollutants under 40 CFR 401.16 and for which best available technology (BAT) and effluent limitations guidelines, New Source Performance Standards (NSPS), and pretreatment standards are established in this part.
- *Nonconventional pollutants*—(1) Any pollutant that is not statutorily listed or which is poorly understood by the scientific community; (2) parameters selected for consideration in performance standards that have not been previously designated as either conventional or toxic pollutants; (3) for the pesticide industry, parameters such as nonpriority pollutant pesticides, chemical oxygen demand (COD), ammonia, and manganese.
- *Noncriteria pollutants*—Any identified potential pollutants exclusive of criteria pollutants which may include (1) noncarcinogenic pollutants such as HCl and Cl; (2) suspect carcinogenic elements such as Be, As, Cd, Cr^{6+}, NI; and (3) organic carcinogens such as polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and polychlorinated biphenyls (PCBs).
- *Non-pass-through pollutants*—Pollutants that are biodegradable and do not pass through biological oxidation treatment systems.
- *Pass-through pollutants*—Pollutants that are not readily biodegradable and pass through biological oxidation treatment systems.
- *Persistent pollutants*—A pollutant that is not subject to decay, degradation, transformation, volatilization, hydrolysis, or photolysis.
- *Primary pollutants*—Pollutants emitted directly from a polluting stack; according to NATO-78/10, pollutants remaining in the form that they are in when emitted from the source.
- *Primary significance pollutants*—The pollutants recommended for regulation because of their deleterious effects on humans and the environment.
- *Priority pollutants*—(1) In the CWA, the over 100 pollutants listed in 40 CFR 423, Appendix A; (2) those pollutants listed under CWA Section 307(a).
- *Process wastewater pollutants*—Pollutants present in process wastewater.
- *Refractory pollutants*—Pollutants that resist treatment.
- *Secondary pollutants*—(1) Pollutants produced by the primary pollutants (directly emitted from a source); examples of secondary pollutants include ozone and organic nitrates, which are produced from primary pollutants such as nitrogen oxides and hydrocarbons by photochemical reactions. (2) A pollutant formed in the atmosphere by chemical changes taking place between primary pollutants and other substances present in the air.
- *Secondary significance pollutants*—Pollutants not recommended for regulation but specifically listed for consideration on a case-by-case basis for potential deleterious effects on humans and the environment.

- *Toxic air pollutants*—(1) The aggregate emissions of benzene, 1,3 butadiene, polycyclic organic matter (POM), and acetaldehyde and formaldehyde; (2) materials contaminating the environment that cause death, disease, or birth defects in organisms that ingest or absorb them. The quantities and length of exposure necessary to cause these effects can vary widely.
- *Toxic pollutants*—(1) Those pollutants or combinations of pollutants (including disease-causing agents) that, after discharge and upon exposure, ingestion, inhalation, or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will (on the basis of information available) cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions, or physical deformations in such organisms or their offspring; (2) toxic pollutants listed in CFR 401.15–92; (3) materials that cause death, disease, or birth defects in organisms that ingest or absorb them. The quantities and exposures necessary to cause these effects can vary widely.
- *Traditional pollutant parameters*—The pollutant parameters considered and used in the development of best practicable control technology (BPT) guidelines. These parameters include BOD, chemical oxygen demand (COD), total organic carbon (TOC), total suspended solids (TSS), and ammonia.

SOIL, WATER, AND AIR POLLUTION: THE INTERFACE

Pollutants that contaminate soil, water, and air are interrelated (see Figure 4.6). Because of these interrelationships, studying soil pollution without studying water pollution and air pollution is difficult. In the chapters that follow, we examine each medium separately, but you should keep in mind that the three environmental mediums are interrelated and, in a sense, are all part of a single problem: pollution. (Case Study 4.3 illustrates how a single source can pollute all three mediums.)



Key

1. *Acid rain:* Caused by air pollution. Damages both aquatic and terrestrial ecosystem.
2. *Incineration:* Incineration of waste products to conserve and protect land resources can cause air pollution problems.
3. *Air control system pollution:* Certain air pollution control systems such as “scrubbers” produce a flow of dirty water that can cause water pollution.
4. *Leachate production:* Leachate seeping through landfills can contaminate surface water and groundwater.

FIGURE 4.6 Environmental pollution problems pertaining to soil, water, and air quality are interrelated. (Adapted from Nathanson, J.A., *Basic Environmental Technology*, 5th ed., Prentice Hall, Upper Saddle River, NJ, 2007.)

Case Study 4.3. Problem Wastes—Tire Disposal

Since the invention of the automobile, what to do with worn-out tires has presented a significant disposal problem. America's love affair with cars means that hundreds of millions of tires are discarded every year. Stockpiles across the country store billions of worn-out tires. Some of these stockpiles are legal, others are not, but all present us with problems, including the risk of catastrophic fire and the creation of prime breeding habitats for mosquitoes, some varieties of which carry encephalitis (Maine DEP, 1994).

Tire fires have received national attention. Tire fires are particularly difficult to extinguish. Using water as an extinguishing agent can create an oily runoff, and burning tires emit toxic black smoke, resulting in pollution problems for air, surface, and groundwater supplies and the soil. Smothering the fire with dirt and sand appears to be the most cost-effective and efficient way to control burning tire stockpiles; however, sometimes more unusual problems occur with tire fires.

In 1996, a major road in Ilwaco, Washington, began to heat up, and 2 months later a major oil leak appeared that was the result of a massive underground fire. Although response teams immediately contained the oil, they were forced to allow the fire to smolder while they figured out how to even get to it (WHEN, 1998). Using scrap tires as subgrade road base is probably the most successful effort at recycling used tires, along with using shredded tires as supplemental fuel for modern, scrubber-equipped boilers; however, the potential for further episodes of burning roads, which could create contamination problems in all of our environmental media, means that the risks associated with the use of scrap tires are great. As more states enact legislation prohibiting the disposal of tires in landfills, reliance on recycling, stockpiling, and waste tire dumps will increase until we can properly manage, store, and process these wastes (PaDEP, 1998).

DISCUSSION QUESTIONS

1. Discuss anthropogenic practices as the ultimate pollution source.
2. Define and discuss natural pollutants. Describe how human activities may affect them.
3. Define and discuss general pollutants.
4. Discuss the problems and the current possible solutions related to tire disposal.

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Section II

Air

> Approximately 80% of our air pollution stems from hydrocarbons released by vegetation, so let's not go overboard in setting and enforcing tough emission standards from man-made sources.
>
> **—Ronald Reagan (1980)**

This statement by President Reagan allowed his critics to deride him for his ignorance of environmental issues. The truth? Check the research conducted in this area; it shows that Reagan was correct. However, do not tell the deriders this; they will never agree with you.

5 Air

Sun and Air

The air staggers under the sun, and heat morasses
Flutter the birds down; wind barely climbs the hills,
Saws thin and splinters among the roots of the grasses;

All air sickens, and falls into barn shadows, spills
Into hot hay and heat-hammered road dust, makes no sound,
Waiting the sun's siege out to collect its wills.

As a hound stretched sleeping will all on a sudden bound,
Air will rise all sinews, crack-crying, tear tether,
Plow sheets of powder high, heave sky from milling ground.

So sun and air, when these two goods war together,
Who else can tune day's face to a softest laugh,
Being sweet beat the world with a most wild weather,

Trample with light or blow all heaven blind with chaff.

—Richard Wilbur, American poet

There's so much pollution in the air now that if it weren't for our lungs there'd be no place to put it all.

—Robert Orben, American comedy writer

INTRODUCTION*

Do you ever think about atmospheric air? Unless you are an air scientist, an air technology specialist, or a practitioner of air science, probably not. The rest of us? No, not really. We usually only think about air, the air we breathe, when there is not enough of it to breathe or when it offends us. Air, like water and soil, is simply one of those things that are all around us. Air, water, and soil are everywhere and seemingly limitless. We breathe air, we drink water, we plant our crops in soil (and are sometimes interred in it). These things are just out there, all three of them—especially air, which literally enshrouds the planet we live on. On the average, we each need at least 30 pounds of air every day to live, but we need only about 3 pounds of water and less of food. A person can live about 5 weeks or so without food and about 5 days without water, but only 5 minutes without air. Why don't we give air a second or even a first thought? Normally, we don't—and this is somewhat surprising when we consider that if we take our air away then life ends. Simply, air is necessary for the survival of most life forms on Earth.

Maintaining air quality is important—important to the point of being vital to our very existence. A study published in *The New England Journal of Medicine* suggested that cleaner air might add 5 months to life, thus lending support to the importance of continuing to clean the air (Szabo, 2009). In this chapter and the next two chapters, we pay a lot of attention to air. We talk about the environmental problems and more—about air itself, air pollution (Chapter 6), and air pollution remediation technologies (Chapter 7).

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* Parts of this chapter are adapted from Spellman, F.R., *The Science of Air*, 2nd ed., CRC Press, Boca Raton, FL, 2009.

ALL ABOUT AIR

Any discussion about air has to begin with a discussion about the Earth's atmosphere. Since human life appeared on Earth, we have described the atmosphere in many different ways—often in ways that glorify its mysteriousness. More often, though, it is quite simply described as that mixture of gases that surrounds the Earth or as that envelope of gases that encapsulates the Earth. To put Earth's atmosphere in perspective, we can use the following popular analogy: If the Earth were the size of an apple, the atmosphere would be no thicker than the apple skin. Beyond the atmosphere (the skin) is an infinite expanse of space. The atmosphere plays a major role in the various cycles of nature (biogeochemical cycles), including the water cycle, carbon cycle, and nitrogen cycle. The temperature of the atmosphere decreases with increasing altitude, and the air pressure decreases exponentially. The density of air also decreases, but not drastically.

What is air? Air is a mixture of gases that constitutes the Earth's atmosphere. The approximate composition of dry air is, by volume at sea level, nitrogen (78%); oxygen (21%), which is necessary for life as we know it; argon (0.93%); and carbon dioxide (0.03%), together with very small amounts of numerous other constituents, including water vapor (see Table 5.1). The water vapor content is highly variable and depends on atmospheric conditions. Air is said to be pure when none of the minor constituents is present in sufficient concentration to be injurious to the health of human beings or animals, to damage vegetation, or to cause loss of amenity (e.g., through the presence of dirt, dust, or odors or by diminution of sunshine).

Our lives depend on a relatively thin layer of gases that are prevented from escaping by the pull of the Earth's gravity. Three-quarters of the atmosphere's mass lies below a height of 35,000 feet. As noted earlier, atmospheric pressure decreases with height in the atmosphere. The air at the top of Mt. Everest is only one-third as thick as at sea level. The weight of the atmosphere is 5.7×10^{15} tons, about one-millionth the weight of the Earth.

Where does air come from? Genesis 1:2 states that God separated the water environment into the atmosphere and surface waters on the second day of creation. Many scientists state that 4.6 billion years ago a cloud of dust and gases forged the Earth and also created a dense molten core enveloped in cosmic gases. This was the *proto-atmosphere* or *proto-air*, composed mainly of carbon dioxide, hydrogen, ammonia, and carbon monoxide, but it was not long before it was stripped away by a tremendous outburst of charged particles from the sun. As the outer crust of Earth began to solidify, a new atmosphere began to form from the gases outpouring from gigantic hot springs and volcanoes. This created an atmosphere of air composed of carbon dioxide, nitrogen oxides, hydrogen, sulfur dioxide, and water vapor. As the Earth cooled, water vapor condensed into highly acidic rainfall, which collected to form oceans and lakes.

TABLE 5.1
Composition of Air/Earth's Atmosphere

Gas	Chemical Symbol	Volume (%)
Nitrogen	N_2	78.08
Oxygen	O_2	20.94
Carbon dioxide	CO_2	0.03
Argon	Ar	0.093
Neon	Ne	0.0018
Helium	He	0.0005
Krypton	Kr	Trace
Xenon	Xe	Trace
Ozone	O_3	0.00006
Hydrogen	H_2	0.00005

For much of Earth's early existence (the first half), only trace amounts of free oxygen were present, but then green plants evolved in the oceans, and they began to add oxygen to the atmosphere as a waste gas. Eventually, oxygen increased to about 1% of the atmosphere and with time to its present 21%. How do we know for sure about the evolution of air on Earth? Are we guessing, using voodoo science? There is no guessing or voodoo involved in the historical geological record. Consider, for example, geological formations that are dated to 2 billion years ago. In these early sediments there is a clear and extensive band of red sediment (red-bed sediments), sands colored with oxidized (ferric) iron. Earlier, ferrous formations had been laid down showing no oxidation. But, there is more evidence. We can look at the time frame of 4.5 billion years ago, when carbon dioxide in the atmosphere was beginning to be lost in sediments. The vast amounts of carbon deposited in limestone, oil, and coal indicate that carbon dioxide concentrations must once have been many times greater than today, when it stands at only 0.03%. The first carbonated deposits appeared about 1.7 billion years ago, the first sulfate deposits about 1 billion years ago. The decreasing carbon dioxide was balanced by an increase in the nitrogen content of the air. The forms of *respiration* that exist advanced from fermentation 4 billion years ago to anaerobic photosynthesis 3 billion years ago to aerobic photosynthesis 1.5 billion years ago. The aerobic respiration that is so familiar today only began to appear about 500 million years ago.

Fast-forward to the present. The atmosphere itself continues to evolve, but human activities—with their highly polluting effects—have now taken over Nature's role in determining the changes.

CHARACTERISTICS AND PROPERTIES OF THE COMPONENTS OF AIR[*]

As pointed out earlier, air is a combination of component parts: gases and other matter (suspended minute liquid or particulate matter). In this section, we discuss each of these components.

Atmospheric Nitrogen

Nitrogen (N_2) makes up the major portion of the atmosphere (78.03% by volume, 75.5% by weight). It is a colorless, odorless, tasteless, nontoxic, and almost totally inert gas. Nitrogen is nonflammable, will not support combustion, and is not life supporting. Not life supporting? No, gaseous nitrogen is not. The obvious question is if gaseous nitrogen does not support life then what is it doing in our atmosphere and what good is it? Nitrogen is, in fact, good. Without nitrogen, we could not survive.

Nitrogen is part of Earth's atmosphere primarily because, over time, it has simply accumulated in the atmosphere and remained in place and in balance. This nitrogen accumulation process has occurred because, chemically, nitrogen is not very reactive. When released by any process, it tends not to recombine with other elements and accumulates in the atmosphere. This is a good thing, because we need nitrogen—not for breathing but for other life-sustaining processes.

Let's take a look at a couple of reasons why gaseous nitrogen is so important to us. Although nitrogen in its gaseous form is of little use to us, after oxygen, carbon, and hydrogen it is the most common element in living tissues. As a chief constituent of chlorophyll, amino acids, and nucleic acids (the building blocks of proteins, which are used as structural components in cells), nitrogen is essential to life. Nitrogen is dissolved in and carried by the blood. Nitrogen does not appear to undergo any chemical combining as it is carried throughout the body. Each time we breathe, the same amount of nitrogen is exhaled as is inhaled. Animals cannot use nitrogen directly but only when it is obtained by eating plant or animal tissues; plants obtain the nitrogen they need when it is in the form of inorganic compounds, principally nitrate and ammonium.

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[*] Much of the information pertaining to atmospheric gases that follows was adapted from *Handbook of Compressed Gases* (Compressed Gas Association, 1990), *Environmental Science and Technology: Concepts and Applications* (Spellman and Whiting, 2006), and *The Science of Air* (Spellman, 2008).

TABLE 5.2
Physical Properties of Nitrogen

Chemical formula	N_2
Molecular weight	28.01
Density of gas at 70°F	0.072 lb/ft^3
Specific gravity of gas at 70°F and 1 atm (air = 1)	0.967
Specific volume of gas at 70°F and 1 atm	13.89 ft^3
Boiling point at 1 atm	–320.4°F
Melting point at 1 atm	–345.8°F
Critical temperature	–232.4°F
Critical pressure	493 psia
Critical density	19.60 lb/ft^3
Latent heat of vaporization at boiling point	85.6 Btu/lb
Latent heat of fusion at melting point	11.1 Btu/lb

Gaseous nitrogen is converted to a form usable by plants (nitrate ions) chiefly through the process of nitrogen fixation via the *nitrogen cycle* (see Chapter 2, Figure 2.2), when aerial nitrogen is converted into nitrates mainly by microorganisms, bacteria, and blue–green algae. Lightning also converts some aerial nitrogen gas into forms that return to the Earth as nitrate ions in rainfall and other types of precipitation. Ammonia plays a major role in the nitrogen cycle. Excretion by animals and anaerobic decomposition of dead organic matter by bacteria produce ammonia. Ammonia, in turn, is converted by nitrification bacteria into nitrites and then into nitrates. This process is known as *nitrification*. Nitrification bacteria are aerobic. Bacteria that convert ammonia into nitrites are known as nitrite bacteria (*Nitrosococcus* and *Nitrosomonas*). Although nitrite is toxic to many plants, it usually does not accumulate in the soil. Instead, other bacteria (such as *Nitrobacter*) oxidize the nitrite to form nitrate (NO_3^-), the most common biologically usable form of nitrogen.

Nitrogen reenters the atmosphere through the action of denitrifying bacteria, which are found in nutrient-rich habitats such as marshes and swamps. These bacteria break down nitrates into nitrogen gas and nitrous oxide (N_2O), which then reenter the atmosphere. Nitrogen also reenters the atmosphere from exposed nitrate deposits and emissions from electric power plants, automobiles, and volcanoes.

Physical Properties of Nitrogen

The physical properties of nitrogen are provided in Table 5.2.

Uses for Nitrogen

In addition to being the preeminent (with regard to volume) component of Earth's atmosphere and an essential ingredient in sustaining life, nitrogen gas has many commercial and technical applications. As a gas, it is used to heat-treat primary metals, in the production of semiconductor electronic components, as a blanketing atmosphere (e.g., blanketing of oxygen-sensitive liquids and volatile liquid chemicals), to inhibit aerobic bacteria growth, and in the propulsion of liquids through canisters, cylinders, and pipelines.

Nitrogen Oxides

The six oxides of nitrogen are nitrous oxide (N_2O), nitric oxide (NO), dinitrogen trioxide (N_2O_3), nitrogen dioxide (NO_2), dinitrogen tetroxide (N_2O_4), and dinitrogen pentoxide (N_2O_5). Nitric oxide, nitrogen dioxide, and nitrogen tetroxide are fire gases. One or more of them is generated when certain nitrogenous organic compounds (polyurethane) burn. Nitric oxide is the product of incomplete combustion, whereas a mixture of nitrogen dioxide and nitrogen tetroxide is the product of complete combustion. The nitrogen oxides are usually collectively symbolized by the formula NO_x. The U.S. Environmental Protection Agency (USEPA), under the Clean Air Act (CAA), regulates the amount of nitrogen oxides that commercial and industrial facilities may emit to the atmosphere. The primary and secondary standards are the same: The annual concentration of nitrogen dioxide may not exceed 100 μg/m^3 (0.05 ppm). Much more will be said about primary and secondary air standards under CAA and nitrogen oxides later in the text.

ATMOSPHERIC OXYGEN

Oxygen (O_2; from Greek *oxys* for "acid" and *genes* for "forming") constitutes approximately a fifth (21% by volume and 23.2% by weight) of the air in Earth's atmosphere. Gaseous oxygen (O_2) is vital to life as we know it. On Earth, oxygen is the most abundant element. Most oxygen on Earth is not found in the free state but in combination with other elements as chemical compounds. Water and carbon dioxide are common examples of compounds that contain oxygen, but there are countless others. At ordinary temperatures, oxygen is a colorless, odorless, tasteless gas that supports not only life but also combustion. All elements except the inert gases combine directly with oxygen to form oxides; however, oxidation of different elements occurs over a wide range of temperatures. Oxygen is nonflammable but readily supports combustion. All materials that are flammable in air burn much more vigorously in oxygen. Some combustibles, such as oil and grease, burn with nearly explosive violence in oxygen if ignited.

Physical Properties of Oxygen

The physical properties of oxygen are provided in Table 5.3.

Uses for Oxygen

The major uses of oxygen stem from its life-sustaining and combustion-supporting properties. It also has many industrial applications (when used with other fuel gases such as acetylene), including metal cutting, welding, hardening, and scarfing.

Ozone: Just Another Form of Oxygen

Ozone (O_3) is a highly reactive pale-blue gas with a penetrating odor. Ozone is an allotropic modification of oxygen. An allotrope is a variation of an element that possesses a set of physical and chemical properties significantly different from the "normal" form of the element. Only a few elements have allotropic forms; oxygen, phosphorus, and sulfur are some of them. Ozone is just another form of oxygen. It is formed when the molecule of the stable form of oxygen (O_2) is split by ultraviolet (UV) radiation or electrical discharge. It has three instead of two atoms of oxygen per molecule;

TABLE 5.3
Physical Properties of Oxygen

Chemical formula	O_2
Molecular weight	31.9988
Freezing point	–361.12°F
Boiling point	–297.33°F
Heat of fusion	5.95 Btu/lb
Heat of vaporization	91.70 Btu/lb
Density of gas at boiling point	0.268 lb/ft^3
Density of gas at room temperature	0.081 lb/ft^3
Vapor density (air = 1)	1.105
Liquid-to-gas expansion ratio	875

thus, its chemical formula is represented by O_3. Ozone forms a thin layer in the upper atmosphere, which protects life on Earth from ultraviolet rays, a cause of skin cancer. At lower atmospheric levels it is an air pollutant that contributes to the greenhouse effect. At ground level, ozone, when inhaled, can cause asthma attacks, stunted growth in plants, and corrosion of certain materials. It is produced by the action of sunlight on air pollutants, including car exhaust fumes, and is a major air pollutant in hot summers. More will be said about ozone and the greenhouse effect later in the text.

ATMOSPHERIC CARBON DIOXIDE

Carbon dioxide (CO_2) is a colorless, odorless gas (although it is felt by some persons to have a slight pungent odor and biting taste) that is slightly soluble in water and denser than air (one and half times heavier than air); it is a slightly acid gas. Carbon dioxide gas is relatively nonreactive and nontoxic. It will not burn, and it will not support combustion or life. CO_2 is normally present in atmospheric air at about 0.035% by volume and cycles through the biosphere via the carbon cycle (see Chapter 2, Figure 2.1). Carbon dioxide, along with water vapor, is primarily responsible for the absorption of infrared energy re-emitted by the Earth, and, in turn, some of this energy is reradiated back to the Earth's surface. It is also a normal endproduct of human and animal metabolism. Exhaled breath contains up to 5.6% carbon dioxide. In addition, the burning of carbon-laden fossil fuels releases carbon dioxide into the atmosphere. Much of this carbon dioxide is absorbed by ocean water, some of it is taken up by vegetation through photosynthesis in the carbon cycle (see Figure 2.1), and some remains in the atmosphere. Today, it is estimated that the concentration of carbon dioxide in the atmosphere is approximately 400 parts per million (ppm) and is rising at a rate of approximately 20 ppm every decade. The increasing rate of combustion of coal and oil has been primarily responsible for this occurrence, which (as we will see later in this text) may eventually have an impact on global climate.

Physical Properties of Carbon Dioxide

The physical properties of carbon dioxide are provided in Table 5.4.

Uses for Carbon Dioxide

Solid carbon dioxide is used quite extensively to refrigerate perishable foods while in transit. It is also used as a cooling agent in many industrial processes, such as grinding, rubber work, cold-treating metals, vacuum cold traps, and so on. Gaseous carbon dioxide is used to carbonate soft drinks, for pH control in water treatment, in chemical processing, as a food preservative, and in pneumatic devices.

TABLE 5.4
Physical Properties of Carbon Dioxide

Chemical formula	CO_2
Molecular weight	44.01
Vapor pressure at 70°F	838 psig
Density of the gas at 70°F and 1 atm	0.1144 lb/ft^3
Specific gravity of the gas at 70°F and 1 atm (air = 1)	1.522
Specific volume of the gas at 70°F and 1 atm	8.741 ft^3/lb
Critical temperature	–109.3°F
Critical pressure	1070.6 psia
Critical density	29.2 lb/ft^3
Latent heat of vaporization at 32°F	100.8 Btu/lb
Latent heat of fusion at triple point	85.6 Btu/lb

DID YOU KNOW?

The atmospheric concentration of carbon dioxide is currently around 400 parts per million (ppm). The global carbon dioxide concentration is increasing by about 2 ppm per year. Assuming that current trends continue, by 2100 the atmospheric concentration of greenhouse gases would reach 1000 ppm. This would result in a global temperature increase of up to 6°C.

ATMOSPHERIC ARGON

Argon (Ar; from Greek *argos* for "idle") is a colorless, odorless, tasteless, nontoxic, nonflammable gaseous element (noble gas). It constitutes almost 1% of the Earth's atmosphere and is plentiful compared to the other rare atmospheric gases. It is extremely inert and forms no known chemical compounds. It is slightly soluble in water.

Physical Properties of Argon

The physical properties of argon are provided in Table 5.5.

Uses for Argon

Argon is used extensively in filling incandescent and fluorescent lamps and electronic tubes, to provide a protective shield for growing silicon and germanium crystals, and as a blanket in the production of titanium, zirconium, and other reactive metals.

ATMOSPHERIC NEON

Neon (Ne; from Greek *neon* for "new") is a colorless, odorless, gaseous, nontoxic, chemically inert element. Air is about 2 parts per 1000 neon by volume.

Physical Properties of Neon

The physical properties of neon are provided in Table 5.6.

TABLE 5.5
Physical Properties of Argon

Chemical formula	Ar
Molecular weight	39.95
Density of the gas at 70°F and 1 atm	0.103 lb/ft^3
Specific gravity of the gas at 70°F and 1 atm	1.38
Specific volume of the gas at 70°F and 1 atm	9.71 ft^3/lb
Boiling point at 1 atm	–302.6°F
Melting point at 1 atm	–308.6°F
Critical temperature at 1 atm	–188.1°F
Critical pressure	711.5 psia
Critical density	33.444 lb/ft^3
Latent heat of vaporization at boiling point and 1 atm	69.8 Btu/lb
Latent heat of fusion at triple point	12.8 Btu/lb

TABLE 5.6
Physical Properties of Neon

Chemical formula	Ne
Molecular weight	20.183
Density of the gas at 70°F and 1 atm	0.05215 lb/ft^3
Specific gravity of the gas at 70°F and 1 atm	0.696
Specific volume of the gas at 70°F and 1 atm	19.18 ft^3/lb
Boiling point at 1 atm	–410.9°F
Melting point at 1 atm	–415.6°F
Critical temperature at 1 atm	–379.8°F
Critical pressure	384.9 psia
Critical density	30.15 lb/ft^3
Latent heat of vaporization at boiling point	37.08 Btu/lb
Latent heat of fusion at triple point	7.14 Btu/lb

Uses for Neon

Neon is used principally to fill lamp bulbs and tubes. The electronics industry uses neon singly or in mixtures with other gases in many types of gas-filled electron tubes.

ATMOSPHERIC KRYPTON

Krypton (Kr; from Greek *kryptos* for "hidden") is a colorless, odorless, inert gaseous component of Earth's atmosphere. It is present in very small quantities in the air (about 114 ppm).

Physical Properties of Krypton

The physical properties of krypton are provided in Table 5.7.

Uses for Krypton

Krypton is used principally to fill lamp bulbs and tubes. The electronics industry uses it singly or in mixtures in many types of gas-filled electron tubes.

TABLE 5.7
Physical Properties of Krypton

Chemical formula	Kr
Molecular weight	83.80
Density of the gas at 70°F and 1 atm	0.2172 lb/ft^3
Specific gravity of the gas at 70°F and 1 atm	2.899
Specific volume of the gas at 70°F and 1 atm	4.604 ft^3/lb
Boiling point at 1 atm	–244.0°F
Melting point at 1 atm	–251°F
Critical temperature at 1 atm	–82.8°F
Critical pressure	798.0 psia
Critical density	56.7 lb/ft^3
Latent heat of vaporization at boiling point	46.2 Btu/lb
Latent heat of fusion at triple point	8.41 Btu/lb

TABLE 5.8
Physical Properties of Helium

Chemical formula	He
Molecular weight	4.00
Density of the gas at 70°F and 1 atm	0.0103 lb/ft^3
Specific gravity of the gas at 70°F and 1 atm	0.138
Specific volume of the gas at 70°F and 1 atm	97.09 ft^3/lb
Boiling point at 1 atm	–452.1°F
Critical temperature at 1 atm	–450.3°F
Critical pressure	33.0 psia
Critical density	4.347 lb/ft^3
Latent heat of vaporization at boiling point and 1 atm	8.72 Btu/lb

ATMOSPHERIC HELIUM

Helium (He; from Greek *helios* for "sun") is inert (and, as a result, does not appear to have any major effect on, or role in, the atmosphere), nontoxic, odorless, tasteless, nonreactive, and colorless; it forms no compounds and occurs at about 0.00005% (5 ppm) by volume of air in the Earth's atmosphere. Helium is a noble gas, as are neon, krypton, hydrogen, and xenon. Helium is the second lightest element; only hydrogen is lighter. It is one-seventh as heavy as air. Helium is nonflammable and is only slightly soluble in water.

Physical Properties for Helium

The physical properties of helium are provided in Table 5.8.

ATMOSPHERIC XENON

Xenon (Xe; from Greek *xenon* for "stranger") is a colorless, odorless, nontoxic, inert, heavy gas that is present in very small quantities in the air (about 1 part in 20 million).

Physical Properties of Xenon

The physical properties of xenon are provided in Table 5.9.

TABLE 5.9
Physical Properties of Xenon

Chemical formula	Xe
Molecular weight	131.3
Density of the gas at 70°F and 1 atm	0.3416 lb/ft^3
Specific gravity of the gas at 70°F and 1 atm	4.560
Specific volume of the gas at 70°F and 1 atm	2.927 ft^3/lb
Boiling point at 1 atm	–162.6°F
Melting point at 1 atm	–168°F
Critical temperature at 1 atm	61.9°F
Critical pressure	847.0 psia
Critical density	68.67 lb/ft^3
Latent heat of vaporization at boiling point	41.4 Btu/lb
Latent heat of fusion at triple point	7.57 Btu/lb

TABLE 5.10
Physical Properties of Hydrogen

Chemical formula	H_2
Molecular weight	2.016
Density of the gas at 70°F and 1 atm	0.00521 lb/ft^3
Specific gravity of the gas at 70° and 1 atm	0.06960
Specific volume of the gas at 70°F and 1 atm	192.0 ft^3/lb
Boiling point at 1 atm	–423.0°F
Melting point at 1 atm	–434.55°F
Critical temperature at 1 atm	–399.93°F
Critical pressure	190.8 psia
Critical density	1.88 lb/ft^3
Latent heat of vaporization at boiling point	191.7 Btu/lb
Latent heat of fusion at triple point	24.97 Btu/lb

Uses for Xenon

Xenon is used principally to fill lamp bulbs and tubes. The electronics industry uses it singly or in mixtures in many types of gas-filled electron tubes.

ATMOSPHERIC HYDROGEN

Hydrogen (H_2; from Greek *hydros* for "water" and *gen* for "generator") is a colorless, odorless, tasteless, nontoxic, flammable gas. It is the lightest of all the elements and occurs on Earth chiefly in combination with oxygen as water. Hydrogen is the most abundant element in the universe, where it accounts for 93% of the total number of atoms and 76% of the total mass. It is the lightest gas known, with a density approximately 0.07 that of air. Hydrogen is present in the atmosphere in concentrations of only about 0.5 ppm by volume at lower altitudes.

Physical Properties of Hydrogen

The physical properties of hydrogen are provided in Table 5.10.

Uses for Hydrogen

Hydrogen is used by refinery, petrochemical, and bulk chemical facilities for hydrotreating, catalytic reforming, and hydrocracking. Hydrogen is used in the production of a wide variety of chemicals. Metallurgical companies use hydrogen in the production of their products. Glass manufacturers use hydrogen as a protective atmosphere in a process whereby molten glass is floated on a surface of molten tin. Food companies hydrogenate fats, oils, and fatty acids to control various physical and chemical properties. Electronic manufacturers use hydrogen at several steps in the complex processes for manufacturing semiconductors.

ATMOSPHERIC WATER

Leonardo da Vinci understood the importance of water when he said: "Water is the driver of nature." He was actually acknowledging what most scientists and many of the rest of us have come to realize: Water, propelled by the varying temperatures and pressures in Earth's atmosphere, allows life as we know it to exist on our planet (Graedel and Crutzen, 1995). The water vapor content of the lower atmosphere (troposphere) is normally within a range of 1 to 3% by volume, with a global average of about 1%. The percentage of water in the atmosphere can vary from as little as 0.1% to as much

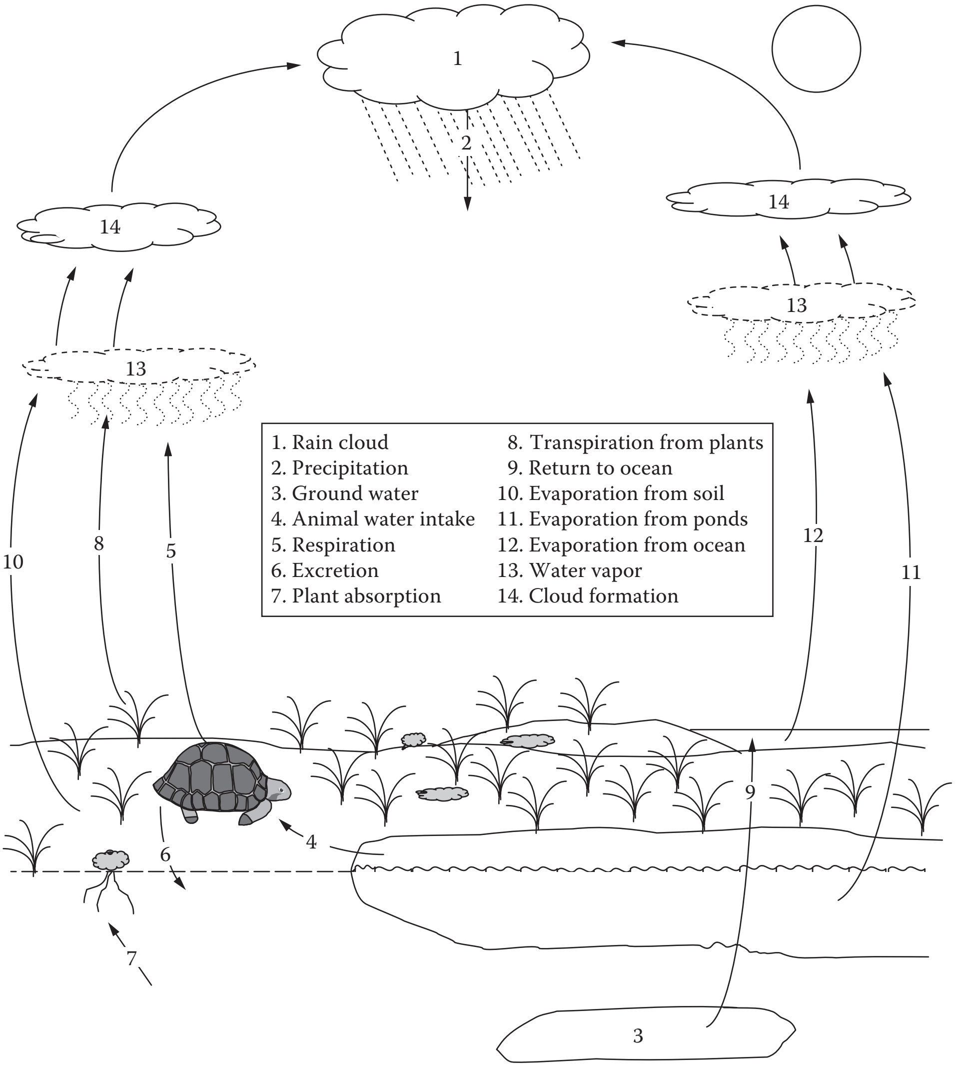

FIGURE 5.1 Water cycle.

as 5% water, depending on altitude; the water content of the atmosphere decreases with increasing altitude. Water circulates in the atmosphere in the hydrological cycle, as shown in Figure 5.1. Water vapor contained in Earth's atmosphere plays several important roles: (1) it absorbs infrared radiation; (2) it acts as a blanket at night, retaining heat from the Earth's surface; and (3) it affects the formation of clouds in the atmosphere.

ATMOSPHERIC PARTICULATE MATTER

Significant numbers of particles (particulate matter) are suspended in the atmosphere, particularly the troposphere. These particles originate in nature from smokes, sea sprays, dusts, and the evaporation of organic materials from vegetation. There is also a wide variety of Nature's living or semi-living particles—spores and pollen grains, mites and other tiny insects, spider webs, and diatoms. The atmosphere also contains a bewildering variety of anthropogenic (manmade) particles produced by automobiles, refineries, production mills, and many other human activities.

Atmospheric particulate matter varies greatly in size (colloidal-sized particles in the atmosphere are called *aerosols*—usually less than 0.1 µm in diameter). The smallest are gaseous clusters and ions and submicroscopic liquids and solids. Somewhat larger ones produce the beautiful blue haze in distant vistas, those 2 to 3 times larger are highly effective in scattering light, and the largest consist of such things as rock fragments, salt crystals, and ashy residues from volcanoes, forest fires, or incinerators.

The concentrations of particulates in the atmosphere vary greatly, ranging from more than 10,000,000/cm^3 to less than 1/L (0.001/cm^3). Excluding the particles in gases as well as vegetative material, sizes range from 0.005 to 500 µm, a variation in diameter of 100,000 times. The largest numbers of airborne particulates are always in the invisible range. These numbers vary from less than 1 liter to more than a half a million per cubic centimeter in heavily polluted air and to at least 10 times more than that when a gas-to-particle reaction is occurring (Schaefer and Day, 1981).

Based on particulate level, there are two distinct regions in the atmosphere: very clean and dirty. The clean parts have so few particulates that they are almost invisible, making them difficult to collect or measure. In the dirty parts of the atmosphere—the air of a large metropolitan area—the concentration of particles includes an incredible variety of particulates from a wide variety of sources.

Atmospheric particulate matter performs a number of functions, undergoes several processes, and is involved in many chemical reactions in the atmosphere. Probably the most important function of particulate matter in the atmosphere is that it serves as nuclei for the formation of water droplets and ice crystals. Vincent J. Schaefer, who invented cloud seeding, used dry ice in his early attempts, but the process later evolved to adding condensing particles to atmospheres supersaturated with water vapor and the use of silver iodide, which forms huge numbers of very small particles. Another important function of atmospheric particulate matter is that it helps determine the heat balance of the Earth's atmosphere by reflecting light. Particulate matter is also involved in many chemical reactions in the atmosphere such as neutralization, catalytic effects, and oxidation reactions. These chemical reactions will be discussed in greater detail later.

AIR FOR COMBUSTION

It is difficult to imagine where humans would be today or how far we would have progressed from our beginnings to the present day if we had not discovered and developed the use of fire. Today, of course, we are quite familiar with fire. We use the terms *fire*, *combustion*, *oxidation*, and *burning* pretty much to mean the same thing; however, there is a subtle difference between combustion and oxidation. During combustion, two or more substances chemically unite. In practice, one of them is almost always atmospheric oxygen, but combustion reactions are known in which oxygen is not one of the reactants. Thus, it is more correct to describe combustion as a rapid oxidation—or fire. To state that atmospheric air plays an important role in combustion is to understate its significance; that is, we are stating the obvious, something that is readily apparent to most of us. Though air is important in combustion, most of us give little thought to the actual chemical reaction involved in combustion. Combustion is a chemical reaction—one in which a fuel combines with air (oxygen) to produce heat (burning). The combustion of fuels containing carbon and hydrogen is said to be complete when these two elements are oxidized to carbon dioxide and water (e.g., the combustion of carbon $C + O_2 = CO_2$). In air pollution control, it is incomplete combustion that concerns us. Incomplete combustion may lead to (1) appreciable amounts of carbon remaining in the ash, (2) emission of some of the carbon as carbon monoxide, and (3) reaction of the fuel molecules to give a range of products emitted as smoke.

AIR FOR POWER

Along with performing its important function in Earth's atmosphere and its vital role in combustion, most industrial processes use gases to power systems of one type or another. The work is actually performed by a gas under pressure in the system. A gas power system may function as part of a process, such as heating and cooling, or it may be used as a secondary service system, such as compressed air. Compressed air is the gas most often found in industrial applications, but nitrogen and carbon dioxide are also commonly used. A system that uses a gas for transmitting force is referred to as a *pneumatic system*. The word *pneumatic* is derived from the Greek word for an unseen gas. Originally, pneumatic referred only to the flow of air, but today it is used to refer to the flow of any gas in a system under pressure. Pneumatic systems perform work in many ways, including operating pneumatic tools, door openers, linear motion devices, and rotary motion devices. Have you ever watched an automobile mechanic remove and replace a tire on your car? The device used to take off and put on tire lug nuts is a pneumatic (air-operated) wrench. Pneumatic hoisting equipment may be found in heavy fabricating environments, and pneumatic conveyors are used in the processing of raw materials. Pneumatic systems are also used to control flow valves in chemical process equipment and in large air-conditioning systems. The pneumatic system in an industrial plant usually handles compressed air, which is used for operating portable air tools, such as drills, wrenches, and chipping tools; for vises, chucks, and other clamping devices; for movable locating stops; for operating plastic molding machines; and for supplying air used in various manufacturing processes. Although the pieces of pneumatic equipment just described are different from each other, they all convert compressed air into work. Later we will review some of the laws of force and motion and their relation to pneumatic principles.

STRATIFICATION OF THE ATMOSPHERE

The lowest level of the atmosphere, the troposphere (see Figure 5.2), is heated by the Earth, which is warmed by infrared and visible radiation from the sun. The atmosphere extends from sea level to a height of about 10 to 17 km (6 to 11 miles); it contains approximately 75% of the total air mass on Earth and virtually all of the water vapor. Warm air cools as it rises in the troposphere, causing

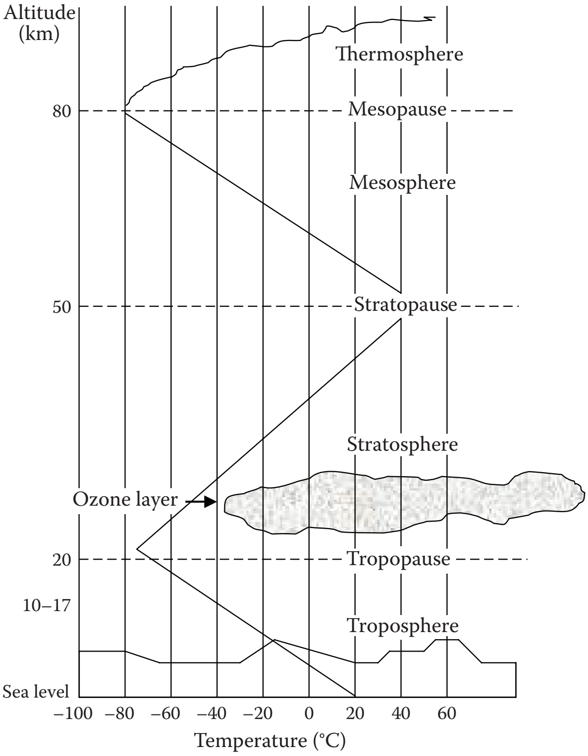

FIGURE 5.2 Stratification of the atmosphere (not to scale).

rain and most other weather phenomena; all cloud formations, precipitation, and seasonal changes occur in the troposphere. Prevalent turbulence, mainly winds, in the troposphere causes diffusive (Fickian) transport (i.e., the movement of molecules in air from higher to lower concentration regions) of atmospheric chemicals, along with advective transport (i.e., the transport of a pollutant as it is carried along by the mass movement of air from higher to lower regions of pressure). In the troposphere, chemicals mix in a few weeks, whereas it may take years to mix in the upper layer. There is a general decrease of temperature with height throughout this layer at a mean rate of 6.4°C per km. Typically, the temperature at the top of the layer is –55°C.

The standard atmospheric pressure is 1 atm, or 14.7 lb/in.^{2}, at sea level. At an altitude of 15 km, this decreases to 1.6 psi. Between the layers of the atmosphere, pauses (or regions of transition) exist. The transition between the troposphere and the next stratification is called the *tropopause*, a thin layer of relatively stable temperature. Above the tropopause, the air does not hold enough oxygen to support life.

The layer above the troposphere, the stratosphere, extends up to 50 km and in terms of air circulation patterns is a stable layer. It is deeper than the troposphere but contains only a small part of the total air mass because of its lower density; however, along with the troposphere, almost all of the remaining air mass is contained here, as 99% of air occurs within these two layers. Most of the atmospheric natural ozone (O_3) is contained in the stratosphere. This stratospheric ozone plays a significant environmental role as a barrier to harmful ultraviolet radiation from the sun. Layers of the atmosphere above the stratosphere include the mesosphere, the ionosphere, and the thermosphere. These portions of the atmosphere are essentially unaffected by air pollution and thus are not discussed further in this text.

PHYSICAL PROPERTIES AND DYNAMICS OF AIR

The ability of the atmosphere to accept, disperse, transform, and dispose of pollutants is strongly related to its various physical and dynamic properties; for example, atmospheric winds determine pathways and speeds at which pollutants are transported away from sources. In another physical process, the vertical variation of temperature greatly influences atmospheric stability and hence the turbulent mixing of polluted air with clean air. Thus, a knowledge of air physical properties and basic air physics (or, more correctly stated, the physics of gases and particles) is foundational to gaining an understanding of the characteristics of air pollution and the technology used to correct it. A good working knowledge of a few basic physical properties (such as gas density, pressure drop, viscosity of the gas, and pressure drop in filter media) is important. This section discusses these basic physical properties. Because their application is important to air-quality and emissions sampling and monitoring, emission assessment procedures, data summarization, engineering controls, and air-quality monitoring, special attention is given to the gas laws.

FORCE, WEIGHT, AND MASS

In air science work, you must know the properties of gases to understand air pollution and to make the proper selection and operation of air pollution control devices. You should also be familiar with the terms *force*, *weight*, and *mass*. Force is any influence that tends to change the state of rest or the uniform motion in a straight line of a body. In simple terms, force is a push or a pull exerted on an object to change its position or movement, including starting, stopping, and changing its speed or direction of movement. In a compressed-air (pneumatic) system, force must be present at all times for the system to function. The weight of a substance or an object depends on its mass (the amount of matter in an object and its inertia, or resistance to movement) and the strength of the Earth's gravitational pull, which decreases with height. An object weighs less at the top of a mountain than at sea level. The inertia of an object determines how much force must be used to lift or move the object, or

TABLE 5.11
Densities of Gases at STP (0°C and 1 atm)

Gas	Density (lb/ft^3)
Air	1.3
Hydrogen	0.09
Helium	0.18
Methane	0.72
Nitrogen	1.25
Oxygen	1.43
Carbon dioxide	1.98
Propane	2.02
Butane	2.65

to change its speed or direction of movement. Density, a scaler quantity, is the weight for a specific volume, a measure of a substance's compactness. The density of a substance is equal to its mass per unit volume and is measured in kilograms per cubic meter (kg/m^3) or pounds per cubic foot (lb/ft^3). The density (D) of a mass (m) occupying a particular volume (V) is given by the formula:

$$D = m/V$$

The density of a cubic foot of dry air at atmospheric pressure and a temperature of 60°F is 0.076 lb, more commonly expressed as 0.076 lb/ft^3. The density of wet air at atmospheric pressure, with 100% relative humidity and a temperature of 60°F, is 0.075 lb/ft^3. Humid air is less dense than dry air, because the water vapor limits how much air compresses. As a result, humid air weighs less. The relatively low density of air makes it suitable for long-distance and high-speed control applications in pneumatic systems. The densities of some common gases are given in Table 5.11.

Pressure

Pressure, the amount of force (in pounds) exerted on an object or a substance divided by the area (in square inches) over which this force is exerted, can be measured and specified in different ways but is commonly measured in pounds per square inch (psi). The SI unit of pressure is the pascal (newtons per square meter), equal to 0.01 millibars. At the edge of Earth's atmosphere, pressure is 0, whereas at sea level atmospheric pressure due to the weight of the air above is about 100 kilopascals (1013 millibars, or 1 atmosphere).

Work and Energy

Work is the transference of energy that occurs when a force is applied to a body moving so the force has a component in the direction of the body's motion. In other words, work takes place when a force (in pounds or newtons) moves through a distance (in inches, feet, or meters). The amount of work done is expressed in foot-pounds or inch-pounds, as shown in the following equation:

$$\text{Work} = \text{Force (pounds)} \times \text{Distance (feet or inches)} = \text{Foot-pounds or inch-pounds} \tag{5.1}$$

Power is defined as the time rate of doing work. It is the amount of work (foot-pounds) done in a given length of time (seconds or minutes) and can be expressed as, for example, foot-pounds per minute. The following equation is used to determine the amount of power:

$$\text{Power } (P) = \frac{\text{Work}}{\text{Time}} = \frac{\text{Foot-pounds}}{\text{Seconds (or minutes)}} \tag{5.2}$$

To convert foot-pounds to inch-pounds, multiply by 12. Note that for the amount of power calculated to be meaningful it must be compared with a unit of measurement. The common unit of power measurement is horsepower, calculated as follows:

$$1 \text{ hp} = \frac{33{,}000 \text{ ft-lb}}{\text{Seconds (or minutes)}} \tag{5.3}$$

Energy is expended when power is used to perform work. The law of conservation of energy states: “Energy cannot be created or destroyed. It can only be transformed.” We use one kind of energy to get other kinds of energy. Some of this energy does useful work, but some of it is wasted in overcoming friction (as heat energy—remember that energy cannot be destroyed or lost).

DIFFUSION AND DISPERSION

Diffusion is the spontaneous and random movement of molecules or particles in a gas (or liquid) from a region in which they are at a high concentration to regions of lower concentration, until a uniform concentration is achieved throughout. This process involves no mechanical mixing or stirring. Do not confuse dispersion with evaporation, which is the changing of a liquid to a gas. *Dispersion* can be described as the temporary mixing of liquid particles with a gas. Diffusion and dispersion are important processes in air pollution. In dispersion, air pollutants are diluted and reduced in concentration. Air pollution dispersion mechanisms are a function of the prevailing meteorological conditions.

COMPRESSIBILITY

Air, unlike water, is readily compressed, and large quantities can be stored in relatively small containers. The more the air is compressed, the greater its pressure becomes. The higher the pressure in a container, the stronger the container must be. Gases are important compressible fluids, not only from the standpoint that a gas can be a pollutant but also because gases convey particulate matter and gaseous pollutants (Hesketh, 1991).

GAS LAWS

Gases can be pollutants as well as the conveyors of pollutants. Air (which is mainly nitrogen) is usually the main gas stream. Gas conditions are usually described in two ways: *standard temperature and pressure* (STP) and *standard conditions* (SC). STP represents 0°C (32°F) and 1 atm. SC is more commonly used and represents typical room conditions of 20°C (70°F) and 1 atm; SC is usually measured in cubic meters (m^3), Nm^3, or standard cubic feet (scf). To understand the physics of air it is imperative to have an understanding of various physical laws that govern the behavior of pressurized gases. One of the more well-known physical laws is Pascal’s law, which states: “A confined gas (fluid) transmits externally applied pressure uniformly in all directions, without change in magnitude.” This is easily demonstrated by a container that is flexible and assumes a spherical shape (think of a balloon). You probably have noticed that most compressed-gas tanks are cylindrical in shape (which allows the use of thinner sheets of steel without sacrificing safety) with spherical ends to contain the pressure more effectively.

BOYLE'S LAW

Though gases are compressible, note that, for a given mass flow rate, the actual volume of gas passing through the system is not constant within the system due to changes in pressure. This physical property (the basic relationship between the pressure of a gas and its volume) is described by Boyle's law, named for the Irish physicist and chemist Robert Boyle, who discovered this property in 1662. It states: "The absolute pressure of a confined quantity of gas varies inversely with its volume, if its temperature does not change." For example, if the pressure of a gas doubles, its volume will be reduced by a half, and *vice versa*; that is, as pressure goes up, volume goes down, and the reverse is true. This means, for example, that if 12 ft^3 of air at 14.7 psia (pounds per square inch absolute) is compressed to 1 ft^3, air pressure will rise to 176.4 psia, as long as air temperature remains the same. This relationship can be calculated as follows:

$$P_1 \times V_1 = P_2 \times V_2 \tag{5.4}$$

where

P_1 = Original pressure (units for pressure must be absolute).
P_2 = New pressure (units for pressure must be absolute).
V_1 = Original gas volume at pressure P_1.
V_2 = New gas volume at pressure P_2.

This equation can also be written as

$$P_2/P_1 = V_1/V_2 \quad \text{or} \quad P_1/P_2 = V_2/V_1 \tag{5.5}$$

To allow for the effects of atmospheric pressure, always remember to convert from gauge pressure (psig, or pounds per square inch gauge) *before* solving the problem, then convert back to gauge pressure *after* solving it:

Pounds per square inch absolute (psia) = Pounds per square inch gauge (psig) + 14.7 psi

and

Pounds per square inch gauge (psig) = Pounds per square inch absolute (psia) – 14.7 psi

In a pressurized gas system where gas is caused to move through the system by the fact that gases will flow from an area of high pressure to that of low pressure, we will always have a greater actual volume of gas at the end of the system than at the beginning (assuming the temperature remains constant). Let's take a look at a typical gas problem using Boyle's law.

■ EXAMPLE 5.1

Problem: What is the gauge pressure of 12 ft^3 of air at 25 psig when compressed to 8 ft^3?

Solution:

$$25 \text{ psig} + 14.7 \text{ psi} = 39.7 \text{ psia}$$

$$P_2 = P_1 \times \frac{V_1}{V_2} = 39.7 \times \frac{12}{8} = 59.6 \text{ psia}$$

$$\text{psig} = \text{psia} - 14.7 \text{ psi} = 59.6 \text{ psia} - 14.7 \text{ psi} = 44.9 \text{ psig}$$

The gauge pressure is 44.9 psig (remember that the pressures should always be calculated on the basis of absolute pressures instead of gauge pressures).

CHARLES'S LAW

Another physical law dealing with temperature is Charles's law, discovered by French physicist Jacques Charles in 1787. It states: "The volume of a given mass of gas at constant pressure is directly proportional to its absolute temperature." The absolute temperature is the temperature in Kelvin (273 + °C); absolute zero = –460°F, or 0°R on the Rankine scale. This is calculated by using the following equation:

$$P_2 = P_1 \times (T_2/T_1) \tag{5.6}$$

Charles's law also states: "If the pressure of a confined quantity of gas remains the same, the change in the volume (V) of the gas varies directly with a change in the temperature of the gas," as given below:

$$V_2 = V_1 \times (T_2/T_1) \tag{5.7}$$

IDEAL GAS LAW

The ideal gas law combines Boyle's and Charles's laws because air cannot be compressed without its temperature changing. The ideal gas law can be expressed as:

$$(P_1 \times V_1)/T_1 = (P_2 \times V_2)/T_2 \tag{5.8}$$

Note that the ideal gas law is still used as a design equation even though the equation shows that the pressure, volume, and temperature of the second state of a gas are equal to the pressure, volume, and temperature of the first state. In actual practice, however, other factors such as humidity, heat of friction, and efficiency losses all affect the gas. Also, this equation uses absolute pressure (psia) and absolute temperatures (°R) in its calculations.

In air pollution science, the importance of the ideal gas law cannot be overstated. It is one of the fundamental principles used in calculations involving gas flow in air-pollution-related work. This law is used to calculate actual gas flow rates based on the quantity of gas present at standard pressures and temperatures. It is also used to determine the total quantity of that contaminant in a gas that can participate in a chemical reaction. The ideal gas law has three important variables:

- Number of moles of gas
- Absolute temperature
- Absolute pressure

In practical applications, practitioners generally use the following standard ideal gas law equation:

$$V = nRT/P \quad \text{or} \quad PV = nRT \tag{5.9}$$

where
V = Volume.
n = Number of moles.
R = Universal gas constant.
T = Absolute temperature.
P = Absolute pressure.

DID YOU KNOW?

Moles are a measure of the number of molecules present. The value of R depends on the units used for the other parameters.

DID YOU KNOW?

Argon is usually not listed in most industrial gas analyses because it is chemically inert and difficult to measure. The argon concentration is often combined with the nitrogen concentration to yield a value of 79.0%.

■ EXAMPLE 5.2

Problem: What is the volume of 1 pound mole (denoted "lb mole") of combustion gas at an absolute pressure of 14.7 psia and a temperature of 68°F? (These are USEPA-defined standard conditions.)

Solution:

$$V = nRT/P$$

Convert the temperature from relative to absolute scale (from °F to °R):

$$T_{\text{Absolute}} = 68°\text{F} + 460 = 528°\text{R}$$

Calculate the gas volume:

$$V = \frac{1 \text{ lb mole} \times \dfrac{10.73\ (\text{psia})(\text{ft}^3)}{(\text{lb mole})(°\text{R})} \times 528°\text{R}}{14.7 \text{ psia}} = 385.4 \text{ ft}^3$$

FLOW RATE

Gas flow rate is a measure of the volume of gas that passes a point in an industrial system during a given period of time. The ideal gas law tells us that this gas flow rate varies depending on the temperature and pressure of the gas stream and the number of moles of gas moving per unit of time. When gas flow rates are expressed at actual conditions of temperature and pressure, the actual gas flow rate is being used. As you will learn later, gas flow rates can also be expressed at standard conditions of temperature and pressure; this is referred to as the *standard gas flow rate*.

GAS CONVERSIONS

Gases of interest in air pollution control are usually mixtures of several different compounds; for example, air is composed of three major constituents: nitrogen (N_2) at approximately 78.1%, oxygen (O_2) at approximately 20.9%, and argon at 0.9%. Many flue gas streams generated by industrial processes consist of the following major constituents: (1) nitrogen, (2) oxygen, (3) argon, (4) carbon dioxide (CO_2), and (5) water vapor (H_2O). Both air and industrial gas streams also contain minor constituents, including air pollutants, present at concentrations that are relatively low compared to these major constituents. We need ways to express both the concentrations of the major constituents of the gas stream and the concentrations of the pollutants present as minor constituents at relatively low concentrations. The following text presents a variety of ways to express gas phase concentrations, which can easily be converted from one type of unit to another.

MAJOR CONSTITUENTS

Volume percent is one of the most common formats used to express the concentrations of major gas stream constituents such as oxygen, nitrogen, carbon dioxide, and water vapor. The format is very common partially because the gas stream analysis techniques used in USEPA emission testing methods provide data directly in a volume percent format. *Partial pressure* is also used to express concentrations. This expression refers to the portion of the total pressure exerted by one of the constituent gases.

Gases composed of different chemical compounds such as molecular nitrogen and oxygen behave physically the same as gases composed of a single compound. At any given temperature, one mole of a gas exerts the same pressure as one mole of any other type of gas. All of the molecules move at a rate that is dependent on the absolute temperature, and they exert pressure. The total pressure is the sum of the pressures of each of the components. The equations below are often referred to as Dalton's law of partial pressures:

$$P_{Total} = p_i + p_{ii} + p_{iii} \dots p_n \tag{5.10}$$

$$P_{Total} = \sum_{i=1}^{n} p_i \tag{5.11}$$

$$\text{Partial pressure (gas)} = \left[\frac{\text{Volume\% (gas)}}{100\%}\right] \times P_{Total} \tag{5.12}$$

Because the partial pressure value is related to the total pressure, concentration data expressed as partial pressure are not the same at actual and standard conditions. The partial pressure values are also different in American engineering units and centimeter–gram–second (CGS) units.

Both Major and Minor Constituents

Mole fraction is simply an expression of the number of moles of a compound divided by the total number of moles of all the compounds present in the gas.

Minor Constituents

All of the concentration units below can be expressed in a dry format as well as corrected to a standard oxygen concentration. These corrections are necessary because moisture and oxygen concentrations can vary greatly in gas streams, causing variations in pollutant concentrations:

- Parts per million (ppm)
- Milligrams per cubic meter (mg/m^3)
- Micrograms per cubic meter (µg/m^3)
- Nanograms per cubic meter (ng/m^3)

GAS VELOCITY

Gas velocity is one of the fundamental design variables for ventilation systems and air pollution control equipment. Gas streams containing particulate are usually maintained at velocities of 3000 to 4500 ft/min in ductwork leading to particulate collectors to minimize particle deposition. The velocity of gas streams without particulate matter is often in the range of 1500 to 3000 ft/min. The gas velocities in air pollution control equipment are usually low to allow for sufficient time to remove the contaminants. For example, gas velocities through electrostatic precipitators are usually in the range of 2.5 to 6 ft/sec. The filtration velocities through pulse jet fabric filters are usually in the range of 2 to 10 ft/min. Variations in the gas velocity can have a direct impact on the contaminant removal efficiency.

The average velocity of a gas stream in an emission testing probe, an industrial duct, or an air pollution control device is a function of the actual gas flow rate and the cross-sectional flow area:

$$\text{Gas velocity } (v) = \text{Gas flow rate (actual)/Area} \tag{5.13}$$

GAS STREAM TREATMENT (RESIDENCE) TIME

The flow rate of the gas stream through an air pollution control system determines the length of time that the pollutants can be removed from the gas stream. This is termed the *treatment time* or *residence time*. These common equipment sizing parameters are defined mathematically below:

$$\text{Treatment time} = \text{Residence time} = \text{Volume of control device/Gas flow rate (actual)} \tag{5.14}$$

GAS DENSITY

Gas density is important primarily because it affects the flow characteristics of the moving gas streams. Gas density affects the velocities of gas through ductwork and air pollution control equipment. It determines the ability to move the gas stream using a fan. Gas density affects the velocities of gases emitted from the stack and thereby influences the dispersion of the pollutants remaining in the stack gases. It affects the ability of particles to move through gases. It also affects emission testing. Gas density data are needed in many of the calculations involved in air pollution control equipment evaluation, emission testing, and other studies related to air pollution control.

As discussed earlier, the volume of a gas increases as the temperature increases due to the motion of the gas molecules. As the volume occupied by the gas increases, its density decreases. Density is the mass per unit volume:

$$P_{(T=I,P=j)} = \frac{m}{V_{(T=I,P=j)}} \tag{5.15}$$

where

$R_{(T=I,\ P=j)}$ = Density at $T = I$, $P = j$.
m = Mass of a substance.
$V_{(T=I,\ P=j)}$ = Volume at $T = I$, $P = j$.
T = Absolute temperature.
P = Absolute pressure.

HEAT CAPACITY AND ENTHALPY

The heat capacity of a gas is the amount of heat required to change the temperature of a unit-mass of gas one temperature degree. Enthalpy represents the total quantity of internal energy, such as heat, measured for a specific quantity of material at a given temperature. Enthalpy data are often represented in units of energy (e.g., Btu, kcal, joule). The enthalpy content change is often expressed in Btu/unit mass (Btu/lb_m or Btu/scf). The change in enthalpy of the total quantity of material present in a system is expressed in units of Btu/unit time (Btu/min). The symbols H and ΔH denote enthalpy and the change in enthalpy, respectively.

DID YOU KNOW?

Gas density is expressed as the mass per unit of volume of gas. The gas volume is always expressed at actual conditions. The gas volume is not corrected for temperature, pressure, moisture, or oxygen levels.

HEAT AND ENERGY IN THE ATMOSPHERE

The prime source of the energy that drives Earth's climatic system is the sun, from which energy reflects, scatters, and is absorbed and reradiated within the system but which does not distribute uniformly. More energy enters some areas than is lost; in other areas, more energy is lost than gained. If this situation were to continue, the areas with surplus energy would become too hot and those with a deficit would become too cold. Because the temperature differences produced help to drive the wind and ocean currents of the world, they carry heat with them and help to counteract the radiation imbalance. Normally, warm winds from the tropics carry excess heat with them. Polar winds blow from areas with a heat deficit and so are cold. Acting together, these energy transfer mechanisms help to produce the current climates on Earth.

ADIABATIC LAPSE RATE

The atmosphere is always moving, either horizontally or vertically, or both. As air rises, pressure decreases and the air expands. This expansion of air expends energy. Because temperature is a measure of internal energy, this energy expenditure makes the temperature of the air drop—an important process in air physics known as the adiabatic lapse rate. *Adiabatic* refers to a process that occurs without the gain or loss of heat, such as the expansion or contraction of a gas in which a change takes place in the pressure or volume although no heat enters or leaves. *Lapse rate* refers to the rate at which air temperature decreases with increasing height. The normal lapse rate in stationary air is on the order of 3.5°F/1000 ft (6.5°C/km). This value varies with latitude and with changing seasonal and atmospheric conditions:

$$T = T_0 - Rh \tag{5.16}$$

where

T = Temperature of the air.
T_0 = Temperature of the air at the level from which the height is measured.
R = Lapse rate.
h = Height of air.

When a parcel of warm dry air is lifted in the atmosphere, it undergoes adiabatic expansion and cooling. This adiabatic cooling results in a lapse rate of –1°C/100 m or 1 to 10°C/km, the dry adiabatic lapse rate. When the ambient lapse rate exceeds the adiabatic lapse rate, the ambient rate is said to be *superadiabatic*, and the atmosphere is highly unstable. When the two lapse rates are exactly equal, the atmosphere is said to be neutral. When the ambient lapse rate is less than the dry adiabatic lapse rate, the ambient lapse rate is termed *subadiabatic* and the atmosphere is stable. The cooling process within a rising parcel of air is assumed to be adiabatic (occurring without the addition or loss of heat). Under adiabatic conditions, a rising parcel of air behaves like a rising balloon, with the air in that distinct parcel expanding as it encounters air of lesser density, until its own density is equal to that of the atmosphere that surrounds it. This process is assumed to occur with no heat exchange between the rising parcel and the ambient air (Peavy et al., 1985).

VISCOSITY

All fluids (gases included) resist flow. *Absolute viscosity* is a measure of this resistance to flow. The absolute viscosity of a gas for given conditions can be calculated from the following formula:

$$\mu = 51.12 + 0.372(T) + 1.05 \times 10^{-4}(T)^2 + 53.147\ (\%O_2/100\%) - 74.143\ (\%H_2O/100\%) \tag{5.17}$$

DID YOU KNOW?

Gas viscosity actually increases very slightly with pressure, but this variation is very small in most engineering calculations related to air pollution.

where
μ = Absolute viscosity of gas at the prevailing conditions (micropoise, or μP).
T = Gas absolute temperature (K).
$\%O_2$ = Oxygen concentration (% by volume).
$\%H_2O$ = Water vapor concentration (% by volume).

As this equation indicates, the viscosity of a gas increases as the temperature increases. It is more difficult to push something (e.g., particles) through a hot gas stream than a cooler one due to increased molecular activity as temperature rises, which results in increased momentum transfer between the molecules. For liquids, the opposite relationship between viscosity and temperature holds. The viscosity of a liquid decreases as temperature increases, so it is more difficult to push something through a cold liquid than a hot one because in liquids hydrogen bonding increases with colder temperatures. Gas viscosity actually increases slightly with pressure, but this variation is very small in most air-pollution-related engineering calculations.

The absolute viscosity and density of a gas are occasionally combined into a single parameter because both of these parameters are found in many common equations describing gas flow characteristics. The combined parameter is termed the *kinematic viscosity*:

$$u = \mu/p \tag{5.18}$$

where
u = Kinematic viscosity (m^2/sec).
μ = Absolute viscosity (Pa·sec).
p = Gas density (g/cm^3).

The kinematic viscosity can be used in equations describing particle motion through gas streams. The expression for kinematic viscosity is used to simplify these calculations.

FLOW CHARACTERISTICS

When fluids such as gases are moving slowly, the bulk material moves as distinct layers in parallel paths, as illustrated in Figure 5.3. The only movement across these layers is the molecular motion, which creates viscosity. This is termed *laminar flow*. As the velocity of the gas stream increases, the bulk movement of the gas changes. Eddy currents develop and cause mixing across the flow stream. This is called *turbulent flow* and is essentially the only flow characteristic that occurs in air pollution control equipment and emission testing situations. Turbulent flow is illustrated in Figure 5.4.

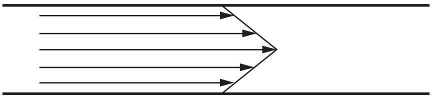

FIGURE 5.3 Laminar (streamline) flow.

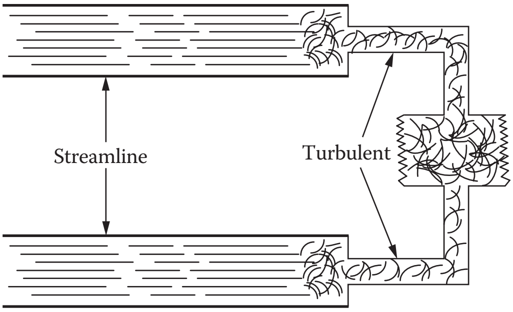

FIGURE 5.4 Turbulent flow.

A dimensionless parameter called the *Reynolds number* is used to characterize fluid flow. It is the ratio of the inertial force that is causing gas movement to the viscous force that is restricting movement. The Reynolds number is calculated as below; consistent units must be used to ensure that the Reynolds number is dimensionless:

$$N_{\mathrm{Re}(g)} = Lvp/\mu \tag{5.19}$$

where

L = Linear dimension (usually duct diameter).
v = Fluid velocity.
p = Fluid density.
μ = Fluid viscosity.

Reynolds numbers less than 2000 are associated with laminar flow conditions. Due to the relatively low velocities associated with this type of flow, they are rarely encountered in air pollution field situations. Reynolds numbers above 10,000 are associated with turbulent flow. In many field situations, the Reynolds numbers exceed 100,000.

Essentially, all gas flow situations are turbulent in air pollution control systems, emission testing and monitoring equipment, and dispersion modeling studies; however, this does not mean that the gas stream is entirely well mixed. In reality, the side-to-side mixing (and even mixing in the direction of flow) can be limited. For this reason, it is possible to have different concentrations of pollutants at different positions in the duct. This condition is called *pollutant stratification* and can be caused by a variety of factors: combining of two separate gas streams into a single duct, temperature differences in the gas stream, and in-leakage of cold ambient air into the duct.

Stratification does not exist in most industrial gas handling systems; however, it is important to check for this condition prior to installation of continuous emission monitors or other instruments, which are located at a single sampling or measurement point in the gas stream. These measurements can be in error if stratification is severe.

DID YOU KNOW?

Between Reynolds numbers of 2000 and 10,000, turbulent flow conditions have not fully developed. This condition is referred to as the *transitional flow range*. Flow in this transitional range has characteristics of both laminar and turbulent flow.

PARTICLE PHYSICS

In air pollution and air pollution control technology, understanding the physics of airborne particles or particulate matter (or aerosol) that might be entrained within the gaseous stream is essential. Particulates represent a major class of air pollution. Present in a wide variety of shapes, particulates include dusts, fumes, mists, and smoke and have a wide range of physical and chemical properties. Particulate matter characteristics that can affect control technologies include size, size distribution, shape, density, stickiness, corrosivity, reactivity, and toxicity. Because of this wide range of characteristics, many types of collection device are needed for collection of different particle types. Particle size is based on particle behavior in the Earth's gravitational field. The *aerodynamic equivalent diameter* refers to a spherical particle of unit density that falls at a standard velocity. Particle size determines atmospheric lifetime, effects on light scattering, and deposition in the lungs. Do not confuse particle size with particle shape, however. For the sake of simplicity, and for theoretical and learning applications, common practice assumes that particles are spherical, but they are not; they are usually quite irregularly shaped. In pollution control technology design applications, size of the particle is taken into consideration, but we are most concerned with the behavior of the particle in a gaseous wastestream. Size and shape, as well as other factors, affect particle movement. Particle density must also be taken into consideration.

CHARACTERISTICS OF PARTICLES

Understanding the characteristics of particles is important in air pollution control technology for the following reasons: The efficiency of the particle collection mechanisms strongly depends on particle size, the particle size distribution of flue gas dictates the manner in which air testing is performed, the particle size distribution of flue gas determines the operating conditions necessary to collect the particles, and particle characteristics are important in determining the behavior of particles in the respiratory tract.

SURFACE AREA AND VOLUME

The size range of particles of concern in air pollution studies is remarkably broad. Some of the droplets collected in the mist eliminators of wet scrubbers and the solid particles collected in large-diameter cyclones are as large as raindrops. Some of the small particles created in high-temperature incinerators and metallurgical processes can consist of less than 50 molecules clustered together. It is important to recognize the categories because particles behave differently depending on their size. Most particles of primary interest in air pollution emission testing and control have diameters that range from 0.1 to 1000 µm. Following are some useful conversions for particle sizes:

$$\text{Micrometer} = 1/1{,}000{,}000 \text{ meter} \tag{5.20}$$

$$\text{Micrometer} = 1/10{,}000 \text{ centimeter} \tag{5.21}$$

$$1000 \text{ micrometers} = 1.0 \text{ millimeter} = 0.1 \text{ centimeter} \tag{5.22}$$

To appreciate the differences in particle sizes commonly found in emission testing and air pollution control, compare the diameters, volumes, and surfaces areas of the particles shown in Table 5.12; for example, 1000-µm particles are 1,000,000,000,000 (1 trillion) times larger in volume than 0.1-µm particles. As an analogy, assume that the 1000-µm particle is a large domed sports stadium. A basketball in this stadium would be equivalent to a 5-µm particle. Approximately 100,000

TABLE 5.12
Spherical Particle Diameter, Volume, and Area

Particle Diameter (µm)	Particle Volume (cm^3)	Particle Area (cm^2)
0.1	5.23×10^{-16}	3.14×10^{-10}
1	5.23×10^{-13}	3.14×10^{-8}
10	5.23×10^{-10}	3.14×10^{-6}
100	5.23×10^{-7}	3.14×10^{-4}
1000	5.23×10^{-4}	3.14×10^{2}

Source: Adapted from USEPA, *Basic Concepts in Environmental Sciences*, U.S. Environmental Protection Agency, Washington, D.C., 2007.

spherical particles of 0.1-µm diameter would fit into this 5-µm basketball. Now consider that the entire 1000-µm stadium is the size of a small raindrop. As previously stated, particles over this entire size range of 0.1 to 1000 µm are of interest in air pollution control (USEPA, 2007).

Equations for calculating the volume and surface area of spheres are provided below:

$$\text{Surface area of a sphere} = 4\pi r^2 = \pi D^2 \tag{5.23}$$

$$\text{Volume of a sphere} = 4\pi r^3/3 = \pi D^3/6 \tag{5.24}$$

where

r = Radius of sphere
D = Diameter of sphere

■ EXAMPLE 5.3

Problem: Calculate the volumes of three spherical particles (in cm^3) given that their actual diameters are 0.6, 6.0, and 60 µm.

Solution:

$$V = 4/3\pi r^3 = 4.19r^3$$

For a 0.6-µm particle, $r = 0.3$ µm = 0.00003 cm:

$$V = 4.19(0.00003\text{ cm})^3 = 1.13 \times 10^{-13}\text{ cm}^3$$

For a 6.0-µm particle, $r = 3.0$ µm = 0.0003 cm:

$$V = 4.19(0.0003\text{ cm})^3 = 1.13 \times 10^{-10}\text{ cm}^3$$

For a 60-µm particle, $r = 30$ µm = 0.003 cm:

$$V = 4.19(0.003\text{ cm})^3 = 1.13 \times 10^{-7}\text{ cm}^3$$

AERODYNAMIC DIAMETER

Particles emitted from air pollution sources and formed by natural processes have a number of different shapes and densities. Defining particle size for a spherical particle is easy; it is simply the diameter of the particle. For nonspherical particles, the term "diameter" is not strictly applicable. In air pollution control, particle size is based on particle behavior in the Earth's gravitational field. The *aerodynamic equivalent diameter* refers to a spherical particle of unit density that falls at a standard velocity. As noted earlier, particle size is important because it determines atmospheric lifetime, effects on light scattering, and deposition in the lungs. It is important to keep in mind that, when we speak of particulate size, we are not referring to particulate shape. This is an obvious point but also a very important one. For the sake of simplicity, it is common practice to assume that particles are spherical, even though particles are not spherical and are usually quite irregularly shaped. In pollution control technology design applications, size of the particle is taken into consideration, but it is the behavior of the particle in a gaseous wastestream that we are most concerned with.

To better understand this important point, drop a flat piece of regular typing paper from the top of a 6-foot ladder. The paper will fall irregularly to the floor. Now, crumple the same sheet of paper and drop it from the ladder and see what happens. The crumpled paper will fall rapidly. Thus, size is important but other factors such as particle shape are also important. The aerodynamic diameter for all particles greater than 0.5 µm can be approximated using the following equation (for particles less than 0.5 µm, refer to aerosol textbooks to determine the aerodynamic diameter):

$$d_{pa} = d_{ps}\sqrt{P_p} \tag{5.25}$$

where

d_{pa} = Particle aerodynamic diameter (µm).
d_{ps} = Stokes diameter (µm).
P_p = Particle density (g/cm^3).

Along with particle size and shape, particle density must be taken into consideration; for example, a baseball and a whiffle ball have approximately the same diameter but behave quite differently when tossed into the air. Particle density affects the motion of a particle through a fluid and is taken into account in Equation 5.25. The Stokes diameter for a particle is the diameter of the sphere that has the same density and settling velocity of the particle. It is based on the aerodynamic drag force caused by the difference in velocity of the particle and the surrounding fluid. For smooth, spherical particles, the Stokes diameter is identical to the physical or actual diameter.

Inertial sampling devices such as cascade impactors are used for particle sizing to determine the aerodynamic diameter. The aerodynamic diameter is a useful measure for all particles including fibers and particle clusters, but it is not a true size because nonspherical particles require more than one dimension to characterize their size.

Note: In this text, particle diameter and particle size refer to the aerodynamic diameter, unless otherwise stated.

PARTICLE SIZE CATEGORIES

Because the range of particle sizes of concern for air emission evaluation is quite broad, it is beneficial to divide this range into smaller categories. Defining different size categories is useful because particles of different sizes behave differently in the atmosphere and the respiratory system. The USEPA has defined terms for categorizing particles of different sizes; Table 5.13 displays this terminology along with the corresponding particle sizes.

DID YOU KNOW?

Particles that appear to have different physical sizes and shapes can have the same aerodynamic diameter. Conversely, some particles that appear to be visually similar can have somewhat different aerodynamic diameters.

TABLE 5.13
USEPA Terminology for Particle Sizes

USEPA Description	Particle Size
Supercoarse	$d_{pa} > 10$ µm
Coarse	2.5 µm $< d_{pa} \leq 10$ µm
Fine	0.1 µm $< d_{pa} \leq 2.5$ µm
Ultrafine	$d_{pa} \leq 0.1$ µm

Note: d_{pa} = particle aerodynamic diameter.

Regulated Particulate Matter Categories

In addition to the terminology provided in Table 5.13, the USEPA also categorizes particles as indicated in the following text. These particle categories are important because particulate matter is regulated and tested for under these categories.

Total Suspended Particulate Matter

Particles ranging in size from 0.1 to about 30 µm in diameter are referred to as total suspended particulate matter (TSP). TSP covers a broad range of particle sizes, including fine, coarse, and supercoarse particles.

PM_{10}

PM_{10} is defined as particulate matter with a diameter of 10 µm collected with 50% efficiency by a PM_{10} sampling collection device. For convenience in this text, the term PM_{10} will be used to include all particles having an aerodynamic diameter of less than or equal to 10 µm. PM_{10} is regulated as a specific type of pollutant because particles this size are considered respirable. In other words, particles less than approximately 10 µm can penetrate into the lower respiratory tract. The particle size range between 0.1 and 10 µm is especially important in air pollution studies. A major fraction of the particulate matter generated in some industrial sources is in this size range.

$PM_{2.5}$

$PM_{2.5}$ is defined as particulate matter with a diameter of 2.5 µm collected with 50% efficiency by a $PM_{2.5}$ sampling collection device. For convenience in this text, the term $PM_{2.5}$ will be used to include all particles having an aerodynamic diameter of less than or equal to 2.5 µm. The USEPA chose 2.5 µm as the partition between fine and coarse particulate matter. Particles less than approximately 2.5 µm are regulated as $PM_{2.5}$. Air emission testing and air pollution control methods for $PM_{2.5}$ particles are different than those for coarse and supercoarse particles. $PM_{2.5}$ particles settle quite slowly in the atmosphere relative to coarse and supercoarse particles. Normal weather patterns can keep $PM_{2.5}$ particles airborne for several hours to several days and allow these particles to cover hundreds of miles. $PM_{2.5}$ particles can cause health problems due to their potentially long airborne retention time and the inability of the human respiratory system to defend itself against particles of this size. In addition, the chemical makeup of $PM_{2.5}$ particles is quite different than that of coarse and supercoarse particles. USEPA data indicate that $PM_{2.5}$ particles are composed primarily of sulfates, nitrates, organic compounds, and ammonium compounds. The USEPA has also determined that $PM_{2.5}$ particles often contain acidic materials, metals, and other contaminants believed to be associated with adverse health effects. Particles less than 1 µm in diameter are termed *submicrometer particles* and can be the most difficult size to collect. Particles in the range of 0.2 to 0.5 µm are common in many types of combustion, waste incineration, and metallurgical sources. Particles in the range of 0.1 to 1.0 µm are important because they can represent a significant fraction of the particulate emissions from some types of industrial sources and because they are relatively difficult to collect.

Particles Less Than 0.1 μm

Particles can be much smaller than 0.1 μm. In fact, particles composed of as few as 20 to 50 molecules clustered together can exist in a stable form. Some industrial processes such as combustion and metallurgical sources generate particles in the range of 0.01 to 0.1 μm. These sizes are approaching the size of individual gas molecules, which are in the range of 0.0002 to 0.001 μm. However, particles in the size range of 0.01 to 0.1 μm tend to agglomerate rapidly to yield particles in the greater than 0.1-μm range. Accordingly, very little of the particulate matter entering an air pollution control device or leaving the stack remains in the very small size range of 0.01 to 0.1 μm.

Condensable Particulate Matter

Particulate matter that forms from condensing gases or vapors is referred to as *condensable particulate matter*. Condensable particulate matter forms by chemical reactions as well as by physical phenomena. Condensable particulate matter is usually formed from material that is not particulate matter at stack conditions but which condenses or reacts upon cooling and dilution in the ambient air to form particulate matter. The formation of condensable particulate matter occurs within a few seconds after discharge from the stack. From a health standpoint, condensable particulate matter is important because it is almost entirely contained in the $PM_{2.5}$ classification.

Size Distribution

Particulate emissions from both manmade and natural sources do not consist of particles of any one size. Instead, they are composed of particles over a relatively wide size range. It is often necessary to describe this size range. Particulate matter for size distribution evaluation is measured in a variety of ways. The data must be measured in a manner whereby they can be classified into successive particle diameter size categories.

PARTICLE FORMATION

The range of particle sizes formed in a process is largely dependent on the types of particle formation mechanisms present. The general size range of particles can be estimated by simply recognizing which particle formation mechanisms are most important in the process being evaluated. The most important particle formation mechanisms in air pollution sources include physical attrition/mechanical dispersion, combustion particle burnout, homogeneous and heterogeneous nucleation, and droplet evaporation. Several particle formation mechanisms can be present in an air pollution source. As a result, the particles created can have a wide range of sizes and chemical composition. Particle formation mechanisms are described in detail below.

Physical Attrition

Physical attrition generates primarily moderate-to-large sized particles and occurs when two surfaces rub together; for example, the grinding of a metal rod on a grinding wheel yields small particles that break off from both surfaces. The compositions and densities of these particles are identical to the parent materials. In order for fuel to burn, it must be pulverized or atomized so there is sufficient surface area exposed to oxygen and high temperature. As indicated in Table 5.14, the surface area of particles increases substantially as more and more of the material is reduced in size. Accordingly, most industrial-scale combustion processes use one or more types of physical attrition to prepare their fuel or introduce it into the furnace. For example, oil-fired boilers use pulverizers to reduce the chunks of coal to sizes that can be burned quickly. Oil-fired boilers use atomizers to disperse the oil as fine droplets. In both cases, the fuel particle size is generally reduced to the range of 10 to 1000 μm by physical attrition.

TABLE 5.14
Surface Area Comparison for Spherical Particles of Different Diameters[a]

Total Mass	Diameter of Particles (μm)	Number of Particles (Approximate, in millions)	Total Surface Area (cm^2)	Total Surface Area (m^2)
	1000	0.002	60	0.006
	100	2	600	0.06
1.0 g	10	2000	6000	0.6
	1	2,000,000	60,000	6
	0.1	2,000,000,000	600,000	60

Source: Adapted from USEPA, *Basic Concepts in Environmental Sciences*, U.S. Environmental Protection Agency, Washington, D.C., 2007.

[a] Based on density of 1.0 g/cm^3.

COMBUSTION PARTICLE BURNOUT

When fuel particles are injected into the hot furnace area of the combustion process, such as in fossil-fuel-fired boilers, most of the organic compounds in the fuel are vaporized and oxidized in the gas stream. Fuel particles become smaller as the volatile matter leaves, and they are quickly reduced to only the incombustible matter (ash) and the slow-burning char composed of organic compounds. Eventually, most of the char will also burn, leaving primarily the incombustible material. As combustion progresses, the fuel particles, which started as 10- to 1000-μm particles, are reduced to ash and char particles that are primarily in the range of 1 to 100 μm. This mechanism for particle formation is combustion particle burnout.

HOMOGENEOUS AND HETEROGENEOUS NUCLEATION

Homogeneous and heterogeneous nucleation involves the conversion of vapor-phase materials to a particulate form. In both cases, the vapor-containing gas streams must cool to the temperature at which nucleation can occur, which is the dew point. Each vapor-phase element and compound has a different dew point; therefore, some materials nucleate in relatively hot gas zones while others remain as vapor until the gas stream is cold.

- *Homogeneous nucleation* is the formation of new particles composed almost entirely of the vapor-phase material. The formation of particles by homogeneous nucleation involves only one compound.
- *Heterogeneous nucleation* is the accumulation of material on the surfaces of existing particles. In the case of heterogeneous nucleation, the resulting particle consists of more than one compound.

The two main categories of vapor-phase material that can nucleate air pollution source gas streams are (1) organic compounds, and (2) inorganic metals and metal compounds. In a waste incinerator, waste that volatizes to organic vapor is generally oxidized completely to carbon dioxide and water. However, if there is an upset in the combustion process, a portion of the organic compounds or their partial oxidation products remains in the gas stream as it leaves the incinerator. Volatile metals and metal compounds such as mercury, lead, lead oxide, cadmium, cadmium oxide, and arsenic trioxide can also volatilize in the hot incinerator. Once the gas stream passes through the heat-exchange equipment (i.e., waste heat boiler) used to produce steam, the organic vapors and metal vapors can condense homogeneously or heterogeneously. Generally, the metals and metal compound search their dew point first and begin to nucleate in relatively hot zones of the unit.

The organic vapors begin to condense in areas downstream from the process where the gas temperatures are cooler. These particles must then be collected in the downstream air pollution control systems. Homogeneous and heterogeneous nucleation generally creates particles that are very small, often between 0.1 and 1.0 µm.

Heterogeneous nucleation facilitates a phenomenon known as enrichment of particles in the submicrometer size range. The elemental metals and metal compounds volatized during high-temperature operations (e.g., fossil-fuel combustion, incineration, industrial furnaces, metallurgical processes) nucleate preferentially as small particles or on the very small particles produced by these processes. Consequently, very small particles have more potentially toxic materials than the very large particles leaving the processes. Heterogeneous nucleation contributes to the formation of article distributions that have quite different chemical compositions in different size ranges.

Another consequence of particle formation by heterogeneous nucleation is that a greater variety of chemical reactions may occur in the gas stream than would otherwise happen. During heterogeneous nucleation, small quantities of metals are deposited on the surfaces of many small particles. In this form, the metals are available to participate in catalytic reactions with gases or other vapor-phase materials that are continuing to nucleate. Accordingly, heterogeneous nucleation increases the types of chemical reactions that can occur as the particles travel in the gas stream from the process source and through the air pollution control device.

Droplet Evaporation

Some air pollution control system use solids-containing water recycled from wet scrubbers to cool the gas streams. This practice inadvertently creates another particle formation mechanism that is very similar to fuel burnout. The water streams are atomized during injection into the hot gas streams. As these small droplets evaporate to dryness, the suspended and dissolved solids are released as small particles. The particle size range created by this mechanism has not been extensively studied; however, it probably creates particles that range in size from 0.1 to 20 µm. All of these particles must then be collected in the downstream air pollution control systems.

COLLECTION MECHANISMS

When sunlight streams into a quiet room, particles of many different shapes and sizes can be seen; some appear to float while others slowly settle to the floor. All of these small particles are denser than the room air, but they do not settle very quickly. The solid, liquid, and fibrous particles formed in air pollution sources behave in a manner that is very similar to standard household dusts and other familiar particles. What we instinctively understand about these everyday particles can be applied in many respects to the particles from air pollution sources.

There are, however, two major differences between industrially generated particles and those in more familiar settings. The industrial particles are much smaller than most household particles. Also, some industrial particles have complex chemical compositions and include compounds and elements that are known to be toxic.

Emission testing devices and air pollution control systems apply forces to the particles in order to remove them from the gas stream. These forces include inertial impaction and interception, Brownian diffusion, gravitational settling, electrostatic attraction, thermophoresis, and diffusiophoresis. These forces are basically the "tools" that can be used for separating particles from the gas stream. All of these collection mechanism forces are strongly dependent on particle size.

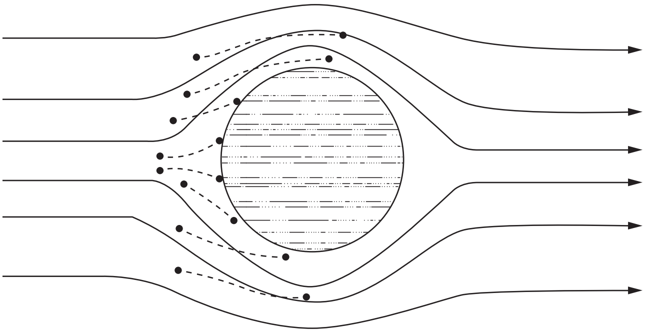

FIGURE 5.5 Particle collection on stationary object.

INERTIAL IMPACTION AND INTERCEPTION

Due to inertia, a particle moving in a gas stream can strike slowly moving or stationary obstacles in its path. As the gas stream deflects around the obstacle, the particle continues toward the object and impacts it. The obstacle may be a solid particle, stationary object (as shown in Figure 5.5), or a water droplet. Two primary factors affect the probability of an impaction occurring: (1) aerodynamic article size, and (2) the difference in velocity between the particle and the obstacle. Larger particles are collected more easily than smaller particles due to their greater inertia. Also, collection efficiency increases as the difference in velocity between the particle in the gas stream and the obstacle (or target) increases. Inertial impaction is analogous to a small car riding down an interstate highway at 65 mph and approaching a merge lane where a slow-moving truck is entering the highway. If the car is unable to get into the passing lane to go around the merging truck, there could be an impaction incident. Larger cars will have more difficulty going around the truck than smaller cars. Also, the faster the car is going relative to the truck, the more probable is an impaction.

The efficiency of impaction is directly proportion to the impaction parameter shown in Equation 5.26. As the value of this parameter increases, the efficiency of inertial impaction increases. This parameter is related to the square of the Stokes particle diameter and the difference in velocity between the particle and the target droplet:

$$K_I = \frac{C_c \left(d_{ps}\right)^2 v P_p}{18 \mu D_c} \tag{5.26}$$

where

K_I = Impaction parameter (dimensionless).
C_c = Cunningham slip correction factor (dimensionless).
d_{ps} = Stokes particle diameter (μm).
v = Difference in velocity (cm/sec).
P_p = Particle density (g/cm^3).
μ = Gas viscosity (g/cm-sec).
D_c = Diameter of a droplet (cm).

DID YOU KNOW?

Inertial impaction and interception are usually highly efficient for particles larger than 10 μm. They become progressively less effective as the size decreases. Impaction is not efficient for particles less than 0.3 μm due to their low inertia.

The Cunningham slip correction factor (also called Cunningham's correction factor) accounts for molecular slip. Molecular slip occurs when the size of the particle is the same magnitude as the distance between gas molecules. The particle no longer moves as a continuum in the gas but as a particle among discrete gas molecules, thereby reducing the drag force. For particles in air with actual diameter of 1.0 μm and less, the Cunningham correction factor is significant.

Inertial impaction occurs when obstacles (e.g., water droplets) are directly in the path of the particle moving in the gas stream. Sometimes the obstacle or target is offset slightly from the direct path of the moving particle. In this instance, as the particle approaches the edge of the obstacle, the obstacle may collect the particle through a process called *interception*.

BROWNIAN DIFFUSION

Brownian diffusion becomes the dominant collection mechanism for particles less than 0.3 μm and is especially significant for particles ranging in size from 0.01 to 0.1 μm. Very small particles in a gas stream deflect slightly when gas molecules strike them. Transfer of kinetic energy from the rapidly moving gas molecule to the small particle causes this deflection, called *Brownian diffusion*. These small particles are captured when they impact a target (e.g., liquid droplet) as a result of this random movement. *Diffusivity* is a measure of the extent to which molecular collisions influence very small particles, causing them to move in a random manner across the direction of gas flow. The diffusion coefficient in the equation below represents the diffusivity of a particle at certain gas stream conditions.

$$D_p = \frac{C_c KT}{3\pi d_{pa}\mu} \tag{5.27}$$

where

D_p = Diffusion coefficient (cm^2/sec).
C_c = Cunningham slip correction factor (dimensionless).
K = Boltzmann constant (g-cm^2/sec^2 K).
T = Absolute temperature (degrees K).
d_{pa} = Particle aerodynamic diameter (μm).
μ = Gas viscosity (kg/m-sec).

GRAVITATIONAL SETTLING

Particles in still air have two forces acting on them: (1) a gravitational force downward, and (2) the air resistance (or drag) force upward. When particles begin to fall, they quickly reach a terminal settling velocity, which represents the constant velocity of a falling particle when the gravitational force downward is balanced by the air resistance (or drag) force upward. The terminal settling velocity can usually be expressed using Equation 5.28. (Note that Equation 5.28 is applicable for particles less than 80 μm in size [aerodynamic diameter] with a Reynolds number less than 2.0 and a low velocity.)

$$v_t = \frac{GP_p\left(d_{ps}\right)^2 C_c}{18\mu} \tag{5.28}$$

where

v_t = Terminal settling velocity (cm/sec).
G = Gravitational acceleration (cm/sec^2).
P_p = Density of particle (g/cm^3).
d_{ps} = Stokes particle diameter (cm).
C_c = Cunningham slip correction factor (dimensionless).
μ = Viscosity of air (g/cm-sec).

DID YOU KNOW?

Due to the low settling velocities of essentially all particles with aerodynamic diameters less than 80 µm, gravitational settling of particles is not used for the initial separation of particles from the gas stream. However, this does not mean that gravitational settling is unimportant. Settling by gravity plays an important role in the removal of large clumps of dust when fabric filter bags and electrostatic precipitation collection plates are cleaned.

ELECTROSTATIC ATTRACTION

In air pollution control, electrostatic precipitators (ESPs) utilize electrostatic attraction for particulate collection. Electrostatic attraction of particles is accomplished by establishing a strong electrical field and creating unipolar ions. The particles passing through the electrical field are charged by the ions being driven along the electrical field lines. Several parameters dictate the effectiveness of electrostatic attraction, including the particle size, gas flow rate, and resistivity. The particles will eventually reach a maximum or saturation charge, which is a function of the particle area. The saturation charge occurs when the localized field created by the already captured ions is sufficiently strong to deflect the electrical field lines. Particles can also be charged by diffusion of ions in the gas stream. The strength of the electrical charges imposed on the particles by both mechanisms is particle size dependent.

Resistivity is a measure of the ability of the particle to conduct electricity and is expressed in units of ohm-cm. Particles with low resistivity have a greater ability to conduct electricity (and higher electrostatic attraction) than particles with high resistivity. The following factors influence resistivity:

- Chemical composition of the gas stream
- Chemical composition of the particle
- Gas stream temperature

THERMOPHORESIS

Thermophoresis is particle movement caused by thermal differences on two sides of the particle. Gas molecules at higher temperatures have greater kinetic energy than those at lower temperatures. Therefore, when the particle collides with a gas molecule from the hotter side, the particle receives more kinetic energy than when it collides with a gas molecule from the cooler side. Accordingly, particles tend to be deflected toward the colder area.

DIFFUSIOPHORESIS

Diffusiophoresis is particle movement caused by concentration differences on two sides of the particle. When there is a strong difference in the concentration of gas molecules on two sides of the particle, there is a difference in the number of molecular collisions, which causes an imbalance in

DID YOU KNOW?

Electrostatic precipitators are designed based on the flow rate of the flue gas to be treated. Flow rates that exceed design specifications may result in increased penetration of particulate matter. Flow rates that are too low may allow particulate matter to drop out of the gas stream near the inlet of the electrostatic precipitator and lead to buildup of particulate matter in the ducts.

DID YOU KNOW?

Diffusiophoresis can be important when the evaporation or condensation of water is involved, as these conditions create substantial concentration gradients. The normal differences in pollutant concentration are not sufficient to cause significant particle movement.

the total kinetic energies of the gas molecules. Gas molecules in the high-concentration area that strike a particle transmit more kinetic energy to the particle than do molecules in the area with a lower concentration; therefore, particles tend to move toward the area of lower concentration.

ATMOSPHERIC DISPERSION, TRANSFORMATION, AND DEPOSITION

Applying a knowledge of air pollution dynamics and measurement is an important scientific skill. Practitioners are usually well founded in the pertinent related sciences and modeling aspects applicable to their studies and analyses of air pollutants in the ambient atmosphere. However, to get at the very heart of air pollution, the air pollution practitioner must also be well versed in determining the origin of the pollutants and must understand the mechanics of pollutant dispersal, transport, and deposition.

Air pollutant practitioners must constantly deal with one basic fact—that air pollutants are mobile. They do not stay at their release site. Pollutants are dispersed by mean wind flow conditions and turbulence, local topographic features, and other physical conditions. The air pollution practitioner needs detailed knowledge of the atmospheric processes that govern air contaminant dispersal and fate, along with a thorough understanding of the pollutants themselves. These processes include chemical transformation, deposition, and washout.

Chemical transformation in the atmosphere includes, for example, the conversion of precursor substances to secondary pollutants such as ozone. Transformations affect the final impact of air pollutants and are both chemical and physical. Pollutants emitted to the atmosphere eventually return to Earth via deposition (depletion) mechanisms. Two common ones are dry deposition (the removal of both particles and gases as they come into contact with the Earth's surface) and washout (the uptake of particles and gases by water droplets and snow and their removal from the atmosphere as precipitation). Possibly the most recognizable form of pollution depletion from the atmosphere is acid deposition (acid rain). In the following sections, we discuss atmospheric dispersion of air pollutants in greater detail and the main factors associated with this phenomenon, including weather, turbulence, adiabatic lapse rate, mixing, topography, temperature inversions, plume rise, and transport.

WEATHER

Earth's atmospheric air is in constant motion. Air masses warmed by solar radiation rise at the equator, move toward the poles, sink and flow downward, and eventually return to the equator. As a result of Earth's rotation, major wind patterns develop near the Earth's surface. In daytime, land warms more quickly than the sea and cools more quickly at night, creating local wind patterns driven by this differential warming and cooling between the land and adjacent water bodies. Wind patterns also affect precipitation. Warm, moisture-laden air from the oceans travels inland, where the air masses cool, causing rain, hail, sleet, or snow.

Weather determines many factors related to air quality. Air quality varies tremendously from day to day, even though pollutant emissions may remain relatively constant, because of the many ways weather controls air movement. Weather conditions have significant favorable and unfavorable impacts on air quality and air pollution, especially noticeable in local conditions. On hot, sunny days with calm weather and stagnating high-pressure cells, air pollutants build up at the ground level. Cool, windy, stormy weather with turbulent low-pressure cells and cold fronts allows the upward mixing and dispersal of air pollutants, carrying them quickly away from emission sources.

Weather impacts pollution levels in mechanical and chemical ways. Precipitation works to physically clean pollutants from the air, transferring them to rivers, streams, lakes, or the soil. Winds transport pollutants from one place to another and dilute them with cleaner air, thus lowering pollution levels in release areas. In a low-pressure cell, air and its accompanying pollution are carried high on air heated by the sun. When wind accompanies this rising air mass, the polluted air is mixed with fresh air. In a high-pressure cell, the opposite occurs, with air and pollutants sinking toward the ground. With no wind, pollutants are concentrated and held near the ground—creating serious air pollution episodes.

Weather also affects pollution levels chemically. Air turbulence and winds mix pollutants into a huge atmospheric chemical broth. Solar energy and moisture in the clouds mixed with highly reactive chemicals causes chemical reactions and the formation of secondary pollutants. Often, secondary pollutants are more dangerous than the individual elements that form them.

TURBULENCE

Atmosphere turbulence, which results from wind speed and convective conditions related to the change of temperature with height above the Earth's surface, is directly related to stability, a function of vertical distribution of atmospheric temperature. Atmospheric stability refers to the susceptibility of rising air parcels to vertical motion. Atmospheric stability or instability must be considered when establishing pollutant dispersion rates. The stability of the atmosphere (for our purpose here) refers to the lower boundary of the Earth, where air pollutants are emitted.

The degree of turbulence in the atmosphere is usually classified by stability class. Ambient and adiabatic lapse rates are a measure of atmospheric stability. Stability is divided into three classes—stable, unstable, and neutral:

- A stable atmosphere is marked by air cooler at the ground than aloft, by low wind speeds, and, consequently, by a low degree of turbulence. A plume of pollutants released into a stable lower layer of the atmosphere can remain relatively intact for long distances. Stable air discourages the dispersion and dilution of pollutants.
- An unstable atmosphere is marked by a high degree of turbulence, and a plume of pollutants may exhibit a characteristic looping appearance produced by turbulent eddies.
- A neutrally stable atmosphere (an intermediate class between stable and unstable conditions) is often characterized by a coning appearance as the edges of a plume of pollutants spread out in a V shape.

The importance of the state of the atmosphere and the effects of stability cannot be overstated. How and at what speed pollutants disperse vertically into the atmosphere are mainly determined by the rate of change of air temperature with height (altitude). Air stability is a primary factor in determining where pollutants will be carried and how long they remain aloft. Stable air slows down the dispersion and dilution of pollutants. In unstable air conditions, rapid vertical mixing takes place, encouraging pollutant dispersal and increasing air quality.

MIXING

For effective pollutant dispersal, turbulent mixing must occur within the atmosphere. The result of the movement of air in the vertical dimension, turbulent mixing is enhanced by vertical temperature differences. The larger the vertical air column in which the mixing takes place and the steeper the temperature gradient, the more vigorous the turbulent and convective atmospheric mixing.

TOPOGRAPHY

Topography may affect air motion near point and area sources (areas encompassing less than 100 miles). Most large urban centers in the United States grew along sea and lake coastal areas, which now contain much heavy industry. Pollution dispersion processes in these urban centers are significantly impacted by local air flow patterns. Local weather patterns are also affected by topographic features, especially lakes, seas, and open land. Winds that sweep over long open stretches affect vertical mixing and pollutant dispersal. Heating and cooling land and water surfaces may also precipitate the formation of inversions near the sea or lake shore during seasonal changes.

Hills and mountains tend to cause a decrease in wind speed (because of their surface roughness) and form physical barriers that prevent air movement. This can slow pollutant dispersal. River valley areas also routinely suffer from industry-related pollution. Early settlements often began in river valleys, because of water supply and transportation factors provided by local river systems. Industry came along with the settlers, inevitably and invariably producing air pollutants. Because of the terrain and physical configuration, air pollutants hang in valleys, causing problems with local air quality.

Winds that move through valleys are called *slope winds*, which, like water, flow downhill to the valley floor. There, they transform to valley winds, which flow down-valley with river flow. Down-valley winds, lighter than slope winds, flood the valley floor with a large volume of air. This intensifies normal levels of surface inversion produced by radiative cooling. Over the course of the night, the inversion deepens, often reaching its maximum depth just before dawn. The height of the inversion layer is dependent on the depth of the valley and the intensity of the radiative cooling process.

TEMPERATURE INVERSIONS

Extreme cases of atmospheric stability called *temperature inversions* create a virtual lid on the upward movement of atmospheric pollution. From an air-quality standpoint, two types of inversions are important: radiation and subsidence inversions. Radiation inversions simultaneously trap gases and particulates, creating a concentration of pollutants and also prompting the formation of fog. Characteristically a nocturnal phenomenon, they are caused by surface cooling. The Earth's radiant heat tends to be absorbed by water vapor in the atmosphere on cloudy nights. Some of this heat reradiates back to the surface. Clear winter nights cause the surface to more readily radiate energy to the atmosphere and beyond, which allows the ground to cool more rapidly. The air in contact with the cooler ground also cools, dropping the temperature of the air just above the ground even more, creating an inversion close to the ground that lasts only a matter of hours. In large urban areas, radiation inversions usually begin to form at the worst time of the day for human concerns—when early evening traffic begins to build up. The inversion traps automobile exhaust at ground level, causing elevated concentrations of pollution for commuters. Because during evening hours photochemical reactions halt, carbon monoxide accumulates. When the sun warms the ground at dawn, the inversion starts to break up and pollutants that were trapped in the stable air mass suddenly fall back to Earth. This process, called *fumigation*, can cause short-lived, high concentrations of ground-level pollution (Masters, 2007).

Subsidence inversions (usually associated with a high-pressure system) are also known as *anticyclones*. They may significantly affect pollutant dispersion over large regions. Subsidence inversions are caused by the characteristic sinking motion of air in a high-pressure cell; air in the middle of a high-pressure zone descends slowly and is compressed and heated. Forming a blanket of warm air over the cooler air below, it creates an inversion that prevents further vertical movement of air and can range from several hundred to several thousand meters above the surface.

PLUME RISE

Viewing the shape of a smoke trail or plume from a tall stack located on flat terrain allows us to quickly determine the stability of the lower atmosphere. Plume formation and fate depend on a number of related factors: (1) the nature of the pollutants, (2) meteorological factors, (3) source obstructions, and (4) downwind local topography. Maximum ground-level concentrations occur from the vicinity of the smokestack to some distance downwind.

In a slightly stable atmosphere, a typical plume "cones." In a highly unstable atmosphere, a looping plume forms, and the stream of emitted pollutants undergoes rapid mixing. Winds in unstable atmospheres cause large eddies, sometimes carrying the entire plume to the ground and causing high concentrations close to the stack before dispersion is complete. Extremely stable atmospheres cause a fanning plume to spread horizontally with little mixing. An inversion layer a short distance above the plume source causes the plume to fumigate. Inversion conditions below the plume source cause the plume to loft. When an inversion layer prevails both above and below the plume source, the plume issuing from a smokestack tends to be trapped. Neutral conditions cause the plume to rise directly into the atmosphere.

Of course, pollutants rarely emit from a single point source (e.g., smokestack plume). In large urban areas, many plumes collectively combine into a large city plume, the dispersion of which presents a huge environmental challenge. Local conditions cannot disperse the sheer mass of pollutants. High pollutant concentrations from city plumes frequently affect human health and welfare.

An already contaminated environment also affects and compounds air-quality problems associated with dispersion of city plumes. Though conventional processes work to disperse emissions from point sources within the city plume, microclimates within the city and the volume of pollutants they must handle sometimes prevent the conventional processes from dispersing effectively. Compounding conditions, including topographical barriers, surface inversions, and stagnating anticyclones, work to intensify the city plume and result in high pollutant concentrations.

TRANSPORT

People are surprised to find out that they breathe air contaminated by pollutants from sources many miles away from their location—often hundreds of miles. As far as many people are concerned, if they can't see it then it doesn't exist (along the lines of "out of sight, out of mind"). We often assume that any pollutants we might encounter in our local environment were generated in our local environment; however, air pollutants can travel far beyond their source points—for example, acid precipitation in the northeast comes from Midwestern emissions. The mobility of wastes carried on the air makes tracking what happens to pollutants a challenge. We determine the impact of these pollutants by modeling where and at what speed local conditions will carry them.

DISPERSION MODELS

To predict or describe the fate of airborne gases, particulate matter, and ground-level concentrations downwind of point sources, we use air-quality models. The first consideration for determining the air-quality impact on a particular area is normal background concentrations—pollutant concentrations from natural sources and distant, unidentified manmade sources. Each geographical area has a background level of contamination, or "signature," an annual mean background concentration level of certain pollutants. An area might normally have a particulate matter reading of 30 to 40 $\mu g/m^3$ over a particular area. Significantly higher particulate matter readings than the background level suggest an additional source. Air-quality data related to that site and its vicinity must be collected and analyzed to establish background contamination levels for a particular source under consideration. The USEPA recognized that, in calculating the atmospheric dispersion of air pollutants, a means to maintain consistency in air-quality analysis had to be established. They published two guidebooks to assist in modeling for air-quality analysis: *Guideline on Air Quality Models* (1986a) and *Industrial Source Complex (ISC) Dispersion Model User's Guide* (1986b).

THE BOTTOM LINE

Only when we lack for air or when the air we breathe is fouled do we give it much thought. Once in a while, air and air-quality problems come to our attention through the media. We hear about the damage we are doing to our atmosphere (the source of our air). We hear about the atrocities that industries and our internal combustion engines have committed against air and how the chemicals used in many modern products have choked the atmosphere with pollutants that have the power to affect our health, our well-being, our environment, our lives. Smog can be offensive and deadly. The burning of fossil fuels has given us acid rain. We have air-quality alerts in smaller urban areas—not simply in big cities any more. Many fear a dangerous climate change—a warming trend known as the greenhouse effect. Manmade chemical compounds are shredding the ozone layer, increasingly exposing us to the sun's ultraviolet radiation. We discuss these problems with air quality and the technologies for their control in the next two chapters.

DISCUSSION QUESTIONS

1. Define air, both chemically and from a human use perspective.
2. Describe the physical makeup of the atmosphere.
3. What physical properties are critical to how air behaves? Discuss and describe them.
4. What factors affect atmospheric dispersion, transformation, and deposition? How? Why?
5. How can air scientists study how pollutants might affect an area? What tools can be used, how do they function, and what other uses can they have?
6. What effects can weather have on dispersal?

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6 Air Pollution

> The sacred texts of the Abrahamic religions contain few instructions about the rest of the living world. The Iron Age scribes who wrote them knew war. They knew love and compassion. They knew purity of spirit. But they did not know ecology.
>
> **Wilson (2002)**

YURK AND *SMILODON*

Timeframe: 12,169 BCE

He sat on the bare ground, leaning against a deadfall, his leather-wrapped legs pulled tight under him, and he watched the swamp. He felt disoriented, detached from the world around him. Even the air around him felt strange; this place was unusually warm. A possum waddled from a copse of vine-maple below him, and Yurk watched the possum move off to the left. The possum was in a hurry, constantly jerking his head to the right, over his shoulder. He darted toward the marshy bank and stopped to sniff the ground. Some noise or an odor carried on the wind seemed suddenly to startle the possum into attention, and he looked back toward Yurk, then moved off into the tall marsh grass, where he disappeared from view.

Rain was coming down in a fine drizzle. The wind sighed through the fir boughs, and the afternoon was redolent with the smell of tree-perfumed air. Even with the light rain and wind, though, Yurk was warm—warmer than he ever remembered being before. He had never been so warm, his whole body at the same time. By a fire, only what faced the fire was warm.

Yurk's weathered face wore a mesmerized look as he chewed on a piece of bark and rested against the decaying trunk of the fallen tree, almost as if he was unaware of his surroundings. His eyes glazed over, as if he was there in shell form only—an empty one at that. Maybe his blank state and hypnotized appearance were the result of the view in front of those blank eyes: Great truncated tree trunks blackened by fire stood above the surface of the swamp water, stark remnants of a very ancient past. A misty pall hung over the swamp as blackness lowered over the forest, and the swamp took on an eerie, forbidding, spectral quality with the coming of night.

The cry of an owl drifted through the dark forest as Yurk stood (an effort that required much exertion from his tired, ancient body). Carefully, he stretched and yawned—careful not because of his frailty or from a sense of impending danger but because of instinct—not fear exactly, just instinct. A lifetime, generations of lifetimes, of the vigilance necessary for survival (both conscious and unconscious) had taught Yurk to be vigilant at all times in this place and time. He was leg-weary and footsore, but that really didn't concern him. He knew his ending time was near—that was why he had traveled better than 200 miles to this place. This place he had come to had been familiar to him years before, but in a very different form. He wanted to explore the wonderment of the swampy terrain that lay before him now.

Yurk was viewing something he had heard about from other clan members but something he had never witnessed before. A swamp.

Yes, a swamp … with blackened remnants of trees. In all his years (he was unusually old for his time and circumstances, more than 60 years), Yurk had never seen such a sight. The landscape he had been familiar with had been covered in snow and ice. He had visited this place many times in the past, and it had always seemed to be a bare plain of ice and snow. He had not been on this journey in many years, but the last time he had come, he had crossed through the open area (now the swamp) on a bridge of thick ice and snow. He and no one else had any idea that a swamp lay below the thick layers of ice and snow. In his absence from this place, though, he began to hear tales from the younger clan hunters and decided to take his last journey to see such a place before he died.

It was so warm.

As he stood, wiping his wet brow and looking out upon the swamp, 30 feet to Yurk's left, working her way toward the top of the steep, craggy ledge on the shear cliff edge, climbed a cat. Like Yurk, the cat had come to this place many times in the past. Although she was not able to cognitively determine the exact difference between the past and the present, she, too, knew this place had changed.

It was so warm.

In the past 15 or so years, the cat, along with her running mates (these cats almost always ventured into the wilderness accompanied, as hunting and killing required help, sometimes lots of help), had, like Yurk and his clan members, crossed the swamp using the ice bridge. But now things were different; the cat knew this.

The cat (known today as *Smilodon*, or saber-toothed tiger) continued slowly, inexorably up the steep slope of the stony ridge. Unlike her climbs up to this ledge in the past, when she had to deal with the slipperiness of the ice sheet that covered the ridge, she should have had very little difficulty climbing the high terminal edge, overlooking the swamp. She was on her last legs, though, in all ways, and her difficulty was even more than that. Even though the going was easier now without the ice and snow, she still struggled her way up to the terminal point … it was so hot. She labored even to breathe.

Yurk and the cat were aware of each other. Each knew the other was there—have no doubt about that. Yurk was probably more fearful of the cat than she was of him … but how could anyone tell? They had been bitter enemies throughout their lives. The cat preferred feasting on mammoths and mastodons (Yurk liked that kind of meat himself), but, when confronted with her only true enemy, the cat knew she was wise to be on guard. Life of any sort was difficult enough … not being alert and wary at all times was certainly an invitation to disaster—for both of them. But things were different now.

It was so warm.

Neither the cat nor Yurk was particularly attentive to the other; they were not as alert, as wary of the other as they had been in the past. Each knew that the days of hunting and protecting themselves were behind them—food was no longer a consideration for either. No, food was not a problem; they were not hungry. Afraid? No, not really.

The cat continued her climb and finally reached the summit. She stood looking out upon the swamp (with one eye barely focused on Yurk). Yurk stood below, looking out on the swamp (aware of her presence as well). They both knew, in their own way, that things were different. Hell, they could feel the difference.

It was so warm.

Warm … yes, it was warm. For their entire lives, they had never known such warmth, had never seen the snow and ice melt, had never witnessed the swampy landscape now before them. Their world was different … fearfully and wonderfully changed.

The warming trend had actually begun about several years earlier, although Yurk and the cat had barely been aware of it because the increase in temperatures had been subtle, just about half a degree Fahrenheit each few months or so. But now, now the difference was obvious. The temperature was a least 10 degrees warmer than they had ever experienced—thus the melt, the freshly uncovered swamp, the rock-strewn ledge … and the warmth, of course.

The cat and Yurk stood for a time, gazing out at the swamp. What this change would mean to their clan and mates—those to follow—they were not capable of determining. What this change would bring to their world, they were not capable of speculating. So they stood, until Yurk sat back down on the ground, his back against the deadfall, and the cat lay down on the heated rocks of the ledge; they were both exhausted, tired, worn out—old, so old, and warm, too warm.

About an hour later, as darkness fell upon the blackened, spectral landscape before them, they both went to sleep, the sleep of the dead, and their own warmth turned cold.

The ambient temperature continued to rise, even now that it was dark, night. A night that when ended would bring the dawn of a new day … and the dawn of a new era.

It was so warm … and getting warmer.

INTRODUCTION

Atmospheric air pollution—what is it? The standard answer might be "contamination of the atmosphere with the harmful byproducts of human activity." Another answer might be "contamination of the atmosphere by the discharge (accidental or deliberate) of one or more of a wide range of toxic airborne substances." The second definition is better than the first because its qualifications about "accidental or deliberate" and its inclusion of "a wide range of toxic airborne substances" are truer to the actual situation. Let's see if we can clear up the confusion and come up with our own definition of air pollution.

First, we need to agree that air pollutants are those substances in the air that are not normal constituents of the atmosphere (e.g., oxygen, nitrogen, water vapor); these abnormal substances are, of course, air pollutants. Another reason why we prefer the second definition is because it is not implicit in its assumption that air pollution is anthropogenic (caused by human activities alone). Air pollution can result from natural sources, and the resulting pollutants can have much more severe and long-lasting effects than air pollution from human activities. For example, an eruption from a volcano can spew vast quantities of dust and gases into the atmosphere in a relatively short period of time. Pollutants from such an eruption can reach the upper atmosphere and act as sunlight reflectors, causing global temperatures to fall slightly for a few years or longer. Other natural air pollutants include smoke from forest fires, salt sea spray, dust blown from desert areas, and pollen grains.

What all this means is that a more definitive definition of air pollution is needed: "Air pollution is the natural or human-induced presence of certain substances in the air in high enough concentrations and for long enough duration to cause undesirable effects."

TYPES AND SOURCES OF AIR POLLUTANTS

Table 1.1 in Chapter 1 lists the categories and types of air pollutants, and Figure 6.1 shows a general classification scheme for air pollutants. Note, however, that we have more than one way to categorize air pollutants. Air pollutants can be classified as either primary or secondary air pollutants. Primary air pollutants are made up of constituents emitted directly into the air from a stationary source (a source contributor) such as factory smoke stack. Secondary air pollutants, however, are made up of elements emitted directly from sources that then form into new substances in the atmosphere as a result of complex chemical reactions involving the primary pollutants and sunlight, such as the conversion of non-methane volatile organic compounds (VOCs) to ozone (O_3). Primary air pollutants may also be categorized by being either stationary (e.g., power plants) or mobile (e.g., automobiles) sources. Indoor and outdoor (or ambient) air pollutants are other frequently used classifications. In this text, we focus on ambient air pollutants but point out that indoor air pollution is beginning to receive the attention it merits.

At the present, two types of ambient air pollutants are regulated under the Clean Air Act (CAA): criteria and hazardous air pollutants. Under the National Ambient Air Quality Standards (NAAQS) promulgated under the CAA, six primary pollutants are characterized. These six pollutants are hazardous to human health or welfare and are generated in relatively large quantities.

Source contributors of air pollutants are shown in Figure 6.2. Transportation is the largest contributor of pollutants, at approximately 46%. Fuel combustion at stationary facilities is the next highest contributor at almost 40%. Industrial processes and miscellaneous sources contribute about 6% each, while solid waste disposal accounts for about 2%.

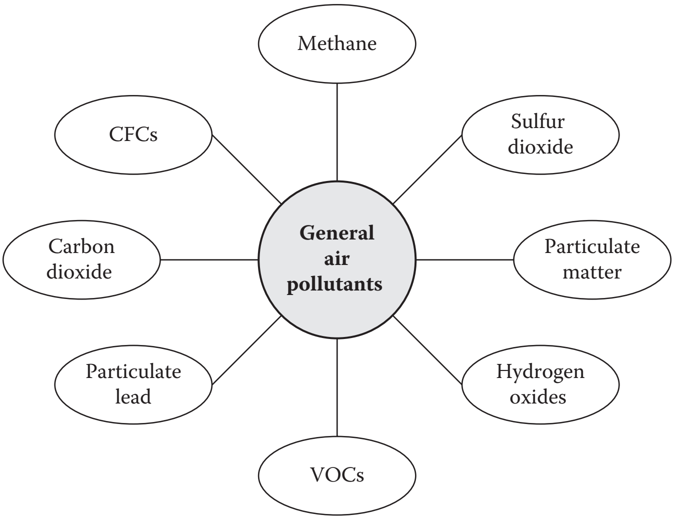

FIGURE 6.1 General air pollutants.

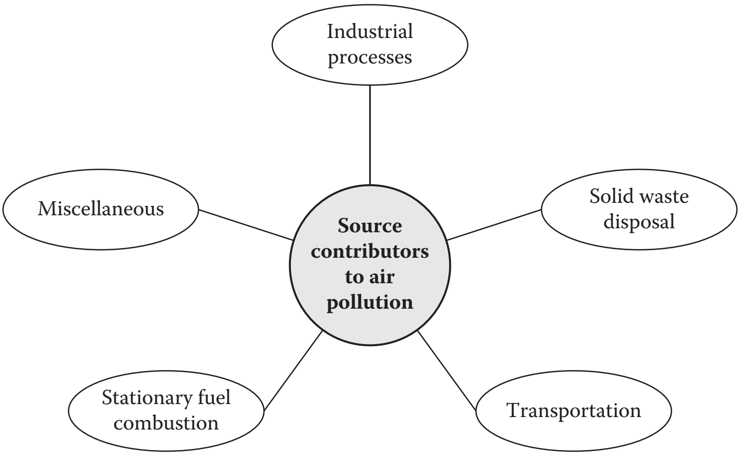

FIGURE 6.2 Source contributors to air pollution.

CRITERIA AIR POLLUTANTS

As shown in Figure 6.3, the criteria air pollutants consist of the six primary criteria pollutants sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), particulates, particulate lead (Pb), and ozone (O_3).

Sulfur Dioxide

The element sulfur may be contained in certain fossil fuels such as coal. The sulfur is oxidized during burning of these fuels, producing sulfur dioxide gas. Sulfur dioxide is a colorless gas with a sharp, choking odor; it irritates the eyes, nose, and throat and causes chronic bronchitis. Approximately 25 million tons of SO_2 are discharged into the atmosphere in the United States each year, mostly from fossil fuel combustion used in electric utility power plants. SO_2 is a constituent of acid rain, and visibility reduction occurs due to the presence of suspended sulfate particles in the atmosphere.

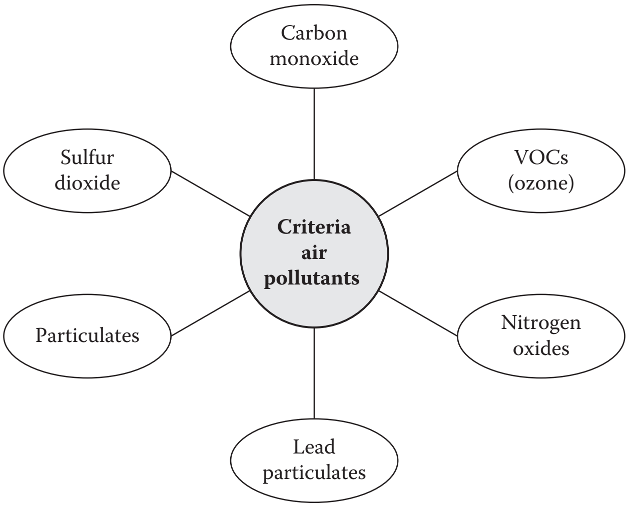

FIGURE 6.3 Criteria air pollutants.

Nitrogen Oxides

Characterized collectively as NO_x, nitrogen oxides come in many forms. Most emissions are initially in the form of nitrogen oxide (NO), which by itself is not harmful at the concentrations usually found in the atmosphere. However, when NO oxidizes to NO_2 in the presence of sunlight, it can react with hydrocarbons to form photochemical smog. NO_2 also reacts with the hydroxyl radical (OH^-) to form nitric acid (HNO_3), a contributor to acid rain. NO is colorless; however, when converted to NO_2 it tends to give smog a reddish-brown color. The largest source of nitrogen oxides is from the oxidation of nitrogen compounds during the combustion of certain fossil fuels, such as coal and gasoline.

Case Study 6.1. Meeting Air Pollution Standards[*]

In 1998, the U.S. Environmental Protection Agency (USEPA) directed 22 states from Missouri to Massachusetts to cut nitrogen emissions by 1.1 million tons by the year 2003. This action, aimed at helping to solve the long-standing dispute between the Midwest and northeastern states over air pollutants that cause smog and acid precipitation, chiefly affected scores of coal-burning power plants from Illinois to Virginia. These plants frequently have smokestacks as tall as 100-story-high buildings and have been responsible for sending tons of the chemicals that produce smog high into the atmosphere, where winds carry them far from their sources. The prevailing winds can carry these pollutants, which are components of ozone and which cause and exacerbate respiratory illnesses, from the Midwest to the Northeast. While lowering allowable emission quantities would reduce the Northeast's levels of smog, the new standards were also designed to create cleaner air in the Midwest and help communities meet air quality standards. The affected Midwestern states criticized the new USEPA standards, however. Some states were faced with having to reduce emissions by as much as 24 to 36%. Total costs over 10 years were estimated at $17 billion. They lobbied for lowered emission standards, citing lower costs for compliance to resolve the air pollution concerns. The USEPA was not impressed with their proposals, however, seeing them as less than significant in terms of emission reduction. The regional nature of this problem had been a concern for many years. In the Northeast, state

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[*] Adapted from Associated Press, Tougher air pollution standards too costly, Midwestern states say, *Lancaster New Era* (Lancaster, PA), September 25, 1998.

officials and utility executives welcomed the USEPA's entry into the situation. The tougher pollution controls on the Midwestern coal-burning plants inevitably increased the costs of energy production, which had been kept artificially low because of the lower environmental costs the Midwestern companies paid.

Carbon Monoxide

Incomplete combustion of fossil fuels produces carbon monoxide (CO). Completely invisible, carbon monoxide is colorless, odorless, and tasteless. CO can be a serious health hazard, causing effects that range from slight headaches to nausea to death, depending on concentration and conditions.

Particulate Matter

Particulates are extremely small fragments of solids or liquid droplets suspended in air. Particulates (lead being the exception) are distinguished on the basis of particle size and source, rather than by chemical composition. Most particulates range in size from 0.1 to 100 µm. The particulate materials of most concern for adverse effects on human health (ones that can easily be inhaled and penetrate deeply into the innermost recesses of our lungs and cause upper respiratory infection, cardiac disorder, bronchitis, asthma, pneumonia, and emphysema) are generally less than 10 µm in size and are referred to as PM_{10}. Smaller sized particles, those less that 10 µm in diameter, tend to pose the greatest health concern because they can pass through the nose and throat and get into the lungs. Particulates also reduce visibility and intensify certain chemical reactions in the atmosphere.

Lead Particulates

Lead can be present in the air as either a particle or gas. Lead particulates in fume form (less than 0.5 µm in size) are toxic and can lead to anemia, destructive behavior, learning disabilities, seizures, brain damage, and death. Major sources of lead in the past were motor vehicles that burned gasoline containing lead-based antiknock additives. The USEPA now requires the use of unleaded gasoline, but lead is still emitted from petroleum refining and smelting operations and other industrial activities.

Ozone (O_3)

Ozone (O_3), the key component of photochemical smog (smog = smoke + fog), is a secondary air pollutant in the troposphere formed by a complex chemical reaction between nitrogen dioxide (NO_2) and volatile organic compounds. VOCs are hydrocarbons that are gaseous under normal atmospheric conditions. The reactions are initiated by ultraviolet energy in sunlight. Along with producing smog, ozone irritates the eyes, nose, and throat; reduces lung function; damages plants; and causes cracking of paints, rubber, and textiles.

DEPOSITION OF POLLUTANTS IN THE ATMOSPHERE

When pollutants are released from their sources into the atmosphere, their fate may be affected by three different mechanisms: (1) physical deposition, (2) transport and dispersal downwind, and (3) photochemical and oxidizing atmospheric chemical reactions. Physical deposition is the process whereby gravitational settling, impaction, absorption, and wet deposition with precipitation occur, effectively removing many pollutants from the atmosphere near the source. Dispersion of pollutants in the atmosphere occurs when pollutants emitted from smokestacks or automobile exhausts are dispersed and transported away from the source, following the motion of the gas in which they are borne. Atmospheric reactions are the result of photochemical reactions driven by energy from the sun and chemical transformations as a result of oxidation reactions, both of which contribute to many atmospheric pollution problems. For example, oxides of sulfur and nitrogen are oxidized in the atmosphere to form acids, contributing to acid rain.

PROBLEMS OF ATMOSPHERIC POLLUTION

Many air pollution problems have been recognized, ranging from small areas affected by a single industry to citywide problems caused by multiple contaminants to global-scale contamination by universal pollutants. Specifically, the problems pertain to acid deposition, smog formation, stratospheric ozone depletion, climate change, chlorofluorocarbons, global dimming, haze, particulates, and roadway air dispersion. In this section, we discuss each one of these atmospheric pollution problems.

Acid Deposition

During the 1970s, the press began reporting about a new environmental hazard: acid deposition. They described it in grim terms as “acid rain” and in even grimmer terms as “death from the sky.” So, what is acid deposition? Are the reports of its effects on Earth as dire as reporters first claimed in the 1970s? Acid deposition (acid rain) results when gaseous emissions of sulfur oxides (SO_x) and nitrogen oxides (NO_x) interact with water vapor and sunlight and are chemically converted to strong acidic compounds such as sulfuric acid (H_2SO_4) and nitric acid (HNO_3). Along with other organic and inorganic chemicals, these compounds are deposited on the Earth as aerosols and particulates (dry deposition) or are carried to the Earth by raindrops, snowflakes, fog, or dew (wet deposition).

Keep in mind that most rainfall is naturally slightly acidic. Decomposing organic matter, the movement of the sea, and volcanic eruptions all contribute to natural acidity levels in precipitation; however, the principal contributor to the acid rain phenomenon is atmospheric carbon dioxide, which causes carbonic acid to form. Acid rain with a $pH < 5.6$ is produced by the conversion of the primary pollutants sulfur dioxide and nitrogen oxide to the secondary pollutants sulfuric acid and nitric acid, respectively. These complex processes depend on physical dispersion and chemical conversion rates.

Although we think of acidic precipitation as a relatively new problem, it is not necessarily a modern phenomenon nor does it result solely from industrial pollution; however, the rise in manufacturing which began with the Industrial Revolution literally dwarfs all other contributions to the problem. The chief source of sulfur dioxide emissions is the burning of fossil fuels (including oil and coal). Nitrogen oxide, formed mostly from internal combustion engine emissions, is readily transformed into nitrogen dioxide. They mix in the atmosphere to form sulfuric acid and nitric acid.

Acid deposition is usually seen in or near industrialized and highly populated areas. For example, in the United States, most of the blame for the problem can be traced to the many coal-burning electric utility plants that are found in the Midwest and the East (see Case Study 6.1). Their smokestacks account for approximately 68% of the sulfur dioxide emitted annually. Approximately 11% comes from industrial burning. Other emissions (from automobile exhausts, for example) account for the other 21%. Acid deposition is felt most severely in the eastern United States because of wind patterns. Most of the United States lies within 30° to 60° north latitude, where the prevailing winds come from the west. The wind picks up much of the sulfur and nitrogen emitted in the Midwest, carries it eastward to mingle with the emissions already there, and then fans the entire mass out in a broad north-to-south pattern. The fact is, no matter what part of the world is affected, the hardest hit regions always lie in the path of the winds approaching from industrial and highly populated areas.

Note that, when dealing with atmospheric acid deposition, the Earth’s ecosystems are not completely defenseless; through natural alkaline substances in soil or rocks that buffer and neutralize acids, they can deal with a certain amount of acid. The American Midwest and southern England possess highly alkaline soil (limestone and sandstone), which provides some natural neutralization. Areas with thin soil and those laid on granite bedrock, however, suffer most from acid rain. Many of our environments have little ability to neutralize acid deposition.

We have explained what acid deposition is, but we still need to answer the other question: Are the reports of its affects on Earth as grim as reported? Scientists continue to study the acid deposition problem. Over the years, acid deposition has been accused of doing much damage; for example, it has been blamed for damaging freshwater life, forests, food crops, buildings, and even our physical health. What is the truth? Again, scientists are studying how living beings are damaged or killed by the effects of acid deposition. This complex subject has many variables, many of them related to the fact that pollution can travel over very long distances. Bodies of water in Canada and New York, for example, suffer the effects of coal burning in the Ohio Valley. Because lakes are so seriously affected by acid deposition, most of the scientific studies have taken place in the world's lakes, where acid precipitation quickly affects lake populations. Smaller organisms often die off first, leaving the larger animals to die by starvation.

In the United States, some locations report that rainfall acidity levels have fallen well below pH 5.6. In the northeastern United States, for example, the average pH of rainfall is 4.6, and rainfall with a pH of 4.0, which is 100 times more acidic than distilled water, is not uncommon.

So, what is the answer? Is acidic deposition as bad as they say it is? Is it "death from the sky"? Despite intensive, ongoing research into most aspects of acid deposition, the jury is still out. Scientists still are faced with many areas of uncertainty and disagreement—actually, scientific opinion is divided on the answer to this question. Most scientists, however, do not believe that acid deposition is solely at fault for all the damage being done, nor do most think it is completely innocent of causing such damage. Rather, they feel that much of the damage attributed to acid deposition is actually the result of a combination of factors, some of which—such as the weather—are fashioned by nature, while others are anthropogenic pollutants. Acid deposition has simply joined these forces to worsen their impact.

Where do we stand today in our attempt to solve the acid deposition puzzle? Let's attempt to answer this question with a question: Have you ever attempted to complete a jigsaw puzzle when a few of the pieces were missing? If you have, then you can appreciate where we are in solving the acid deposition puzzle; we know that a few of the puzzle pieces are still missing. The parts of the puzzle that are complete show us a picture of a wide range of acid deposition damage. This damage includes destabilizing of ecosystems such as forests. Lakes, streams, and watersheds, and aquatic life within them, are victims of acid deposition. Manmade monuments (statues, for example) have been disfigured by the corrosive behavior of acid deposition. We also see (in the part of the puzzle that is complete) that even human health is at risk from trace metals leached into the water supply by acidified groundwater. These pieces of the puzzle we can see; these things we know. The problems is we do not know what we do not know—we don't know what information is contained in the missing pieces of the puzzle. Because of this—because we are not exactly sure of the total impact of acid deposition but nonetheless have suspicions about its consequences, the USEPA in the Clean Air Act strengthened its requirements to permanently reduce levels of SO_2 and nitrogen oxides, a prudent move.

SMOG FORMATION

Smog, a term coined more than 50 years ago from the words "smoke" and "fog," is a dirty yellow-brown cloudy formation (created in the lower portion of the troposphere near the ground level) resulting from the photochemical reaction of sunlight on the oxides of nitrogen and hydrocarbons emitted from automobiles. Originally, smog actually referred to the clouds of sulfur dioxide, sulfuric acid droplets, and heavy suspended particles discharged by industries. Since then, this type of smog (known as gray smog) had been identified for what it really is: a rare type of smog. The smog we are most familiar with (Los Angeles-type smog) is principally a gas formed by a photochemical process on warm days when nitrogen oxides and hydrocarbons in the atmosphere react to sunlight and turn themselves into ozone, a major constituent of smog. This is the type of smog that causes irritation of the eyes and throat, impairs pulmonary function, damages plants and crops, and makes rubber-based products crack and leak.

An ally to smog that is particularly annoying (and dangerous) is a condition known variously as a thermal inversion or temperature inversion. To understand how a thermal inversion works, we have to begin with the fact that, as the altitude increases, the atmosphere becomes thinner and the pressure drops. This characteristic action causes a parcel of exhausted gas moving upward to undergo

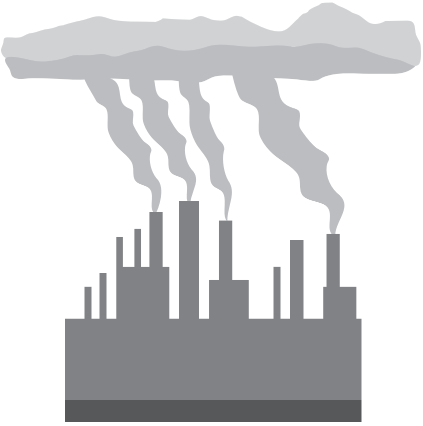

FIGURE 6.4 Temperature inversion.

an expansion that reduces its temperature. This natural phenomenon of a reduction or lapse in temperature is known as the *adiabatic lapse rate* (the rate at which the temperature of the gas parcel drops due to elevation change). Under the assumption that the process is adiabatic, no exchange of heat occurs between the gas parcel and the surroundings.

In simple terms, as Dolan (1991, p. 22) put it, "warm air at ground level rises, becoming cooler at it travels upward, and pollutants are carried along on the upward rise and then can be better dispersed in the atmosphere. A thermal inversion, which often arrives in hot weather, sees a layer of warm air settle in over an area. It is warmer than the air below it, and thus keeps the lower air—and the pollution in it—from rising. Trapped as it is, the lower air becomes increasingly filthy as more and more pollutants are added from car exhaust systems and industrial burnings" (see Figure 6.4).

Typically, such thermal inversions bring about conditions that induce a wide variety of physical discomforts, including watery eyes, coughing, sneezing, choking, nausea, and shortness of breath. Records indicate that such events have also caused deaths; for example, in 1952 in London, such an event caused the deaths of as many as 12,000 people. Another incident, this one at Donora, Pennsylvania, in 1948, was responsible for 20 deaths. Still another thermal inversion in New York City in 1966 caused the deaths of 168 people.

STRATOSPHERE OZONE DEPLETION

Try to imagine, if you can, a hole in the sky as large as the United States—a hole extending some 29,000 feet up through the stratosphere layer. The hole we are referring to is the giant hole first reported in 1985 above Antarctica. The hole is better known as the *ozone hole*. To understand its significance, we need to understand exactly what the ozone layer is and its importance to life on Earth.

Ozone is the Jekyll and Hyde of the Earth's atmosphere; it has a good side and a bad side. As mentioned, ozone in the troposphere is created by the interaction of hydrocarbons, nitrogen oxides, and sunlight and leads to smog-related problems. This is the Hyde, or bad, side of ozone. The stratosphere also contains ozone, at altitudes of 10 to 30 km, that is responsible for absorbing (and shielding us from) harmful ultraviolet rays of the sun before they hit the Earth. This is the Jekyll, or good, side of ozone.

A large percentage of the ozone in the stratosphere is created during electrical storms near the equator. The winds pick it up and shift it toward the polar regions. At the same time, the newly created ozone rises until it reaches the stratosphere, where it spreads like a thin veil over the world and performs its vital function of blocking the flow of harmful ultraviolet radiation. The stratospheric ozone layer is analogous to a layer of gaseous sun block that protects us from ultraviolet radiation.

The obvious question is, “What is causing the hole in the ozone layer?” Scientists theorize that increasing concentrations of synthetic chemicals known as chlorofluorocarbons (CFCs) and others (such as Halon) are breaking down the ozone layer. Sources of CFC gases include aerosol spray cans, refrigerants, industrial solvents, and foam insulation; they do not degrade easily. As a result, when released in the lower atmosphere (troposphere), they rise into the stratosphere, where they are broken down by ultraviolet light. The chlorine atoms from CFCs react with ozone to convert it into two molecules of oxygen. Each chlorine atom can destroy many ozone molecules; it is estimated that one chlorine atom is capable of destroying over 10,000 ozone molecules. The result—the ozone hole.

Case Study 6.2. Ozone Hole Over Antarctica at Record Size

The ozone hole over Antarctica that lets dangerous ultraviolet light reach the Earth is showing no signs of shrinking appreciably. In 1998, satellite data from the U.S. National Aeronautic and Space Administration found that the hole encompassed 10.4 million square miles. Since then, the hole has varied in size from around 9 million square miles to over 11 million square miles. The largest single-day ozone hole recorded by satellite occurred on September 25, 2006, when it was nearly 11.5 million square miles big. The hole is actually an area of thinned ozone, where the gas is depleted by chemical reactions in air trapped over the South Pole during the Antarctic winter. The area covers most of Antarctica.

CLIMATE CHANGE

> Humanity is conducting an unintended, uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to nuclear war. The Earth’s atmosphere is being changed at an unprecedented rate by pollutants resulting from human activities, inefficient and wasteful fossil fuel use, and the effects of rapid population growth in many regions. These changes are already having harmful consequences over many parts of the globe.
>
> **—World Conference on the Changing Atmosphere closing statement, June 1988**

Is Earth’s climate changing? Are warmer times or colder times on the way? Are these times already here? Is the greenhouse effect going to affect our climate, and if so do we need to worry about it? Will the tides rise and flood New York? Does the ozone hole portend disaster right around the corner? Will we all choke to death on human-made air pollutants?

These and many other questions related to climate change have come to the attention of us all, thanks to a constant barrage of newspaper headlines, magazine articles, and television news reports. We have seen reports on El Niño events that have devastated the west coast of the United States, as well as Peru and Ecuador. We have also seen a reduction in the number and magnitude of hurricanes that annually blast the eastern coast of the United States.

Scientists have been warning us of the catastrophic harm that can be done to the world by atmospheric warming. One view states that the effect could bring record droughts, record heat waves, record smog levels, and an increasing number of forest fires. Another caution put forward warns that the increasing atmospheric heat could melt the world’s ice caps and glaciers, causing ocean levels to rise to the point where some low-lying island countries would disappear, while the coastlines of other nations would be drastically altered for ages—or perhaps for all time.

What’s going on? We hear plenty of theories put forward by doomsayers, but are they correct? If they are correct, what does it all mean? Does anyone really know the answers? Should we be concerned? Should we invest in waterfront property in Antarctica? Should we panic? No. While no one really knows the answers, and while we should be concerned, no real cause for panic exists. Still, though, should we take some type of decisive action, should we come up with quick answers and put together a plan to fix these problems? What really needs to be done? What can we do? Is there anything we can do?

The key question here is "What really needs to be done?" We can study the facts, the issues, and the possible consequences, but the key to successfully combating these issues is to stop and seriously evaluate the problems. We need to let scientific fact, common sense, and cool-headedness prevail—shooting from the hip is not called for, makes little sense, and could have colossal consequences for us all. With regard to these global matters, some point to certain inconvenient truths and others to inconvenient truths that become convenient. Remember, however, that feel-good science is not true science. Whether global climate change is natural or human caused is not really the issue. The issue is more one of are we aware of the consequences?

Another question that has merit here is, "If there truly is a problem with global climate change, will we take the correct actions before it is too late?" The key words in this question are "correct actions." Eventually, we may have to take action, but we do not yet know what those actions should be. In this section, we discuss global climate change related to our atmosphere and its problems, actual and potential. Consider this: Any damage we do to our atmosphere affects the other two mediums of water and soil—and biota (including us). Thus, the endangered atmosphere is a major concern to all of us.

The Past

Before beginning our discussion of the past, we need to define the era we refer to when we say "the past." Table 6.1 summarizes the entire expanse of time from Earth's beginning to present. Table 6.2 provides the sequence of geological epochs over the past 65 million years, as dated by modern methods. The Paleocene through Pliocene together make up the Tertiary Period; the Pleistocene and the Holocene compose the Quaternary Period. When we think about general and climatic conditions in the prehistoric past, two things generally come to mind—ice ages and dinosaurs. Of course, in the immense span of time that prehistory covers, those two eras represent only a brief moment in time, so let's look at what we know about the past and about Earth's climate and conditions. One thing to consider is that geological history shows us that the normal climate of the Earth was so warm that subtropical weather reached to 60° north and south latitude, and polar ice was entirely absent. Only during less than about 1% of the Earth's history did glaciers advance and reach as far south as what is now the temperate zone of the northern hemisphere. The latest such advance, which began about 1,000,000 years ago, was marked by geological upheaval and (perhaps) the advent of human life on Earth. During this time, vast ice sheets advanced and retreated and coarsely ground their way over the continents, reducing mountains to fine dirt.

TABLE 6.1
Geologic Eras and Periods

Era	Period	Millions of Years
	Before Present	
Cenozoic	Quaternary	2.5–present
	Tertiary	65–2.5
Mesozoic	Cretaceous	135–65
	Jurassic	190–135
	Triassic	225–190
Paleozoic	Permian	280–225
	Pennsylvanian	320–280
	Mississippian	345–320
	Devonian	400–345
	Silurian	440–400
	Ordovician	500–440
	Cambrian	570–500
	Precambrian	4600–570

TABLE 6.2
65 Million Years of Epochs

Epoch	Million Years Ago
Holocene	01–0
Pleistocene	1.6–0.01
Pliocene	5–1.6
Miocene	24–5
Oligocene	35–24
Eocene	58–35
Paleocene	65–58

A Time of Ice

Nearly 2 billion years ago, the oldest known glacial epoch occurred. A series of deposits of glacial origin in southern Canada, extending east to west about 1000 miles, shows us that within the last billion years or so apparently at least six major phases of massive, significant climatic cooling and consequent glaciation occurred at intervals of about 150 million years. Each lasted perhaps as long as 50 million years.

Examination of land and oceanic sediment core samples clearly indicates that in more recent times (the Pleistocene epoch to the present), many alternating episodes of warmer and colder conditions occurred over the last 2 million years (during the middle and early Pleistocene epochs). In the last million years, at least eight such cycles have occurred, with the warm part of the cycle lasting a relatively short interval.

During the Great Ice Age (the Pleistocene epoch), a series of ice advances began that at times covered over one-quarter of Earth's land surface. Great sheets of ice thousands of feet thick, these glaciers moved across North America many times, reaching as far south as the Great Lakes. An ice sheet thousands of feet thick spread over Northern Europe, sculpting the land and leaving behind lakes, swamps (remember Yurk and *Smilodon*), and terminal moraines as far south as Switzerland. Each succeeding glacial advance was apparently more severe than the previous one. Evidence indicates that the most severe began about 50,000 years ago and ended about 10,000 years ago. Several interglacial stages separated the glacial advances, during which average temperatures were higher than ours today, and, consequently, the ice melted. Wait a minute! Temperatures were higher than they are today? Yes, they were. Think about that as we proceed.

Because one-tenth of the globe's surface is still covered by glacial ice, scientists consider the Earth still to be in a glacial stage. The ice sheet has been retreating since the climax of the last glacial advance, and world climates, although fluctuating, are slowly warming.

From our observations and from well-kept records, we know that the ice sheet is in a retreating stage. The records clearly show that a marked worldwide retreat of ice has occurred over the last 100 years. World famous for its 50 glaciers and 200 lakes, Glacier National Park in Montana does not present the same visual experiences it did 100 years ago. In 1937, a 10-foot pole was put into place at the terminal edge of one of the main glaciers. The pole is still in place, but the terminal end of the glacier has retreated several hundred feet back up the slope of the mountain. Swiss resorts built during the early 1900s to offer scenic glacial views now have no ice in sight. Theoretically, if glacial retreat continues, melting all of the world's ice supply, sea levels would rise more than 200 feet, flooding many of the world's major cities. New York, Boston, and Norfolk, Virginia, would become aquariums.

The question of what causes ice ages is one scientists still grapple with. Theories range from changing ocean currents to sunspot cycles. Of one fact we are absolutely certain, however; an ice age event occurs because of a change in Earth's climate. But what could cause such a drastic change? Climate results from uneven heat distribution over the Earth's surface caused by the Earth's tilt—the angle between the Earth's orbital plane around the sun and its rotational axis. This angle is currently 23.5 degrees, but it has not always been that. The angle, of course, affects the amount of solar energy that reaches the Earth and where it falls. The heat balance of the Earth, which is driven mostly by the concentration of carbon dioxide (CO_2) in the atmosphere, also affects long-term climate. If the pattern of solar radiation changes or if the amount of CO_2 changes, climate change can result. Abundant evidence that the Earth does undergo climatic change exists, and we know that climatic change can be a limiting factor for the evolution of many species. (See Case Study 6.3.)

Case Study 6.3. Are We on a High-Carb Diet?

Due to the increasing atmospheric carbon dioxide levels, we might wonder whether the Earth is on a "high-carb" diet. If so, is it all that bad? Some might argue what difference does it make? What difference does it make if we continue to increase carbon dioxide levels? Doesn't all of the vegetation on Earth need carbon dioxide? Wouldn't increased levels of carbon dioxide increase crop growth? Wouldn't our flowers grow into giants with brighter blooms, and the essence of their fragrance surround us all? Wouldn't higher levels of carbon dioxide in the atmosphere only work to the benefit of Earth, turning it into a veritable jungle? Haven't we always said, "More is better?" An older, wiser saying, however, states, "Too much of a good thing can be a bad thing." If, for example, a doctor prescribes one aspirin per day to help the patient avoid a heart attack, stroke, colon cancer, or any of a number of other medical maladies, the patient taking five aspirin a day instead of one is not likely to receive five times the benefit. Taking that many aspirin per day is not recommended and is more likely to be harmful.

Inside a greenhouse, where conditions are controlled, it is possible to increase the growth of some plants by increasing the level of carbon dioxide. The problem with increasing carbon dioxide throughout the globe in an attempt to "jungle-ize" it is not realistic. The problem is, even if carbon dioxide levels increase to the point where plants are fed super amounts of it, the vegetation can't live on the carbon dioxide alone. Vegetation bulks up via intake of water and organic matter. Even with increased carbon dioxide levels, plants can only grow more profusely if they also increase their water and organic matter intake. Thus, the thought of turning the Sahara Desert, Death Valley and the John Day Desert of eastern Oregon into a jungle is wishful thinking and certainly a pipe dream. The point is that wherever there is a shortage of either water or organic matter an increase in carbon dioxide levels would most likely be more detrimental to vegetation growth than otherwise. Moreover, keep in mind that increasing carbon dioxide levels would also increase global temperatures which would lead to the growth of deserts and other dry land areas.

The bottom line is that they say a low-carb food diet is good for us. And it appears that a low-carbon-dioxide diet is just as good for the globe and for all humankind.

Back to the Ice Ages

Evidence (primarily from soil core samples and topographical formations) tells us that changes in climate include events such as periodic ice ages characterized by glacial and interglacial periods. Long glacial periods lasted up 100,000 years; temperatures decreased about 9°F, and ice covered most of the planet. Short periods lasted up to 12,000 years, with temperatures decreasing by 5°F and ice covering 40° north latitude and above. Smaller periods (e.g., Little Ice Age, which occurred from about 1000 to 1850 AD) experienced about a 3°F drop in temperature. Note that, despite its name, the Little Ice Age was a time of severe winters and violent storms, not a true glacial period. These ages may be or not be significant, but consider that we are currently in an interglacial period and that we may be reaching its apogee. What does that mean? No one knows with any certainty.

Let's look at the effects of ice ages (that is, effects we think we know about). Changes in sea levels could occur. Sea level could drop by about 100 meters during a full-blown ice age, exposing the continental shelves. Increased deposition during melt would change the composition of the exposed continental shelves. Less evaporation would change the hydrological cycle. Significant landscape changes could occur—on the scale of the Great Lakes formation. Drainage patterns

DID YOU KNOW?

The Medieval Warm Period (MWP) was a time of warm climate in the North Atlantic region, lasting from about the 10th century to about the 14th century. It followed the Dark Ages Cold Period and was followed by the Little Ice Age. The MWP is often invoked in discussions of global warming (Ladurie, 1971).

DID YOU KNOW?

Increasing temperatures result in a rise in sea level due to the thermal expansion of water and through the addition of water to the oceans from the melting of continental ice sheets. Thermal expansion, which is well quantified, is currently the primary contributor to sea-level rise and is expected to be the primary contributor over the course of the next century. Glacial contributions to sea-level rise are less important and are more difficult to predict and quantify (Randall and Wood, 2007).

throughout most of the world and topsoil characteristics would change. Flooding on a massive scale could occur. How these changes would affect us depends on whether you live in Northern Europe, Canada, Seattle, Washington, around the Great Lakes, or near a seashore.

We are not sure what causes ice ages, but we have some theories. Scientists point out that, to generate a full-blown ice age (such that a massive ice sheet covers most of the globe), certain periodic or cyclic events must occur. Periodic fluctuations would have to affect the solar cycle, for instance; however, we have no definitive proof that this has ever occurred.

Another theory speculates that periods of volcanic activity could generate masses of volcanic dust that would block or filter heat from the sun, thus cooling down the Earth. Some speculate that the carbon dioxide cycle would have to be periodic or cyclic to bring about periods of climate change. There is reference to a so-called Factor 2 reduction, causing a 7°F temperature drop worldwide. Others speculate that another global ice age could be brought about by increased precipitation at the poles due to changing orientation of continental land masses. Others theorize that a global ice age would result if the mean temperatures of ocean currents decreased. But the question is how? By what mechanism? Are these plausible theories? No one is sure—this is speculation.

Speculation aside, what are the most probable causes of ice ages on Earth? According to the *Milankovitch hypothesis*, ice age occurrences are governed by a combination of factors: (1) the Earth's change of altitude in relation to the sun (the way it tilts in a 41,000-year cycle and at the same time wobbles on its axis in a 22,000-year cycle), making the time of its closest approach to the sun come at different seasons; and (2) the 92,000-year cycle of eccentricity in its orbit around the sun, changing it from an elliptical to a near circular orbit, with the most severe period of an ice age coinciding with the approach to circularity.

There has been much speculation about ice ages and their causes and their effects. We know that ice ages occurred, and we know that they caused certain things to occur (e.g., formation of the Great Lakes). Although there is a lot we do not know, we do recognize the possibility of recurrent ice ages. Right now, no single theory is sound, and doubtless many factors are involved. Keep in mind that the possibility exists that we might still be in the Pleistocene ice age and that it could reach another maximum in another 60,000 plus years or so.

Warm Winter

The headlines we see in the paper sound authoritative: "The Winter of 2015–16 Was the Warmest on Record Worldwide" … "Lower 48 States Just Experienced the Warmest Winter on Record" … "The Arctic Just Had the Warmest Winter on Record" … "The Last Time CO_2 Was This High, Humans Didn't Exist." A number of reports indicate that we are undergoing a warming trend, but conflicting reports abound. This section discusses what we think we know about climate change.

Two environmentally significant events took place late in 1997: El Niño's return and the Kyoto Conference on Global Warming and Climate Change. News reports blamed El Niño for just about anything that had to do with weather conditions throughout the world. Some incidents were indeed El Niño related or generated: the out-of-control fires, droughts, floods, the stretches of dead coral with no sign of fish in the water, and few birds around certain Pacific atolls. The devastating storms that struck the west coasts of South America, Mexico, and California were also probably related to El Niño. El Niño's effect on the 1997 hurricane season, one of the mildest on record, is not in question, either.

Does a connection exist between El Niño and global warming or global climate change? On December 7, 1997, the Associated Press reported that, while delegates at the global climate conference in Kyoto haggled over greenhouse gases and emission limits, a compelling question had emerged: "Is global warming fueling El Niño?" Nobody knows for sure because we need more information than we have today. The data we do have, however, suggests that El Niños are getting stronger and more frequent.

Some scientists fear that the increasing frequency and intensity of El Niños may be linked to global warming. Records show that two of the last century's worst El Niños hit in 1982–83 and 1997–98, and one of the strongest El Niños on record occurred in 2015–16. At the Kyoto conference, experts said the hotter atmosphere is heating up the world's oceans, setting the stage for more frequent and extreme El Niños. Weather-related phenomena seem to be intensifying throughout the globe. Can we be sure that they are related to global warming? No. Without more data, more time, more science, we cannot be sure.

According to the Associated Press coverage of the Kyoto conference, scientist Richard Fairbanks reported that he found startling evidence supporting our need for concern. During 2 months of scientific experiments conducted in autumn 1997 on Christmas Island, the world's largest atoll in the Pacific Ocean, he witnessed a frightening scene. The water surrounding the atoll was 7°F warmer than average for that time of year, which upset the balance of the environmental system. According to Fairbanks, 40% of the coral was dead, the warmer water had killed off or driven away fish, and the atoll's plentiful bird population was almost completely gone.

No doubt, El Niños are having an acute impact on the globe; however, we do not know if these events are caused by or are intensified by global warming. What do we know about global warming and climate change? *USA Today* (Anon., 1997) discussed the results of a report issued by the Intergovernmental Panel on Climate Change. They interviewed Jerry Mahlman of the National Oceanic and Atmospheric Administration and Princeton University, and presented the following information about what most scientists agree on:

- There is a natural greenhouse effect and scientists know how it works; without it, Earth would freeze.
- The Earth undergoes normal cycles of warming and cooling on grand scales. Ice ages occur every 20,000 to 100,000 years.
- Globally, average temperatures have risen 1°F in the past 100 years, within the range that might occur normally.
- The level of manmade carbon dioxide in the atmosphere has risen 30% since the beginning of the Industrial Revolution in the 19th century and is still rising.
- Levels of manmade carbon dioxide will double in the atmosphere over the next 100 years, generating a rise in global average temperatures of about 3.5°F (larger than the natural swings in temperature that have occurred over the past 10,000 years).
- By 2050, temperatures will rise much higher in northern latitudes than the increase in global average temperatures. Substantial amounts of northern sea ice will melt, and snow and rain in the northern hemisphere will increase.
- As the climate warms, the rate of evaporation will rise, further increasing warming. Water vapor also reflects heat back to Earth.

Global Warming

What is global warming? To answer this question we need to discuss the greenhouse effect. Water vapor, carbon dioxide, and other atmospheric gases (greenhouse gases) help warm the Earth. Earth's average temperature would be closer to 0 than its actual 60°F without the greenhouse effect. But, as gases are added to the atmosphere, the average temperature could increase, changing orbital climate. How does the greenhouse effect actually work? Earth's greenhouse effect, of course, took its name because of its similarity to the effects of a greenhouse. Because the glass walls and ceilings of a greenhouse are largely transparent to short-wave radiation from the sun, surfaces and objects inside the greenhouse absorb the radiation. The radiation, once absorbed, transforms into long-wave (infrared) radiation (heat), which radiates out from the greenhouse interior, but the glass prevents the long-wave radiation from escaping again and the warm rays are absorbed. The interior of the greenhouse becomes much warmer than the air outside because of the heat trapped inside.

Earth and its atmosphere undergo a very similar process. Short-wave and visible radiation reaching Earth is absorbed by the surface as heat. The long heat waves radiate back out toward space, but the atmosphere absorbs many of them, trapping them. This natural and balanced process is essential to supporting life systems on Earth. Changes in the atmosphere can radically change the rate of absorption and therefore the amount of heat the atmosphere retains. In recent decades, scientists have speculated that various air pollutants have caused the atmosphere to absorb more heat. At the local level, with air pollution, the greenhouse effect causes heat islands in and around urban centers, a widely recognized phenomenon.

The main contributors to this effect are the greenhouse gases: water vapor, carbon dioxide, carbon monoxide, methane, volatile organic compounds, nitrogen oxides, chlorofluorocarbons, and surface ozone. These gases cause a general climatic warming by delaying the escape of infrared radiation from the Earth into space. Scientists stress that this is a natural process. Indeed, as noted earlier, if the normal greenhouse effect did not exist the Earth would be far cooler than it currently is (Hansen et al., 1984).

Human activities, though, are rapidly intensifying this natural phenomenon which may lead to problems of warming on a global scale. The rate at which the greenhouse effect is intensifying is now more than five times what it was during the 1800s (Hansen et al., 1984). Much debate, confusion, and speculation about this potential consequence of global warming are underway because scientists cannot yet agree about whether the recently perceived worldwide warming trend is because of greenhouse gases, is due to some other cause, or is simply a wider variation in the normal heating and cooling trends they have been studying. Without a doubt, the human impact on the greenhouse effect is real; it has been measured and detected. Unchecked, the greenhouse effect may lead to significant global warming, with profound effects upon our lives and our environment.

Supporters of the global warming theory assume that human activities are significantly altering the Earth's normal and necessary greenhouse effect. The human activities they blame for this increase of greenhouse gases include burning fossil fuels, deforestation, and the use of certain aerosols and refrigerants. From information based on recent or short-term observations, many scientists have observed that the last decade has been the warmest since temperature recordings began in the late 19th century. They can see that the general rise in temperature coincides with the Industrial Revolution and its accompanying increase in fossil fuel use. Other evidence supports the global warming theory. In places that are synonymous with ice and snow—the Arctic and Antarctica, for example—we are seeing evidence of receding ice and snow cover.

Trying to pin down definitively whether or not changing our anthropogenic activities could have any significant effect on lessening global warming, though, is difficult. Scientists look at temperature variations over thousands and even millions of years, taking a long-term view at Earth's climate. The variations in Earth's climate are wide enough that they cannot definitively show that this global warming is anything more than another short-term variation. Historical records show that the Earth's temperature does vary widely, as it grows colder with ice ages and then warms again; because we cannot be certain of the causes of those climate changes, we cannot be certain of what is causing the current warming trend.

Still, debate abounds for the argument that our climate is warming and our activities are part of the equation. In the last century, the Earth's average surface temperature rose approximately 1°F (0.6°C) (USEPA, 2009c). The several record high temperatures that have occurred in this century include a high temperature of 129.2°F (54°C) in Death Valley, California, in June of 2013 and 123.8°F (51°C) in India in May of 2016. Scientists are increasingly convinced that the Earth is getting hotter because of the buildup in the atmosphere of carbon dioxide and other gases produced in large part by the burning of fossil fuels (Anon., 1998). The surface temperature of the Earth could rise by about 1.8 to 6.3°F by 2100. Keep in mind, however, that record cold temperatures continue to occur.

Assuming that we are indeed seeing long-term global warming, we must determine what causes it. But, again, we face the problem that scientists cannot be sure of the precise causes of the greenhouse effect. Our current possible trend in global warming may simply be part of a much longer trend of warming since the last ice age. We have learned much in the past two centuries of science, but little is actually known about the causes of the worldwide global cooling and warming that sent the Earth through major and smaller ice ages. The data we need reaches back over millennia. We simply do not possess enough long-term data to support our theories.

Currently, scientists can point to six factors they think could be involved in long-term global warming and cooling:

1. Long-term global warming and cooling could result if changes in the Earth's position relative to the sun occur (i.e., changes in the Earth's orbit around the sun), with higher temperatures resulting when the two are closer together and lower ones when they are farther apart.
2. Long-term global warming and cooling could result from major catastrophes (e.g., meteor impacts or massive volcanic eruptions) throwing pollutants into the atmosphere that can block out solar radiation.
3. Long-term global warming and cooling could result if changes in albedo (reflectivity of Earth's surface) occur. If the Earth's surface were more reflective, for example, the amount of solar radiation radiated back toward space instead of absorbed would increase, lowering temperatures on Earth.
4. Long-term global warming and cooling could result if the amount of radiation emitted by the sun changes.
5. Long-term global warming and cooling could result if the shape and relationship of the land and oceans change.
6. Long-term global warming and cooling could result if the composition of the atmosphere changes.

"If the composition of the atmosphere changes"—this final factor, of course, defines our current concern: Have human activities had a cumulative impact large enough to affect the total temperature and climate of Earth? Right now, we cannot be sure. The problem concerns us, and we are alert to it, but we are not certain, because, again, we do not know what we do not know about global warming or climate change.

However, we can expect winters to be longer, if global warming is occurring, and summers hotter. Over the next 100 years, sea level will rise as much as a foot or so. Is this bad? Depends on where you live. Keep in mind, however, that not only could sea level rise 1 foot over the next 100 years, but it could continue to do so for many hundreds of years. Another point to consider is that we have routine global temperature measurements for only about 100 years. Even these are unreliable, because instruments and methods of observation have changed over that course of time.

The only conclusion we can safely draw about climate and climate change is that we do not know if drastic changes are occurring. We could be at the end of an geological ice age. Evidence indicates that during interglacials temperatures increase before they plunge. Are we ascending the peak temperature range? We have no way to tell. To what extent does our human activity impact climate? Have anthropogenic effects become so marked that we have affected the natural cycle of ice ages (which lasted for roughly the last 5 million years)? Maybe we just have a breathing spell of a few centuries before the next advance of the glaciers. If this is the case, if we are at the apogee of the current interglacial, then we have to ask ourselves a few questions: Is global warming the lesser of two evils when compared to the alternative, global cooling? If we are headed into another glacial freeze, in this era of expanding population and decreasing resources, where will we get the energy to keep all of us warm? The bottom line with regard to global warming is that, at the present time, we need to trust science and the historical record over authoritative opinion and scare tactics.

Chlorofluorocarbons

Chlorofluorocarbons (CFCs) have been blamed for air pollution problems. Most scientists consider the family of chlorine-based compounds, most notably chlorofluorocarbons and chlorinated solvents (carbon tetrachloride and methyl chloroform), to be the primary culprits involved in ozone depletion. In 1974, Molina and Rowland hypothesized that CFCs, which contain chlorine, were responsible for ozone depletion. They pointed out that chlorine molecules are highly active, and they readily and continually break apart the three-atom ozone into the two-atom form of oxygen generally found close to Earth in the lower atmosphere.

A year later, the Interdepartmental Committee for Atmospheric Sciences (1975) estimated that a 5% reduction in ozone could result in nearly a 10% increase in cancer. This frightening scenario grew even more so when by 1987 evidence showed that CFCs destroy ozone in the stratosphere above Antarctica every spring, and the ozone hole had become larger. More than half of the total ozone column had been wiped out and essentially all ozone was gone from some regions of the stratosphere (Davis and Cornwell, 1991).

In 1988, Zurer reported that on a worldwide basis the ozone layer had shrunk approximately 2.5% in the preceding decade. This obvious thinning of the ozone layer, in addition to increasing the chances of skin cancer and cataracts, is also implicated in suppression of the human immune system and damage to other animals and plants, especially aquatic life and soybean crops. The urgency of the problem spurred the 1987 signing of the Montreal Protocol by 24 countries which required signatory countries to reduce their consumption of CFCs by 20% by 1993 and by 50% by 1998, marking a significant achievement in solving a global environmental problem.

The Clean Air Act of 1990 borrowed from USEPA requirements already on the books in other regulations and mandated phase-out of the production of substances that deplete the ozone layer. Under these provisions, the USEPA was required to develop a list of all regulated substances along with their ozone-depletion potential, atmospheric lifetime, and global warming potentials.

GLOBAL DIMMING

A *USA Today* article with the headline, "Your Eyes Aren't Deceiving You: Skies Are Dimmer," observed that air pollution has caused skies above most the world's land areas to dim slightly over the past 30 years (Rice, 2009). Scientists have found that most of the blame can be traced to aerosols—suspended airborne pollution—that are released from the burning of fossil fuels.

Before discussing global dimming it is important to have a fundamental understanding of *albedo*, which is the ratio between the light reflected from a surface and the total light falling on it (i.e., incident to it). Albedo always has a value less than or equal to 1. An object with a high albedo, near 1, is very bright, while a body with a low albedo, near 0, is dark. Freshly fallen snow typically has an albedo between 75% and 90%; that is, 75% to 90% of the solar radiation that is incident on snow is reflected. Thus, a surface cover such as clean snow has the ability to reflect solar radiation because of its high albedo. At the other extreme, the albedo of a rough, dark surface, such as a green forest, may be as low as 5%. The albedos of some common surfaces are listed in Table 6.3. The portion of insolation not reflected is absorbed by the Earth's surface, warming it. This means Earth's albedo plays an important part in the Earth's radiation balance and influences the mean annual temperature and the climate on both local and global scales.

TABLE 6.3
The Albedos of Various Surfaces

Surface	Albedo (% Reflected)	Surface	Albedo (% Reflected)
Water (low sun)	10–100	Old snow	40–70
Water (high sun)	3–10	Fresh snow	75–90
Grass	16–26	Sea ice	30–40
Glacier ice	20–40	Blacktopped tarmac	5–10
Deciduous forest	15–20	Desert	25–30
Coniferous forest	5–15	Crops	15–25

Global dimming (Stanhill and Moreshet, 2004) is the gradual reduction in the amount of global direct irradiance at the Earth's surface that was observed for several decades (1950 to 1990). The effect varies by location; however, worldwide it has been estimated to be on the order of a 4% reduction from the 1960s to the 1990s (Hegerl et al., 2007). Global dimming is a result of burning fossil fuels, which also contributes to the production of greenhouse gases. More precisely, the byproducts (sulfur dioxide, soot, and ash) of fossil fuel use change the properties of clouds. Clouds are formed when water droplets are seeded by airborne particles, such as ash and pollen. Polluted clouds have a larger number of droplets than unpolluted clouds. This then makes those clouds more reflective of the sun's heat and energy, which are reflected back into space. In addition to fossil-fuel-generated pollutants, it is thought that global dimming is also the result of the increased presence of aerosol particles in the atmosphere caused by human action. However, since 1990, this trend has declined because of the worldwide ban on the use of certain aerosols in spray cans and other applications.

DID YOU KNOW?

A brief interval when the skies were clear of jets (the events of 9/11 and the 3-day aftermath) unmasked a surprising effect on climate. Condensation trails (contrails) from jet aircraft *reduce* the daily temperature range. Contrary to popular belief, contrail pollution turned out not to be a contributor to global warming or global climate change. Studies conducted during the 3-day period when all commercial jets were grounded showed an anomalous increase in the average diurnal temperature range (i.e., the difference between the daytime maximum and nighttime minimum temperatures) for the period from September 11 to 14, 2001. Because persisting contrails can reduce the transfer of both incoming solar and outgoing infrared radiation and so reduce the daily temperature range, we can attribute at least a portion of this anomaly to the absence of contrails over this period (Travis et al., 2002).

DID YOU KNOW?

Some scientists have suggested using aerosols to stave off the effects of global warming. Aerosols could increase planetary albedo up to 0.5%, a level sufficient enough to halve the effect of carbon dioxide doubling. However, Earth would still suffer environmental problems from sulfates creating acid rain. Also, carbon black usage could increase human health problems, dimming could bring about changes in evaporation and rainfall patterns, droughts or increased rainfall could lead to agricultural problems, and aerosols have a relatively short lifetime (Ramanathan, 2006). Thus, using aerosols to mask global warming problems is actually nothing more than a Faustian bargain (short-term gain for a whole lot of pain).

HAZE

The World Meteorological Organization (WMO, 2009) *Manual on Codes* includes a classification of horizontal obscuration into categories of fog, ice fog, steam fog, mist, smoke, volcanic ash, dust, sand and snow, and haze. Haze is an atmospheric phenomenon where dust, smoke, and other dry particles obscure the clarity of the sky. Haze particles form during brush fires, forest fires, agricultural plowing, heavy traffic, and industrial operations.

ROADWAY AIR POLLUTION

Roadway air pollution is one of the most prominent linear or line sources of pollution (meaning it emanates from a one-dimensional source). This pollution source can only be studied using computer models because of the complex variables involved, including vehicle emissions, vehicle speed, meteorology, and terrain geometry (USEPA, 2017c).

THE BOTTOM LINE

When news media personnel, would-be political candidates, and general doomsayers make their dire warnings about global climate change (specifically that the Earth is getting warmer), keep in mind these two points: (1) the transitions from past ice ages to several interglacials (warm periods) are well documented, with considerable actual evidence to support them; and (2) we cannot put the blame for the interglacial warming trends on humans because at that time humans contributed little in the way of carbon dioxide, CFCs, or any other chemical substance to Earth's atmosphere.

The real bottom line: When the doomsayers spout out their fire and brimstone, their warnings of cataclysmic doom and gloom, or try to sell you waterfront property in Antarctica, remember our noble predecessors, Yurk and *Smilodon*.

DISCUSSION QUESTIONS

1. Write your own comprehensive definition and description of air pollution. Include the elements you consider most important and why.
2. Discuss the problems associated with air pollution migration.
3. What are the chief types of air pollutants? What are their common sources and most detrimental effects?
4. What mechanisms affect the fate of air pollutants? How does each work?
5. Describe and discuss the four chief problem areas related to air pollutants.
6. Discuss air pollution and its possible relationship to climate change.
7. What are the possible and probable ways global warming could affect human populations?

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7 Air Pollution Monitoring, Sampling, and Remediation

> Nobody ever has enough.
>
> **Lapham (1988)**

> … left the city of Rummidge and passed into an area known as the Dark Country—so called because of the pall of smoke that hung over it, and the film of coal dust and soot that covered it, in the heyday of the Industrial Revolution … rich mineral deposits were discovered here in the early nineteenth century: coal, iron, limestone. Mines were sunk, quarries excavated, and ironworks sprang up everywhere to exploit the new technique of smelting iron ore with cork, using limestone as a flux. The fields were gradually covered with pitheads, foundries, factories, and workshops, and rows of wretched hovels for the men, women, and children who worked in them: a sprawling, unplanned, industrial conurbation that was gloomy by day, fearsome by night. A writer called Thomas Carlyle described it in 1824 as: "A frightful scene … a dense cloud of pestilential smoke hangs over it forever … and at night the whole region becomes like a volcano spitting fire from a thousand tubes of brick." A little later, Charles Dickens recorded traveling "through miles of cinder-paths and blazing furnaces and roaring steam engines, and such a mass of dirt, gloom, and misery as I never before witnessed." Queen Victoria had the curtains of her train window drawn when she passed through the region so that her eyes should not be offended by its ugliness and squalor.
>
> **Lodge (1988)**

AIR MONITORING AND SAMPLING[*]

Unless you are choking or sneezing or otherwise having difficulty breathing because of obvious air contamination, the fact that the air you are breathing is contaminated might not be so apparent—until too late. A good example of this is the inhalation of invisible asbestos fibers. People exposed to asbestos would have no clue of what they were breathing until approximately 20 to 30 years later when diagnosed with asbestosis or mesothelioma. This is why air monitoring is widely used to measure human exposure and to characterize emission sources. It is often employed within the context of a general survey, for investigating a specific complaint, for confirming the suspected presence of various contaminants, or simply for regulatory compliance. If monitoring is conducted to determine the presence of contaminants and does, in fact, find them to be present, then air sampling protocols are used to determine the level of exposure. If unacceptable levels of contaminants are found, then remedial actions must be taken to protect those who could be exposed.

AIR SAMPLE VOLUME

The publications *Sampling and Analytical Methods* (OSHA) and *Manual of Analytical Methods* (NIOSH) list a range of air sample volumes, from minimum volume (VOL-MIN) to maximum volume (VOL-MAX), that should be collected for an exposure assessment. The volume is based on the

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[*] This material is adapted from Spellman, F.R., *Industrial Hygiene Simplified*, 2nd ed., Bernan Press, Lanham, MD, 2017.

sampler's sorptive capacity and assumes that the measured exposure is the Occupational Safety and Health Administration's permissible exposure limit (PEL). The range of volumes listed may not collect a sufficient mass for accurate laboratory analysis if the actual contaminant concentration is less than the PEL or the threshold limit value time-weighted average (TLV-TWA). If a collection method recommends sampling 10 liters of air, then the industrial hygienist cannot be sure that an 8.5-liter air sample will collect sufficient mass for the lab to quantify. This makes an important point—that is, finding that an insufficient air volume was sampled after the lab results are returned can turn out to be an enormous waste of resources. To avoid this situation, it is essential to understand the two restrictions faced by analytical labs: *limit of detection* (LOD) and *limit of quantification* (LOQ). To compute a minimum air sample volume required to provide useful information for the evaluation of airborne contaminant concentrations in the workplace, industrial hygienists must understand how to correctly manipulate the LOD and the LOQ. Knowledge of these limits will provide increased flexibility in sampling.

Limit of Detection

The limit of detection (LOD) has many definitions in the literature. For example, the American Chemical Society (ACS) Committee on Environmental Analytical Chemistry has defined the LOD as the lowest concentration level that can be determined to be statistically different from a blank sample, which is a sample of a carrying agent—a gas, liquid, or solid—that is normally used to selectively capture a material of interest and that is subjected to the usual analytical or measurement process to establish a zero baseline or background value, which is then used to adjust or correct routine analytical results. For our purposes, the ACS definition of LOD is used in this discussion. The analytical instrument output signal produced by the sample must be three to five times the instrument's background noise level to be at the limit of detection; that is, the signal-to-noise (S/N) ratio is three to one (3:1). The S/N ratio is the analytical method's lower limit of detection.

Limit of Quantification

The limit of quantification (LOQ) is the concentration level above which quantitative results may be obtained with a certain degree of confidence; that is, the LOQ is the minimum mass of the analyte above which the precision of the reported result is better than a specified level. The recommended value of the LOQ is the amount of analyte that will give rise to a signal that is 10 times the standard deviation of the signal from a series of media blanks.

PRECISION, ACCURACY, AND BIAS

Sample results are only as good as the sampling technique and equipment used. Thus, in any type of air monitoring operation (air, water, or soil), it is important for industrial hygienists to factor in the precision, accuracy, and any possible bias involved in the monitoring process. *Precision* is the reproducibility of replicate analyses of the same sample (mass or concentration); for example, how close to each other is a target shooter able to place a set of shots anywhere on the target? *Accuracy* is the degree of agreement between measured values and the accepted reference value. Investigators must carefully design their sampling program and use certain statistical tools to evaluate the data before making any inferences from the data. In our target shooting analogy, accuracy can be equated to how close does a target shooter come to the bull's eye? *Bias* is the error introduced into sampling that causes estimates of parameters to be inaccurate. More specifically, bias is the difference between the average measured mass or concentration and a reference mass or concentration, expressed as a fraction of the reference mass or concentration. For example, how far from the bull's eye is the target shooter able to place a cluster of shots?

CALIBRATION REQUIREMENTS

The American National Standards Institute has defined calibration as the set of operations that establishes, under specified conditions (i.e., instrument manufacturer's guidelines or regulator's protocols), the relationship between values indicated by a measuring instrument or measuring system and the corresponding standard or known values derived from the standard. Note that before any air monitoring device can be relied on as accurate it must be calibrated. Calibration procedures can be found in the Occupational Safety and Health Administration's *Personal Sampling for Air Contaminants* (https://www.osha.gov/dts/osta/otm/otm_ii/otm_ii_1.html).

TYPES OF AIR SAMPLING

Although the information provided in the following discussion is area specific (*area sampling*), it is important to point out that one of the most important air sampling operations is *personal sampling*, which puts the sample detection device on the worker. This is done to obtain samples that represent the worker's exposure while working. As the preferred method of evaluating worker exposure to airborne contaminants, personal sampling requires the worker to wear the detection device on their person in the breathing zone area. A small air pump and associated tubing connected to the detector are also worn by the worker. Personal sampling allows the industrial hygienist to define a potential hazard, check compliance with specific regulations, and determine the worker's daily time-weighted average exposure.

ANALYTICAL METHODS FOR SAMPLING GASES AND VAPORS

In routine practice, industrial hygienists will collect air samples to determine the concentration of a known contaminant or group of contaminants and will request or conduct analyses for these compounds. The first step in this procedure is to develop a sampling plan. When developing a sampling plan or strategy, the sampler should review the specific sampling and analytical methods available for the contaminants of interest. Several organizations have compiled and published collections of sampling and analytical methods for gases and vapors:

- *NIOSH Manual of Analytical Methods*, 5th ed.
  National Institute for Occupational Safety and Health
  Centers for Disease Control and Prevention
  4676 Columbia Parkway
  Cincinnati, OH 45226
- *Annual Book of ASTM Standards*
  American Society for Testing and Materials
  100 Barr Harbor Drive
  West Conshohocken, PA 19428
- *OSHA Analytical Methods Manual*
  Occupational Safety and Health Administration
  OSHA Salt Lake Technical Center
  P.O. Box 65200
  Salt Lake City, UT 84165
- *Methods of Air Sampling and Analysis*, 3rd ed.
  James P. Lodge, Jr., Editor
  Lewis Publishers
  2000 Corporate Blvd. NW
  Boca Raton, FL 33431

For discussion purposes, analytical methods for gases and vapors (a vapor is the gaseous phase of a substance that is liquid or solid at normal temperature and pressure; vapors diffuse) are grouped into chromatographic, volumetric, and optical methods. In the following, we briefly discuss chromatography.

The primary type of analytical equipment used in chromatography for the analysis of gases and vapors in air samples is the *gas chromatograph* (GC), which is a powerful tool for the analysis of low-concentration air contaminants. It is generally a reliable analytical instrument. GC analysis is applicable to compounds with sufficient vapor pressure and thermal stability to dissolve in the carrier gas and pass through the chromatographic column in sufficient quantity to be detectable. Air samples to be analyzed by GC are typically collected on sorbent tubes and desorbed into a liquid for analysis. It should be noted that the GC instrument cannot be used for reliable identification of specific substances. Because of this limitation, the GC is often married to the mass spectrometer (MS) instrument to provide specific results. When industrial hygienists or engineering analysts use the GC instrument to separate compounds before analysis with an MS instrument, a complementary relationship exists. The technician has access to both the retention times and mass spectral data. Many environmental professionals consider GC/MS analysis to be a tool for conclusive proof of identity—the "gold standard" in scientific analysis. Some common applications of GC/MS include the following:

1. Evaluation of complex mixtures
2. Identification of pyrolysis and combustion products from fires
3. Analysis of insecticides and herbicides (conventional analytical methods frequently cannot resolve or identify the wide variety of industrial pesticides currently in use, but GC/MS can both identify and quantify these compounds)

AIR MONITORING VS. AIR SAMPLING

In the practice of industrial hygiene, the terms *air monitoring* and *air sampling* are often used interchangeably to mean the same thing. But are they the same? It depends. In reality, they are different; that is, air monitoring and air sampling are separate functions. The difference is related to time: real time vs. time integration. Air monitoring is real-time monitoring and generally includes monitoring with hand-held, direct-reading units such as portable gas chromatographs (GCs), photoionization detectors (PIDs), flame ionization detectors (FIDs), dust monitors, and colorimetric tubes. Real-time air monitoring instrumentation is generally easily portable and allows the user to collect multiple samples in a relatively short sample period—ranging from a few seconds to a few minutes. Most portable real-time instruments measure low parts per million (ppm) of total volatile organics.

Real-time monitoring methods have higher detection limits than time-integrated sampling methods, react with entire classes of compounds, and, unless real-time monitoring is conducted continuously, provide only a snapshot of the monitored ambient air concentration. Air monitoring instruments and methods provide results that are generally used to evaluate short-term exposure limits and can provide timely information to those engaged in various activities such as confined space entry operations. In confined space operations, proper air monitoring can detect the presence or absence of life-threatening contaminants or insufficient oxygen levels within the confined space, alerting the entrants not to enter before making the space safe (e.g., by using forced air ventilation) for entry.

On the other hand, time-integrated air sampling is intended to document actual exposure for comparison to long-term exposure limits. Air sampling data are collected at fixed locations along the perimeter of the sample area (work area) and at locations adjacent to other sensitive receptors. Because most contaminants are or will be present in ambient air at relatively low levels, some type of sample concentrating is necessary to meet detection limits normally required to evaluate long-term health risks. Air sampling is accomplished using air-monitoring instrumentation designed to continuously sample large volumes of air over extended periods of time (typically from 8 to 24 hours). Air sampling methods involve collecting air samples on sampling media designed specifically for collection of the compounds of interest or as whole air samples. Upon completion of the sampling period the sampling media are collected, packaged, and transported for subsequent analysis. Analysis of air samples usually requires a minimum of 48 hours to complete. Both air sampling and air monitoring are important and significant tools in the industrial hygienist's toolbox.

To effectively evaluate a potentially hazardous worksite, industrial hygienists must obtain objective and quantitative data. To do this, they must perform some form of air sampling, depending on the airborne contaminant in question. Moreover, sampling operations involve the use of instruments to measure the concentration of the particulate, gas, or vapor of interest. Many instruments perform both sampling and analysis. The instrument of choice in conducting sampling and analysis typically is a direct-reading type of instrument. Industrial hygienists must be familiar with the uses, advantages, and limitations of such instruments. In addition, they must be able to use math calculations to calculate sample volumes, sample times, threshold limit values (TLVs), and air concentrations from vapor pressures and to determine the additive effects of chemicals when multiple agents are used in the workplace. These calculations must take into account changing conditions, such as temperature and pressure changes, in the workplace. Finally, industrial hygienists must understand how particulates, gases, and vapors are generated, how they enter the human body, how they impact workers' health, and how to evaluate particulate-, gas-, and vapor-laden workplaces.

Because air sampling is integral to just about everything industrial hygienists do and are about, the following text includes important sections focusing on air sampling principles, airborne particulates, airborne gases and vapors, direct-reading instruments, and basic air sampling calculations.

AIR SAMPLING PRINCIPLES

The results obtained by air sampling depend very much on the time and place where the samples are taken and the type of instrument used. Those concerned with setting hygiene standards usually take into account the wide variation in the results that may be obtained, and they take great care that there will be no misreading of the values inserted in the standards. Dust concentrations can vary around the average value from zero up to 2.5 times the average, even in conditions where the work appears to be done at a steady rate. Industrial hygiene standards may place an upper limit on the average concentration over a work shift or on the maximum concentration during this period, or both. It is important to determine the concentration of a contaminant in the air that may be inhaled. When planning and executing a survey of the particulates in workroom air, one should bear in mind that the concentration close to a machine or process is usually quite different from the concentration in the inhaled air. In fact, the concentration may vary considerably over a distance of a few feet to even over a distance of a few inches. This is especially true when there are few sources of contaminants and the employees work close to a source. There should be no physical obstruction between the air sampler inlet and the operator's nose and mouth. When there is any doubt, the sampler inlet should be within a foot of the operator's nose and mouth and yet be out of the line of sight.

SAMPLING FOR AIRBORNE PARTICULATES

Airborne particulates, or particulate matter (PM), include solid and liquid matter such as

- *Dusts* have diameters that range from 1 to 150 μm; they are produced mechanically by grinding and other abrasive actions occurring in natural and commercial operations.
- *Fumes* have diameters that range from 0.2 to 1 μm; they are produced by such processes as combustion, distillation, calcinations, condensation, sublimation, and chemical reactions. They form true colloidal systems in air. Examples are such substances as heated metals or metallic oxides, ammonium chloride, hot asphalt, and volatilized polynuclear hydrocarbons from coking operations.

DID YOU KNOW?

No two different types of airborne particulate sampler yield the same result. It takes the most painstaking test to yield similar results for two identical instruments. Thus, the instrument used must be the same type and must be used in the same way as that inferred in the industrial standard.

- *Mists and fogs* comprise a category that covers a wide range of particle sizes that are considered to be primarily liquid; they may consist of liquids, such as water vapor, condensed on the surfaces of submicroscopic particles of dust or gaseous ions.
- *Smokes* are colloidal systems whose particle sizes range from 0.3 to 0.5 µm in diameter. They are produced by the incomplete combustion of carbonaceous materials such as coal, oil, tobacco, and wood.
- *Aerosols and bioaerosols* are airborne solid or liquid substances. Aerosol particles normally present in ambient air have been dispersed as a result of nature or human activities. The latter source is of greater concern for environmental control specialists. Aerosols are generated by fire, erosion, sublimation, and the abrading action of friction on minerals, metallurgical materials, organic and other inorganic substances in construction, manufacturing, mining, agriculture, transportation, and other gainful pursuits.
- *Fibers* (minerals, vegetable, or animal) are a unique category insofar as exposures are concerned. Inhalation of asbestos fibers up to 200 µm in length has been reported (Harrington, 1939; Timbrell, 1965). Microscopic procedures are used to assist in the identification of fibrous materials and to determine their atmospheric concentration.

Inhalation of particulates is a major cause of occupational illness and disease. Pneumoconiosis ("dusty lung") is a lung disease caused by inhaling dust (e.g., coal dust). There are four critical factors that influence the health impact of airborne particulates. Each of these four factors is interrelated in such a way that no one factor can be considered independently of the others:

- Size of the particles
- Duration of exposure time
- Nature of the dust in question
- Airborne concentration of the dust in the breathing zone of the exposed person

DUSTS

Dusts are generated by mechanical processes such as grinding or crushing. Dusts range in size from 0.5 to 50 µm in size. Note that *dust* is a relatively new term used to describe dust that is hazardous when deposited anywhere in the respiratory tree, including the nose and mouth. It has a 50% cut-point of 10 µm and includes the big and the small particles. The cut-point describes the performance of cyclones and other particle size selective devices. For personal sampling, the 50% cut-point is the size of the dust that the device collects with 50% efficiency. Common workplace dusts are either inorganic or organic.

DID YOU KNOW?

The *breathing zone* of the worker can be described by a hemisphere bordering the shoulders to the top of the head with a radius of 6 to 9 inches.

Inorganic dusts are derived from metallic and nonmetallic sources. Nonmetallic dusts can be silica bearing—that is, in combined or free silica as crystalline or amorphous form. Organic dusts are either synthetic or natural. Natural organic dusts can be animal or vegetable derived. Examples of organic and inorganic dusts include sand (inorganic, nonmetallic, silica-bearing, free silica, crystalline), beryllium (inorganic, metallic), and cotton (organic, naturally occurring, vegetable). Dusts can also be classified on the basis of their health effects (Grantham, 1992):

- *Innocuous*—Iron oxide, limestone (may also be considered as nuisance dusts)
- *Acute respiratory hazards*—Cadmium fumes
- *Chronic respiratory hazards*—Airborne asbestos fibers
- *Sensitizers*—Many hardwood dusts

Duration of Exposure

The duration of exposure may be *acute* (short term) or *chronic* (long term). Some airborne particulates, such as beryllium, may exert a toxic effect after a single acute exposure, or metal fume fever may occur following acute exposure to metal fumes. Other particulates, such as lead or manganese, may exert a toxic effect following a longer period of exposure, maybe several days to several weeks. Such exposures could be termed *subchronic*. Chronic lung conditions, such as pneumoconiosis or mesothelioma, may follow prolonged exposure to silica dusts or asbestos (crocidolite or blue asbestos), respectively.

Particle Size

Particle size is critical in determining where particulates will settle in the lung. Smaller particles outnumber larger ones but vary widely in size. Larger particles will settle in the upper respiratory tract in the bronchi and the bronchioles and will not tend to penetrate the smaller airways found in the alveolar (air sac) region. These are termed *inspirable* particles. The smaller sized particles that can penetrate the alveolar (gas-exchange) region of the lungs are termed *respirable* particles. Particle size is expressed as aerodynamic or equivalent diameter. This is equal to the diameter of spherical particles of unit density that have the same falling velocity (terminal velocity or settling velocity) in air as the particle in question. The terminal velocity is proportional to the specific gravity of the particle and the square of its diameter.

Particles with an aerodynamic diameter greater than approximately 20 μm will be trapped in the nose and upper airways. Particles in the region of 7 to 20 μm will penetrate to the bronchioles and are inspirable, whereas particles in the size range of 0.5 to 7 μm are respirable. Particles smaller than this will not settle out because their terminal velocity is so small that there is insufficient time for them to be deposited in the alveolus and they are exhaled out again.

An understanding of aerodynamic diameter is important when calculating terminal settling rates of particulates. Constants for these calculations include the following:

$1\ \mathrm{gm/cm^3}$ = Unit density
Gravity = $32.2\ \mathrm{ft/sec^2}$ or $98\ \mathrm{cm/sec^2}$

Stokes's Law

Stokes's law is the relationship that relates the settling rate to the density and diameter of a particle. Stokes's law applies to the fate of particulates in the atmosphere and can be given as

$$\mu = \frac{gd^2\rho_1 - \rho_2}{18\eta} \tag{7.1}$$

where

u = Settling velocity (cm/s).
g = Acceleration due to gravity (cm/s^2).
d^2 = Diameter of particle squared (cm^2).
ρ_1 = Particle density (g/cm^3).
ρ_2 = Air density (g/cm^3).
η = Air viscosity (poise; g/cm · s).

What Stokes's law tells us is that, all other things being constant, dense particles settle faster, larger particles settle faster, and denser, more viscous air causes particles to settle more slowly. Stokes's law is used in several ways. We can predict the settling rate for a given particle if its diameter and density are known, or we can use it to estimate particle diameters (Stokes diameters) from the observed settling rates.

Airborne Dust Concentration

The concentration of dust to which a person is exposed is a critical factor with regard to the impact on the health of the worker exposed. The concentration is measured in the breathing zone of the worker. Airborne concentrations of dust are usually assessed by collecting dust on a preweighed filter. A known volume of air is drawn through the filter, which is then reweighed. The difference in weight is the mass of dust, usually in milligrams (mg) or micrograms (μg), and the volume is expressed as cubic meters of air (m^3). Hence, the overall concentration of dust in air is measured in mg/m^3 or μg/m^3.

PARTICULATE COLLECTION

In order to evaluate the workplace atmosphere for particulates a sample must be taken and analyzed. To obtain a sample the following collection mechanisms are used:

- Impaction
- Sedimentation
- Diffusion
- Direct interception
- Electrostatic attraction

The filter is the most common particulate collection device. The mixed cellulose ester membrane filter is the most commonly used type of filter. This type of filter is used for collecting asbestos and metals. Other filter types include polyvinyl chloride, silver, glass-fiber, and Teflon.

ANALYSIS OF PARTICULATES

Several methods are available for the analysis of particulates:

- *Gravimetric*—Coal dust, free silica, total dust
- *Instrumental*—Atomic absorption (AA) for metals
- *Optical microscopy*—Fibers, asbestos, dust
- *Direct-reading instruments*—Aerosol photometers, piezoelectric instruments
- *Wet chemical*—Lead, isocyanates, free silica

HEALTH AND ENVIRONMENTAL IMPACTS OF PARTICULATES

Particulates have a wide variety of health and environmental impacts. Many scientific studies have linked breathing particulates to a series of significant health problems, such as

- Aggravated asthma
- Increases in respiratory symptoms such as coughing and difficult or painful breathing
- Chronic bronchitis
- Decreased lung function
- Premature death

Particulate matter is the major cause of reduced visibility (haze) in parts of the United States, including many of our national parks. Particles can be carried over long distances by wind and then settle on ground or water. The effects of this settling include the following:

- Making lakes and streams acidic
- Changing the nutrient balance in coastal waters and large river basins
- Depleting the nutrients in soil
- Damaging sensitive forests and farm crops
- Affecting the diversity of ecosystems

Control of Particulates

As with all other methods of industrial hygiene hazard control, control of particulates is most often accomplished through the use of engineering controls, administrative controls, and personal protective equipment (PPE). The best method for controlling particulates is the use of ventilation—an engineering control. To be most effective, the particulate generating process should be totally enclosed with a negative pressure exhaust ventilation system in place. Administrative controls include using wet methods of housekeeping and wet cleanup methods to minimize dust regeneration and prohibiting the use of compressed air to clean work surfaces. PPE, used as a last resort, includes equipping workers with proper respiratory protection to prevent the inhalation of particulates and protective clothing to prevent worker contact with particulates.

AIR SAMPLING FOR GASES AND VAPORS

Gases and vapors are elastic fluids, so-called because they take the shape and volume of their containers. A fluid is generally termed a *gas* if its temperature is very far removed from that required for liquefaction; it is called a *vapor* if its temperature is close to that of liquefaction. In the industrial hygiene field, a substance is considered a gas if this is its normal physical state at room temperature and atmospheric pressure. It is considered a vapor if, under the existing environmental conditions, conversion of its liquid or solid form to the gaseous state results from its vapor pressure affecting its volatilization or sublimation into the atmosphere of the container, which may be the process equipment or the worksite. Our chief interest in distinguishing between gases and vapors lies in our need to assess the potential occupational hazards associated with the use of specific chemical agents, an assessment that requires knowledge of the physical and chemical properties of these substances (Keenan, 1973). The type of air sampling for gases and vapors employed depends on the purpose of sampling, environmental conditions, equipment available, and nature of the contaminant.

Gas Laws

When sampling gases and vapors, it is important to have a basic understanding of the physics of air. Specifically, it is important to have an understanding of the gas laws (Spellman, 2009). Gases can be contaminants as well as the conveyors of contaminants. Air (which is mainly nitrogen) is usually the main gas stream. Gas conditions are usually described in two ways: *standard temperature and pressure* (STP) and *standard conditions* (SC). STP represents 0°C (32°F) and 1 atm. SC is more commonly used and represents typical room conditions of 20°C (70°F) and 1 atm; SC is usually measured in cubic meters (m^3), Nm^3, or standard cubic feet (scf). To understand the physics of air it is imperative to have an understanding of various physical laws that govern the behavior of pressurized gases.

Pascal's law states that a confined gas (fluid) transmits externally applied pressure uniformly in all directions without change in magnitude. If the container is flexible, it will assume a spherical (balloon) shape.

Boyle's law states that the absolute pressure of a confined quantity of gas varies inversely with its volume at a given temperature; for example, if the pressure of a gas doubles, its volume will be reduced by half, and *vice versa*. Boyle's law is expressed in equation form as:

$$P_1 \times V_1 = P_2 \times V_2 \tag{7.2}$$

where

P_1 = Original pressure (units for pressure must be absolute).
P_2 = New pressure (units for pressure must be absolute).
V_1 = Original gas volume at pressure P_1.
V_2 = New gas volume at pressure P_2.

Charles's law states that the volume of a given mass of gas at constant pressure is directly proportional to its absolute temperature. The absolute temperature is the temperature in Kelvin (273 + °C). Absolute zero = –460°F, or 0°R on the Rankine scale. This is calculated as follows:

$$P_2 = P_1 \times T_2/T_1 \tag{7.3}$$

Charles's law also states that, if the pressure of a confined quantity of gas remains the same, the change in the volume (V) of the gas varies directly with a change in the temperature of the gas, as given below:

$$V_2 = V_1 \times T_2/T_1 \tag{7.4}$$

The *ideal gas law* combines Boyle's and Charles's laws because air cannot be compressed without its temperature changing. The ideal gas law can be expressed as

$$P_1 \times V_1/T_1 = P_2 \times V_2/T_2 \tag{7.5}$$

Note that the ideal gas law is still used as a design equation even though the equation shows that the pressure, volume, and temperature of the second state of a gas are equal to the pressure, volume, and temperature of the first state. In actual practice, however, other factors such as humidity, heat of friction, and efficiency losses all affect the gas. Also, this equation uses absolute pressure (psia) and absolute temperatures (°R) in its calculations. The ideal gas law can also be expressed as

$$PV = nRT \tag{7.6}$$

where

P = Absolute pressure.
V = Volume.
n = Number of moles.
R = Universal gas constant.
T = Absolute temperature.

Note that this relationship explains why 1 gram molecular weight (GMW) of gas occupies 22.4 liters of space at STP. This number represents the number of molecules in 1 mole of any compound.

TYPES OF AIR SAMPLES

No matter the type of air sampling used, workplace samples must be obtained that represent the worker's exposure (i.e., a representative sample). When taking a representative sample, a sampling plan should be used that specifies the following:

- Where to sample
- Whom to sample
- How long to sample
- How many samples to take
- When to sample

Generally, two methods of sampling for airborne contaminants are used: personal sampling and area sampling. Personal sampling (where the worker wears a sampling device that collects an air sample) is the preferred method of evaluating worker exposure to airborne contaminants. Area monitoring (e.g., in confined spaces) is used to identify high exposure areas.

METHODS OF SAMPLING

Standardized sampling methods provide the information needed to sample air for specific contaminants. Standard air sampling methods specify procedures, collection media, sample volume, flow rate, and chemical analysis to be used. For example, NIOSH's *Manual of Analytical Methods* and OSHA's *Chemical Information Manual* provide the information necessary to sample air for specific contaminants. Generally, two methods of sampling are used to sample for airborne contaminants: *grab sampling* and *continuous* (or integrated) *sampling*. Grab sampling (i.e., instantaneous sampling) is conducted using a heavy-walled evacuated (air removed) flask. The flask is placed in the work area and a valve is opened to allow air to fill the flask. The sample represents a snapshot of an environmental concentration at a particular point in time. The sample is analyzed either in the laboratory or with suitable field instruments. Continuous sampling is the preferred method for determining time-weighted average (TWA) exposures. The sample is taken from a sample air stream.

AIR SAMPLING COLLECTION PROCESSES

Airborne contaminants are collected on media or in liquid media through absorption or adsorption processes. *Absorption* is the process of collecting gas or vapor in a liquid (dissolving gas/vapor in a liquid). Absorption theory states that gases and vapors will go into solution up to an equilibrium concentration. Samplers include gas washing bottles (impingers), fritted bubblers, spiral and helical absorbers, and glass-bead columns. *Gas adsorbents* (gas onto a solid) typically use activated charcoal, silica gel, or other materials to collect gases. *Diffusive samplers* (passive samplers) depend on the flow of contaminant across a quiescent layer of air (where no pump is used to draw air across an adsorbent) or a membrane. Diffusion depends on well-established rules from physical chemistry, known as Fick's law.

CALIBRATION OF AIR SAMPLING EQUIPMENT

In order to gather accurate sampling data, the equipment used must be properly calibrated. The calibration of any instrument is an absolute necessity if the data are to have any meaning. Various devices are used to calibrate air sampling equipment. Calibration is based on primary or secondary calibrations standards. Primary calibration standards include

- Soap bubble meter (or frictionless piston meter)
- Spirometer (measures displaced air)
- Mariotti bottle (measures displaced water)
- Electronic calibrators (provide instantaneous airflow readings)

Secondary calibration standards include

- Wet test meter
- Dry gas meter
- Rotameters

DIRECT-READING INSTRUMENTS FOR AIR SAMPLING

Direct-reading instruments are used for onsite evaluations for a number of reasons:

- Find the sources of emission of hazardous contaminants on the spot.
- Ascertain if select OSHA air standards are being exceeded.
- Check the performance of control equipment.
- Continuously monitor fixed locations.
- Trigger an alarm system in the event of breakdown in a process control that could result in the accidental release of copious amounts of harmful substances to the workroom atmosphere.
- Obtain permanent recorded documentation of the concentrations of a contaminant in the atmospheric environment for future use in epidemiological and other types of occupational studies, in legal actions, to inform employees as to their exposure, and for information required for improved design of control measures.

Such onsite evaluations of the atmospheric concentrations of hazardous substances make possible the immediate assessment of undesirable exposures and allow industrial hygienists to make an immediate correction of an operation, in accordance with their evaluation of the seriousness of a situation, without permitting further risk of injury to the workers (USPHS, 1973).

It cannot be over-emphasized that strict caution must be employed in the use of direct-reading instruments and in the interpretation of their results. The industrial hygienist must be aware of the nonspecificity of these instruments, which makes it absolutely necessary to make certain that onsite findings are supplemented by sampling and laboratory analyses to fully characterize the chemical nature of the contaminants in the work area and to develop the supporting quantification data with more specific and accurate methods. This precautions becomes even more imperative when the industrial hygienist has not had extensive experience with the particular process and production areas in question or when a change in the process or a substitution of chemical substances may have occurred.

Regardless of the type of air sampling or monitoring being performed, one particularly critical point must be made here: Never sample or monitor anything without first calibrating the instruments. Again, the calibration of any direct-reading instrument is an absolute requirement if the data are to have any meaning. It must be recognized that the frequency of calibration is dependent on the type of instrument as well as individual instruments within any use class. To emphasize this point further, consider that any person who willingly enters an unknown and untested confined space either is not very bright or possibly has a death wish. Calibrate, calibrate, calibrate—often! And only enter a confined space where the atmosphere has been tested safe. Experience has demonstrated that certain classes of instruments, because of their complexity, require more frequent calibration than others. Because all instruments are not the same (that is, they have their own quirks), it is important to recognize that this is the case. The fact is that different instruments produce variations in their response and general performance; therefore, they require a greater amount of attention and more frequent calibration than other instruments of the same design.

Another factor that can be evaluated only by experience is the variability of sampling locations. With regard to the danger of entering a confined space with uncalibrated or dysfunctional air sampling instrument (or none at all), those with experience know that there is more to this story. Some confined spaces have fixed-space monitors. When these monitors are operating properly, there is no problem. Keep in mind, however, that fixed monitors installed in certain spaces are subjected to the same contaminants and conditions they are intended to monitor or sample. Thus, consideration must be given to such problems as the presence of interfering chemical substances, the corrosive nature of contaminants (hydrogen sulfide is a good example of a harsh corrosive; exposure to it eats through cement and iron pipe, so imagine what it can do to delicate instruments), vibrations, voltage fluctuations, and other disturbing influences that may affect the response of the instrument (USPHS, 1973).

Finally, when sampling atmospheric conditions, the required accuracy of the measurements must be determined initially. Obviously, if an accuracy of ±3% is required, then more frequent calibration must be made than if ±25% accuracy is adequate.

DIRECT-READING PHYSICAL INSTRUMENTS

One type of direct-reading instruments used in air sampling is a *direct-reading physical instrument*. The physical properties of gases, aerosols, and vapors are used in the design of direct-reading physical instruments for quantitative estimations of these types of contaminants in the atmosphere. The various types of these instruments, the principle of operation, and a brief description of application are presented in the following discussion.

Aerosol photometry—Measures, records, and controls particulates continuously in areas requiring sensitive detection of aerosol levels; detects particles 0.05 to 40 µm in diameter. Computer interface equipment is available.

Chemiluminescence—Measures NO in ambient air selectivity and NO_x after conversion to NO by hot catalyst; specific measurement of O_2. No atmospheric interferences.

Colorimetry—Measures and separately records NO_2^-, NO_x, SO_2, total oxidants, H_2S, HF, NH_3, Cl_2, and aldehydes in ambient air.

Combustion—Detects and analyzes combustible gases in terms of percent lower explosive limit (LEL) on a graduated scale; available with alarm set at 1/3 LEL.

Conductivity, electrical—Records SO_2 concentrations in ambient air. Some operate off a 12-volt car battery and some can operate unattended for periods up to 30 days.

Coulometry—Continuous monitoring of NO, NO_2, O_x, and SO_2 in ambient air. Provided with strip chart recorders; some require attention only once a month.

Flame ionization (hydrocarbon analyzer)—Continuous monitoring of total hydrocarbons in ambient air; potentiometric or optional current outputs compatible with any recorder. Electronic stability from 32° to 110°F.

Flame ionization (with gas chromatograph)—Continuous determination and recording of methane, total hydrocarbons, and carbon monoxide. Catalytic conversion of SO to CH_4. Operates up to 3 days unattended. Separate model for continuous monitoring of SO_2, H_2S, and total sulfur in air. Unattended operation up to 3 days.

Gas chromatograph, portable—Onsite determination of fixed gases, solvent vapors, nitro and halogenated compounds, and light hydrocarbons. Instruments available with choice of flame ionization, electron capture, or thermal conductivity detectors and appropriate columns for desired analyses. Rechargeable batteries.

Infrared analyzer (photometry)—Continuous determination of a given component in a gaseous or liquid stream by measuring the amount of infrared energy absorbed by the component of interest using a pressure sensor technique. Wide variety of applications for CO, CO_2, freons, hydrocarbons, nitrous oxide, NH_3, SO_2, and water vapor.

Particle counting (near-forward scattering)—Reads and prints directly particle concentrations at one of three preset time intervals of 100, 1000, or 10,000 seconds, corresponding to 0.01, 0.1, and 1 cubic foot of sampled air.

Photometry, ultraviolet (tuned to 253.7 nm)—Direct readout of mercury vapor; calibration filter is built into the meter. Other gases or vapors that interfere include acetone, aniline, benzene, ozone, and others that absorb radiation at 253.7 nm.

Photometry, visible (narrow-centered 394-nm band pass)—Continuous monitoring of SO_2, SO_3, H_2S, mercaptans, and total sulfur compounds in ambient air. Operates more than 3 days unattended.

Polarography—Monitors gaseous oxygen in flue gases, automobile exhausts, hazardous environments, and food storage atmospheres, as well as dissolved oxygen in wastewater samples. Battery operated, portable, sample temperature range 32° to 110°F, up to 95% relative humidity. Potentiometric recorder output. Maximum distance between sensor and amplifier is 1000 feet.

Radioactivity—(1) Continuous monitoring of ambient gamma and x-radiation by measurement of ion chamber currents, averaging or integrating over a constant recycling time interval; sample temperature limits 32°F to 120°F and 0 to 95% relative humidity (weatherproof detector); up to 1000-foot remote sensing capability. Recorder and computer outputs. Complete with alert, scram, and failure alarm systems. All solid-state circuitry. (2) Continuous monitoring of beta- or gamma-emitting radioactive materials within gaseous or liquid effluents; either a thin-wall Geiger–Müller tube or a gamma scintillation crystal detector is selected depending on the isotope of interest; gaseous effluent flow is 4 cfm; effluent sample temperature limits are 32°F to 120°F using a scintillation detector and –65°F to 165°F using a Geiger–Müller detector. Complete with high radiation, alert, and failure alarms. (3) Continuous monitoring of radioactive airborne particulates collected on a filter tape transport system; rate of air flow is 10 scfm; scintillation and Geiger–Müller detectors optional but a beta-sensitive plastic scintillator is provided to reduce shielding requirements and offer greater sensitivity. Air sample temperature limits are 32°F to 120°F; weight is 550 pounds. Complete with high- and low-flow alarm and filter failure alarm.

Direct-Reading Colorimetric Devices

Direct-reading colorimetric devices are widely used, easy to operate, and inexpensive. They utilize the chemical properties of an atmospheric contaminant for the reaction of that substance with a color-producing reagent, revealing stain length or color intensity. Stain lengths or color intensities can be read directly to provide an instantaneous value of the concentration accurate within ±25%. Reagents used in detector kits may be in either a liquid or a solid phase or provided in the form of chemical-treated papers. The liquid and solid reagents are generally supported in sampling devices through which a measured amount of contaminated air is drawn. On the other hand, chemically treated papers are usually exposed to the atmosphere and the reaction time is noted for a color change to occur (Keenan, 1973).

Calibration of Direct-Reading Instruments

Two common methods used for calibrating direct-reading instruments are

1. *Static method*, which is easy to use and efficient. A known volume of gas is introduced into the instrument and sampling is performed for a limited period of time.
2. *Dynamic method* uses the instrument to monitor a known concentration of the contaminant to test its accuracy.

AIR SAMPLING CALCULATIONS

Gram Molecular Volumes

- 1 mole = 22.4 L at standard temperature and pressure (STP).
- 1 mole = 24.45 L at normal temperature and pressure (NTP).
- Standard pressure is 760 Torr (760 mmHg at sea or atmosphere level).
- Standard temperature is 0°C or 273 K.

Sample Conversions and Calculations Using Boyle's Law

Problem: If 500 mL of oxygen is collected at a pressure of 780 mmHg, what volume will the gas occupy if the pressure is changed to 740 mmHg?

Solution:

$$\text{New volume } (V_2) = 500 \text{ mL} \times (780 \text{ mmHg}/740 \text{ mmHg}) = 527 \text{ mL}$$

Problem: What is the volume of a gas at a pressure of 90 cmHg if 300 mL of the gas was collected at a pressure of 86 cmHg?

Solution:

$$\text{New volume } (V_2) = 300 \text{ mL} \times (86 \text{ cmHg}/90 \text{ cmHg}) = 287 \text{ mL}$$

Problem: Calculate the pressure of a gas that occupies a volume of 110 mL if it occupies a volume of 300 mL at a pressure of 80 cmHg.

Solution:

$$\text{New pressure } (P_2) = 80 \text{ cmHg} \times (300 \text{ mL}/110 \text{ mL}) = 218 \text{ cmHg}$$

Sampling Conversions and Calculations Using Charles's Law

Problem: What volume will an amount of gas occupy at 25°C if the gas occupies a volume of 500 mL at a temperature of 0°C? Assume that the pressure remains constant.

Solution:

$$\text{K} = 273 + {}^\circ\text{C}$$

$$\text{New volume } (V_2) = 500 \text{ mL} \times (298 \text{ K}/273 \text{ K}) = 546 \text{ mL}$$

Problem: What is the volume of a gas at –25°C if the gas occupied 48 mL at a temperature of 0°C?

Solution:

$$\text{New volume } (V_2) = 48 \text{ mL} \times (248 \text{ K}/273 \text{ K}) = 43.6 \text{ mL}$$

Problem: If a gas occupies a volume of 800 mL at 15°C, at what temperature will it occupy a volume of 1000 mL if the pressure remains constant?

Solution:

$$\text{New absolute pressure } (T_2) = 288 \text{ K} \times (1000 \text{ mL}/800 \text{ mL}) = 360 \text{ K}$$

SAMPLE CONVERSIONS AND CALCULATIONS USING BOYLE'S LAW AND CHARLES'S LAW COMBINED

Problem: Calculate the volume of a gas at STP if 600 mL of the gas is collected at 25°C and 80 cmHg.

Solution:

$$\text{New volume } (V_2) = 600\text{ mL} \times (80\text{ cmHg}/76\text{ cmHg}) \times (273\text{ K}/298\text{ K}) = 578\text{ mL}$$

Problem: If a gas occupies a volume of 100 mL at a pressure of 76 mmHg and 25°C, what volume will the gas occupy at 900 mmHg and 40°C?

Solution:

$$\text{New volume } (V_2) = 100\text{ mL} \times (760\text{ mmHg}/900\text{ mmHg}) \times (313\text{ K}/298\text{ K}) = 88.7\text{ mL}$$

Problem: If 500 mL of oxygen is collected at 20°C, and the atmospheric pressure is 725.0 mmHg, what is the volume of the dry oxygen at STP?

Solution:

$$\text{New volume } (V_2) = 500\text{ mL} \times (725.0\text{ mmHg}/760\text{ mmHg}) \times (273\text{ K}/293\text{ K}) = 443.5\text{ mL}$$

Problem: 2.50 g of a gas occupy 240 mL at 20°C and 740 Torr. What is the gram molecular weight of the gas?

Solution:

$$240\text{ mL} \times (273\text{ K}/293\text{ K}) \times (740\text{ Torr}/760\text{ Torr}) = 217\text{ mL}$$

$$(2.50\text{ g}/217\text{ mL}) \times (1000\text{ mL}/1\text{ L}) \times (22.4\text{ L}/1\text{ mol}) = 258\text{ g/mol}$$

PRACTICAL APPLICATION OF GAS LAWS

At 0°C (273 K) and 760 mmHg pressure, a gram molecular weight of any perfect gas will occupy a volume of 22.414 liters. If we ignore deviations from ideal behavior, oxygen of this volume would weigh 32 grams and nitrogen 28 grams, their molecular weights respectively. If there is a change in temperature and pressure the molar volumes of these gases will be altered. According to the laws of Boyle and Charles, the change in molar volume will be inversely proportional to its pressure and directly proportional to its absolute temperature (°C + 273). In order for the actual measured volumes of gases and gas air mixtures to have meaning, they must be corrected to standard conditions of temperature and pressure (STP), or 0°C (273 K) and 760 mmHg pressure. From a consideration of the laws of Charles and Boyle we can derive the following equation:

$$V_{STP} = V_{meas.} \times \frac{P_{bar.}}{760} \times \frac{273}{273 + t°\text{C}}$$

where t°C is the temperature at which the sample was taken.

A correction for the presence of water vapor is made by subtracting the partial pressure of the water vapor in the air from the barometric pressure:

$$V_{STP} = \left(V_{meas.} \times \frac{P_{bar.}}{760}\right) - \left(P_w \times \frac{273}{273 + t°C}\right)$$

If this formula is applied to a grab sample in a 12-L volume bottle taken at 22°C at a barometric pressure 760 mmHg and partial pressure of water vapor at 22°C of 19.8 mm, $V_{\text{STP}} = 10.8$ L. If an analysis of the grab sample showed it contained 5 mg of carbon tetrachloride, then

$$V_{STP} = \left(V_{meas.} \times \frac{P_{bar.}}{760}\right) - \left(P_w \times \frac{273}{273 + t°C}\right)$$

where MW is the molecular weight of carbon tetrachloride and 22.14 = molar volume (liters) of carbon tetrachloride at standard conditions of temperature and pressure (STP).

If the sample was taken in a partially evacuated flask, and a manometer reading showed that 365.1 mm of pressure remained in the flask, then the formula for the correct volume is

$$V_{STP} = V_{meas.} \times \left(\frac{P_{bar.} - P_w - P_p}{760}\right) \times \left(\frac{273}{273 + t°\text{C}}\right)$$

where V_{STP} = 5.5 and PPM = 132.

The common practice among industrial hygienists is to assume that air samples taken in normal factory air are at 25°C and 760 mmHg pressure. One gram molecular weight of a gas occupies 24.45 L under these conditions. Parts per million (PPM) of contaminant can be calculated from an air sample with the following simplified version of the equation given earlier:

$$\text{PPM} = \frac{24{,}450 \times \text{mg per liter}}{\text{Molecular weight (contaminant)}}$$

where mg per liter = mg of contaminant in 1 liter of air sample collected

AIR POLLUTION REMEDIATION

When soil or water becomes contaminated by and with pollutants, we have little difficulty in understanding the need for the procedures and technology typically used to remediate the pollution. Polluted air, however, presents problems that soil and water do not. How do we clean up air once it has become polluted? Do we simply turn on a humongous air-purifying machine and let it do its work? Of course not. In air pollution remediation, we do not scoop the pollutants out of the atmospheric air and clean them. Instead, air pollution remediation is brought about through the use of air pollution prevention techniques. In other words, the technology we principally use today works to remove pollutants from air before that air is discharged to the atmosphere (an end-of-the-pipe technique). We simply clean the polluted air before we discharge it—cleaning wholesale after discharge into the atmosphere is beyond the ability of present-day technology.

POLLUTION PREVENTION

Because air pollution remediation is conducted at the “end of the pipe” by pollution prevention methods, we need to discuss pollution prevention, more commonly known today as P2. This term may be new to you, but it has been around for a while. Although pollution prevention has its origin in efforts to decrease solid waste disposal to the land, its application has been broadened to include other environmental media, including air. The goal of pollution prevention activities is to

CONVERSION FORMULAS

- mg per liter × 1000 = mg per cubic meter
- mg per liter × 28.32 = mg per cubic foot
- mg per cubic foot × 35.314 = mg per cubic meter

decrease waste generation at the source, thus it is also referred to as *source reduction*. Pollution prevention may include the substitution of process chemicals (materials that are less hazardous to human health or the environment than those currently being used), changes in process equipment, changes in plant operating practices, enhanced maintenance of plant equipment that emits pollutants, and changes in plant processes. All of these techniques are used to remediate air pollution—or, stated more precisely, these techniques are used to prevent pollutants from leaving the end of the pipe and entering into the atmosphere. Air pollution remediation is (in the sense we describe it), therefore, air pollution control. Air pollution control and the technology used to effect it are discussed in this text.

REDUCING AIR EMISSIONS

The two general methods of reducing emissions from any system are (Heumann, 1997):

1. Change, modify, or otherwise optimize the process so unwanted emissions are reduced or eliminated.
2. Add a control technology or air pollution control device to the system.

In the sections that follow, we focus on the second general method used to reduce air emissions (control technology). Before beginning a discussion of some of the various types of air emission control technology available and used today, let's take a look at another important point regarding air pollution control (Heumann, 1997):

> There are two primary motivations behind the utilization of industrial air pollution control technologies:
>
> 1. They must be used because of legal or regulatory requirements.
> 2. They are integral to the economical operation of an industrial process.
>
> Although economists would point out that both of these motivations are really the same (that is, it is less expensive for an industrial user to operate with air pollution control than without), the distinction in application type is an important one. … In general, air pollution control is used to describe those applications that are driven by regulations and/or health considerations, while applications that deal with product recovery are considered process applications. Nevertheless, the technical issues, equipment design, operation, etc., will be similar if not identical. In fact, what differs between these uses is that the economics that affect the decision-making process will often vary to some degree.

CLEARING THE AIR*

From the information presented in Chapters 5 and 6, you should now have a clear picture of the problems that air pollution control technology attempts to solve, but another important factor that cannot be overlooked is regulation. Air pollution control and regulations are equally important; in fact, in many ways they drive each other. Air pollution control, as with other forms of pollution control, begins with regulation. Regulations (for example, to remediate, reduce, or eliminate a source of emissions) are generated because of community concerns. Regulations often evolve around three considerations (Davis, 2000):

1. Legal limitations imposed for the protection of public health and welfare
2. Social limitations imposed by the community in which the pollution source is or will be located
3. Economic limitations imposed by marketplace constraints

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*From Spellman, F.R., *The Science of Air*, 2nd ed., CRC Press, Boca Raton, FL, 2009.

The responsible party assigned to mitigate an air pollution problem must meet one important goal: ensuring that the design control methodology used will bring the source into full compliance with applicable regulations. Air emissions control design personnel must first understand the problems and then rely heavily on technology to correct the situation to meet regulation standards. Various air pollution control technologies are available for mitigating air pollution source problems. By careful problem analysis and application of the most effective method on a case-by-case basis, responsible persons and designers can ensure that facilities are in full compliance with regulations and that individual pollution sources are brought under control.

AIR POLLUTION CONTROL: CHOICES

After design engineers develop complete knowledge of the contaminant and the source, acquire all available physical and chemical data on the effluent, and learn the regulations of the control agencies involved, they must then decide which control methodology to employ. Choices are limited, because only a few control methods exist. Atmospheric emission process-level control will generally consist of one of four methods, depending on the process, fuels used, and availability of control equipment, among other site- or situation-specific factors. The four methods are (1) elimination of the process entirely or in part, (2) modification of the operation to a fuel or chemical that will give the desired level of emissions, (3) installation of control equipment between the pollutant source and the receptor, and (4) relocation of the operation. Tremendous costs are involved with eliminating or relocating a complete process, which makes either of these choices one of last resort. Eliminating a process can be extremely difficult, too—especially when the process to be eliminated is the one for which the facility exists. Relocation, while sometimes more feasible, is not always an answer, either. Relocation may help emission levels in an urban area, but it does so by moving them elsewhere. Consider the situation presented in Case Study 7.1.

Case Study 7.1. Cedar Creek Composting

The Cedar Creek Composting (CCC) facility was built in 1970. A 44-acre site designed to receive and process wastewater biosolids from six local wastewater treatment plants, CCC composted biosolids at the rate of 17.5 dry tons per day. CCC used the aerated static pile (ASP) method to produce pathogen-free, humus-like material that could be beneficially used as an organic soil amendment. The final compost product was successfully marketed under a registered trademark name.

Today, the Cedar Creek Composting facility is no longer in operation. The site was shut down in early 1997. From an economic point of view, CCC was highly successful. When a fresh pile of compost had completed the entire composting process (including curing), dump truck after dump truck would line the street outside the main gate, waiting to haul off a load of the popular product. Economics was not the problem. In fact, CCC could not produce enough compost fast enough to satisfy the demand. No, economics was not the problem.

What *was* the problem, then? The answer to this question is actually twofold: social and then eventually legal considerations. Social limitations were imposed by the community in which the compost site was located. In 1970, the 44 acres CCC occupied were located in an out-of-town, rural area. CCC's only neighbor was a regional, small airport on its eastern border. CCC was completely surrounded by woods on the other three sides. The nearest town was 2 miles away. But, by the mid-1970s, things started to change. Population growth and its accompanying urban sprawl quickly turned forested lands into housing complexes and shopping centers. CCC's western border soon became the site of a two-lane road that was upgraded to four and then to six lanes. CCC's northern fence separated it from a mega-shopping mall. On the southern end of the facility, houses, playgrounds, swimming pools, tennis courts, and a golf course were built.

CCC became an island surrounded by urban growth. Further complicating the situation was the airport; it expanded to the point that, by 1985, three major airlines used the facility. CCC's ASP composting process was not a problem before the neighbors moved in. We all know dust and odor control problems are not problems until the neighbors complain—and complain they did. CCC was attacked from all four sides. The first complaints came from the airport. The airport complained that dust from the static piles of compost was interfering with air traffic control.

The new, expanded highway brought several thousand new commuters right up alongside CCC's western fence line. Commuters started complaining any time the compost process was in operation; they complained primarily about the odor—the thick, earthy smell permeated everything.

After the enormous housing project was completed and people took up residence there, complaints were raised on a daily basis. The new homeowners complained about the earthy odor and the dust that blew from the compost piles onto their properties downwind from the site. The shoppers at the mall also complained about the odor.

City Hall received several thousand complaints over the first few months before they took any action. The city environmental engineer was told to approach CCC's management to see if some resolution of the problem could be effected. CCC management listened to the engineer's concerns but stated that there wasn't a whole lot that the site could do to rectify the problem.

As you might imagine, this was not the answer the city fathers were hoping to hear. Feeling the increasing pressure from local inhabitants, commuters, shoppers, and airport management people, the city brought the local state representatives into the situation. The two state representatives for the area immediately began a campaign to close down the CCC facility.

CCC was not powerless in this struggle—after all, CCC was there first, right? The developers and those people in those new houses didn't have to buy land right next to the facility, right? Besides, CCC had the USEPA on their side. CCC was taking a waste product no one wanted, one that traditionally ended up in the local landfill (taking up valuable space), and turning it into a beneficial reuse product. CCC was helping to conserve and protect the local environment, a noble endeavor. The city politicians did not really care about noble endeavors, but they did care about the concerns of their constituents, the voters. They continued their assault through the press, electronic media, legislatively, and by any other means they could bring to bear.

CCC management understood the problem and felt the pressure. They had to do something, and they did. Their environmental engineering division was assigned the task of coming up with a plan to mitigate not only CCC's odor problem but also its dust problem. After several months of research and a pilot study, CCC's environmental engineering staff came up with a solution. The solution included enclosing the entire facility within a self-contained structure. The structure would be equipped with a state-of-the-art ventilation system and two-stage odor scrubbers. The engineers estimated that the odor problem could be reduced by 90% and the dust problem reduced by 98.99%. CCC management thought they had a viable solution to the problem and was willing to spend the $5.2 million to retrofit the plant.

After CCC presented their mitigation plan to the city council, the council members made no comment but said that they needed time to study the plan. Three weeks later, CCC received a letter from the mayor stating that CCC's efforts to come up with a plan to mitigate the odor and dust problems at CCC were commendable and to be applauded but were unacceptable.

From the mayor's letter, CCC could see that the focus of attack had now changed from a social to a legal issue. The mayor pointed out that he and the city fathers had a legal responsibility to ensure the good health and well-being of local inhabitants and that certain legal limitations would be imposed and placed on the CCC facility to protect their health and welfare.

Compounding the problem was the airport. Airport officials also rejected CCC's plan to retrofit the compost facility. Their complaint (written on official FAA paper) stated that the dust generated at the compost facility was hazarding flight operations, and even though the problem would be reduced substantially by engineering controls the chance of control failure was always possible, and then an aircraft could be endangered. From the airport's point of view, this was unacceptable.

Several years went by, with local officials and CCC management contesting each other on the plight of the compost facility. In the end, CCC management decided they had to shut down its operation and move to another location, so they closed the facility.

After shutdown, CCC management staff immediately started looking for another site to build a new wastewater biosolids-to-compost facility. They are still looking. To date, their search has located several pieces of property relatively close to the city (but far enough away to preclude any dust and odor problems), but they have had problems finalizing any deal. Buying the land is not the problem; getting the required permits from various county agencies to operate the facility is. CCC officials have been turned down in each and every case. The standard excuse? Not in my backyard. Have you heard this phrase before? It's so common now that it is usually abbreviated as NIMBY. Whether back in the day or at present, NIMBY is alive and well. CCC officials are still looking for a location for their compost facility, but they are not all that optimistic about their chances of success in this matter.

The second control method—modification of the operation to a fuel or chemical that will give the desired level of emission—often looks favorable to those who have examined the high costs associated with air pollution control systems. Generally, the first approach, modifying the process to eliminate as much of the pollution problem as possible at the source, is frequently a viable method. Let's take a look at an example where substitution from a hazardous chemical to a less hazardous chemical is being made.

Case Study 7.2. Chlorine Regulations

The water and wastewater industries for years have used chlorine as their primary disinfectant. Chlorine is a hazardous material, of course, but it has been used successfully and with little documented environmental harm. However, because of the Bhopal incident in 1984, several air emissions regulations have been generated to protect not only human life but also the environment. The regulations generated as a result of Bhopal (and other such incidents) include OSHA's Process Safety Management (PSM) program (29 CFR 1910.119) and the USEPA's Risk Management Plan (RMP). Under these two standards/regulations, the user of chlorine (and many other hazardous materials) has two choices: (1) continue using the hazardous material but put the facility and its hazardous materials operations into full compliance with PSM and RMP, or (2) substitute.

Many water and wastewater industries have found that complying with PSM and RMP for chlorine and other hazardous materials is very difficult. These regulations (especially RMP) have some reporting requirements that are touchy, to say the least; that is, covered parties are required to provide chemical inventory and location information to the public and anyone else who desires it. The obvious problem is why would a facility want to make available sensitive information that any would-be terrorist or perhaps sociopath would love to have? For example, how much deadly chlorine is stored at a particular plant site?

For this and for other reasons, many water and wastewater entities have decided to switch or substitute sodium hypochlorite for chlorine. Sodium hypochlorite is not a listed hazardous material under PSM and RMP. Thus, substitution eliminates the need for compliance with either rule. The problem is that the change out from chlorine to sodium hypochlorite is estimated (in studies we have conducted) to increase costs by one to three times over chlorine use. Why would anyone decide to make such an expensive change? The answer is individual for each facility that makes the choice, but one general manager told us that he liked to sleep at night … and that a catastrophic chlorine release has the potential to do severe damage but hypochlorite does not.

Under many circumstances, changing the fuel or chemical for air pollution control presents the easiest way to meet regulations. A power plant that burns a particular fuel may emit large quantities of sulfur dioxide and fly ash. Converting to cleaner burning natural gas will often be more cost effective than installing the control equipment necessary for pollutant emission reduction to permitted values.

Fuel changeover, though, sometimes causes its own problems related to costs, availability, and competition. Fuel prices are highly variable. Locating a local source of low-sulfur fuel is not always easy, and many industries own their own dedicated supplies, which, of course, they are unwilling to share with other industries. Regulatory compliance threatens everyone. Responsible persons in every industry want their share of any available low-cost, low-sulfur fuel. The law of supply and demand takes over—and prices go up. Other process modification techniques are sometimes employed by industry. These may include evaluation of alternative manufacturing and production techniques, substitution of raw materials, and improved process control methods (Davis, 2000).

If elimination of the process entirely or in part is impossible, if relocation of the operation will not solve the problem, if modification of the operation to utilize a fuel that gives the desired level of emission cannot be achieved, then only one alternative control method is left: installation of control equipment between the pollutant source and the receptor. The polluted carrier gas is sent through a control device or system that collects or destroys the pollutant, releasing the cleaned carrier gas to the atmosphere (Boubel et al., 1994). Because the choice of which air pollution control methodology to employ often means selecting pollution control equipment and systems as the only feasible and practicable alternative, we focus on air pollution control equipment and systems in the rest of this chapter.

AIR POLLUTION CONTROL EQUIPMENT AND SYSTEMS

Any selection decision for air pollution control equipment or systems must factor in several considerations. Costs are always worthy of careful consideration (remember our chlorine substitution example, where substituting sodium hypochlorite for chlorine increased costs threefold). Air pollution equipment and systems, are, to no one's surprise, expensive. Selecting or designing equipment and systems to comply with applicable regulatory emission limitations is obviously essential. Assessing the operational and maintenance history (factoring in costs of energy, labor, and repair parts) of each type of equipment or system is important because emission control equipment must be operated continually, without interruptions. Any interruption could make the plant subject to severe regulatory penalty—another costly element. Other important factors must also be considered (see Table 7.1).

TABLE 7.1
Factors in Selecting Air Pollution Control Equipment and Systems

1. Best available technology (BAT)
2. Reliability
3. Lifetime and salvage value
4. Power requirements
5. Collection efficiency
6. Capital costs, including operation and maintenance costs
7. Track record of equipment/system and manufacturer
8. Space requirements and weight
9. Power requirements
10. Availability of spare parts and manufacturers' representatives

The major factor to consider in equipment or system selection, however, is the physical characteristics of the pollutant or pollutant stream. Pollutants conveyed in a carrier gas, for example, must be evaluated for carrier gas pressure, temperature, viscosity, toxicity, density, humidity, corrosiveness, inflammability, and more before any selection is made. Process considerations dealing with gas flow rate and velocity, pollutant concentration, allowable pressure drop, and the variability of gas and pollutant flow rates (including temperature) are also of concern. After evaluating these factors, the focus shifts to selecting the best air pollution control equipment or system for the specific needs of the site, pollutant, and facility—the most affordable and practical one that is allowed by regulatory requirements. In the following sections, we discuss two types of pollutants (dry particulates and gaseous pollutants) and the various types of air pollution control equipment and processes available for their removal.

Removal of Dry Particulate Matter

Selecting the proper air pollution control equipment or system for particulate removal requires a basic understanding of particulate matter.

Particulate Matter

Stationary sources, including power plants, industrial processes, mining activities, and incinerators, are the origin of most ambient particulate air pollutants. Particulates, a major class of air pollutants, come in a variety of shapes and sizes. In either liquid droplet or dry dust forms, they display a wide range of physical and chemical characteristics. Dry particulate emissions come from both combustion and non-combustion sources in industry, mining, construction activities, incinerators, and internal combustion engines. Dry particulates also emit from natural sources, such as volcanoes, forest fires, pollen, and windstorms. Certain characteristics of particles and particulate matter, along with process conditions, must be considered in any engineering strategy designed to separate and remove them from a stream of carrier gas; these include particulate size range and distribution, particle shape, corrosiveness, agglomeration tendencies, abrasiveness, toxicity, reactivity, inflammability, and hygroscopic tendencies. These must all be examined in light of equipment limitations.

In air pollution control systems, the application of one or more forces separates particulates from the gas stream in gravity settlers, centrifugal settlers, fabric filters, electrostatic precipitators, or wet scrubbers. After separation, the particles are collected and removed from the system. A stationary object (such as a metal plate, a fabric thread, or a large water droplet) causes approaching fluid flows (engineering and science applications consider both liquid and gaseous states fluid) to diverge around that object. Because of inertia, particles in the fluid will not follow stream flow exactly. Instead, they tend to continue in their original directions. With enough inertia, the particles located close enough to the stationary object will collide with the object and be collected by it.

Impaction, interception, and diffusion methods are all used to collect particles. When the center of mass of a particle that is diverging from the fluid strikes a stationary object, *impaction* occurs. In *interception*, the center of mass of the particle closely misses the object, but the particle strikes the object because of its size. Small particulates diffuse toward the object when passing near it, and *diffusion* occurs. If short-range forces (chemical, electrostatic, and so forth) are strong enough to hold them to the surface, particles that strike the object by any of these means are collected (Cooper and Alley, 1990).

Air Pollution Control Equipment for Particulates

Particulate control equipment is available in different classes, including gravity settlers, cyclones, electrostatic precipitators, wet (Venturi) scrubbers, and baghouse (fabric) filters. In this section, we briefly introduce each of the major types of particulate control equipment and discuss their advantages and disadvantages.

Gravity Settlers

The simplest kind of air cleaning device, gravity settlers have long been used by industry for removing solid and liquid waste materials from gaseous streams. Simply constructed, a gravity settler provides nothing more than an enlarged chamber in which to slow horizontal gas velocity, allowing particles to settle out by gravity. To their advantage, gravity settlers have low initial costs and are relatively inexpensive to operate—not much can go wrong. To their disadvantage, although they are simple in design, gravity settlers require a large space for installation and have relatively low efficiency, especially for removal of small particles (<50 μm).

Cyclone Collectors

Cyclone collectors are a part of the group of air pollution controls collectively referred to as *precleaners*, because they are often used to reduce the inlet loading of particulate matter (PM) to downstream collection devices by removing larger, abrasive particles. Cyclones are also referred to as cyclone collectors, cyclone-separators, centrifugal separators, and inertial separators. In applications where many small cyclones are operating in parallel, the entire system is known as a multiple tube cyclone, multicyclone, or multiclone. The collector of choice for removing particles greater than 10 μm in diameter, the cyclone (or centrifugal) collector removes particles by causing the entire gas stream to flow in a spiral pattern inside a tube. The larger particles move outward by centrifugal force, collide with the wall of the tube, then slide down the wall and fall to the bottom of the cone, where they are collected for removal. The cleaned gas flows out of the cyclone's top. Cyclones have the advantage of low construction costs, and they require a relatively small space for installation. The overall particulate collection efficiency of the cyclone is low, however, especially for particles below 10 μm in size, and they do not handle sticky materials well. The most serious problems encountered with cyclones are their tendency to plug and possible difficulties with air flow equalization. Cyclones are used successfully in applications involving large quantities of gas containing relatively large particles such as feed and grain mills, cement plants, fertilizer plants, and petroleum refineries.

Electrostatic Precipitators

A widely used method, the electrostatic precipitator removes small (fine) particles from moving gas streams at high collection efficiencies. It is popular for use in power plants to remove fly ash from gases prior to discharge. An electrostatic precipitator applies electrical force to separate particles from the gas stream. The precipitator establishes a high-voltage drop between electrodes, which allows particles passing through the resulting electrical field to acquire a charge. The charged particles collect on an oppositely charged plate, and the cleaned gas flows through the device. The plates are periodically cleaned by rapping to shake off the layer of accumulated dust, which is collected in hoppers at the bottom of the device. Electrostatic precipitators have the advantages of low operating costs, capability for operation in high-temperature applications (to 1300°F), and low pressure drop. They can also attain extremely high particulate (coarse and fine) collection efficiencies; however, capital costs are high, and they have high space requirements.

Wet (Venturi) Scrubbers

In widespread use for cleaning contaminated gas streams (e.g., foundry dust emissions, acid mists, furnace fumes), wet scrubbers (or collectors) effectively remove particulate and gaseous pollutants by trapping particulates through the technique of direct contact with an aerosol spray of water or some other liquid. Simple spray-chamber wet scrubbers remove coarse particles, and high-efficiency systems (Venturi-type scrubbers) remove fine particles. Spray chamber and Venturi operations both employ basic principles of inertial impingement or impaction and interception of dust particles by droplets of water. Large, heavy water droplets easily separate from the gas by gravity, and the solid particles are independently separated from the water or the water is somehow treated before reuse or discharge. Increasing the gas velocity or the liquid droplet velocity in a scrubber increases the efficiency, ensuring a greater number of collisions per unit time. The Venturi scrubber is used in applications where high collection efficiency is desired. Most efficient for removing particulate matter in the size range of 0.5 to 5 µm, Venturi scrubbers are especially effective for the removal of submicron particulates associated with smoke and fumes. The Venturi operates at extremely high gas and liquid velocities with a very high pressure drop across the Venturi throat. Wet scrubbers require relatively small space for installation, have low capital costs, and can handle high-temperature, high-humidity gas streams; however, they have relatively high power and maintenance costs compared to dry systems, they present water disposal and corrosion problems, and the final product they produce is collected wet.

Baghouse (Fabric) Filters

The most commonly used air pollution control filtration system, baghouse filters (or fabric filters) are one of the most efficient devices for removing suspended particulates from a gas stream. In a method similar to the common vacuum cleaner, baghouse fabric filter material (capable of removing most particles as small as 0.5 µm and substantial quantities of particles as small as 0.1 µm) is formed into cylindrical or envelope bags and suspended in the baghouse. The particulate-laden gas stream is forced through the fabric, and particulates accumulate on the cloth, providing a cleaned air stream. The pressure drop increases as particulates build up on the inside surfaces of the bags. The bags must be relieved of some of the particulate layer before the pressure drop becomes too severe. Particulates are periodically removed from the cloth through shaking or by reversing the air flow. Relatively simple to operate, fabric filters provide high overall collection efficiencies up to 99+% and are very effective in controlling submicrometer particles. They do have limitations, however, including relatively high capital costs, high maintenance requirements (bag replacement, etc.), high space requirements, and flammability hazards for some dusts.

REMOVAL OF GASEOUS POLLUTANTS: STATIONARY SOURCES

The principal gases of concern in the problem of removing gaseous air pollutants are the sulfur oxides (SO_x), carbon oxides (CO_x), nitrogen oxides (NO_x), organic and inorganic acid gases, and hydrocarbons (HC). Four major treatment processes are currently available for control of these and other gaseous emissions: absorption, adsorption, condensation, and combustion (incineration). Choosing which single, or combined, air pollution control technique to use for stationary sources is not always easy. A wide variety of devices can be used to control gaseous pollutants. Choosing the most cost-effective, most efficient units requires careful attention to the particular operation the control devices are intended to clean. The choice of control technology depends on the pollutants to be removed, the removal efficiency required, pollutant and gas stream characteristics, and specific characteristics of the site (Peavy et al., 1985). Which air pollution control technology to employ is a difficult and often complex decision. Guidelines based on experience are set forth in the prestigious engineering text *Air Pollution Engineering Manual* (Davis, 2000). Table 7.2 summarizes these guidelines.

Absorption

Absorption (or scrubbing), a major chemical engineering unit operation, brings contaminated effluent gas into contact with a liquid absorbent, allowing one or more constituents of the effluent gas to be selectively dissolved (transferred) into a relatively nonvolatile liquid. Designed to transfer the pollutant from a gas phase to a liquid phase, absorption units accomplish this by providing intimate contact between the gas and the liquid. This provides optimum diffusion of the gas into the solution. Removal of a pollutant from the gas stream takes place in three steps: (1) diffusion of the pollutant gas to the surface of the liquid, (2) transfer across the gas–liquid interface, and (3) diffusion of the dissolved gas away from the interface into the liquid (Davis and Cornwell, 1991). Types of absorbers

TABLE 7.2
Comparison of Air Pollution Control Technologies

Treatment Technology	Concentration and Efficiency	Comments
Incineration	<100 ppmv; 90–95% efficient >100 ppmv; 95–99% efficient	Incomplete combustion may require additional controls.
Carbon adsorption	>200 ppmv; 90+% efficiency >1000 ppmv; 95+% efficiency	Recovered organics may require additional treatment, which can increase costs.
Absorption	<200 ppmv; 90–95% efficiency >200 ppmv; 95+% efficiency	Can blowdown stream be accommodated at the site?
Condensation	>2000 ppmv; 80+% efficiency	Must have low temperature or high pressure for efficiency.

Note: Typically, only incineration and absorption technologies can consistently achieve greater than 99% gaseous pollutant removal (Davis, 2000).

available include spray chambers (and towers or columns), plate or tray towers, packed towers, and Venturi scrubbers. Absorption processes are commonly used to control pollutant gases, including sulfur dioxide, hydrogen sulfide, hydrogen chloride, chlorine, ammonia, and oxides of nitrogen.

Plate and packed tower systems are the two most common absorbent units in use today. In plate towers, perforated horizontal plates or trays are designed to provide large liquid–gas interfacial areas. The polluted air stream, usually introduced at one side of the bottom of the tower or column, rises up through the perforations in each plate. The rising gas prevents the liquid from draining through the openings, and the liquid waste is directed through a downpipe. Contact is maintained between air and liquid, allowing gaseous contaminants to be removed, with clean air emerging from the top of the tower during continuous operation. Predominately used to control gaseous pollutants in industrial applications, the packed tower scrubbing system typically demonstrates a removal efficiency of 90 to 95%. The packed tower is literally packed with devices of large surface-to-volume ratio and is usually configured vertically. A large void ratio offers minimum resistance to gas flow. For most effective and efficient operation, the packing should provide even distribution of both fluid phases, should support itself in the tower, and should be low cost, readily available, and easily handled (Hesketh, 1991). The flow through a packed tower is usually countercurrent, with gas entering at the bottom of the tower and liquid entering at the top. Liquid flows over the surface of the packing in a thin film, providing continuous contact with the gases.

Though highly efficient for removal of gaseous contaminants, packed towers may create liquid disposal problems (converting an air pollution problem to a water pollution problem). They become easily clogged when gases with high particulate loads are introduced, and they have relatively high maintenance costs.

ADSORPTION

Adsorption (not to be confused with absorption), a surface phenomenon, is a mass transfer process. It involves passing a stream of effluent gas through the surface of prepared porous solids (adsorbents). The porous surfaces of the solid substance attract and hold the gas (the adsorbate) by physical or chemical adsorption. A gas molecule adheres to the surface of the solid because of an imbalance of electron distribution in physical adsorption (a readily reversible process). In chemical adsorption (which is not readily reversible), the gas molecule adheres to the surface, reacting to it chemically.

Materials that possess adsorptive properties include activated carbon, alumina, bone char, magnesia, silica gel, molecular sieves, and strontium sulfate, among others. Activated charcoal is the most important adsorbent for air pollution control. The surface area of activated charcoal

DID YOU KNOW?

When a gas or vapor is brought into contact with a solid, part of it is taken up by the solid. The molecules that disappear from the gas either enter the inside of the solid or remain on the outside attached to the surface. The former phenomenon is termed *absorption* (or dissolution) and the later *adsorption*.

preferentially adsorbs hydrocarbon vapors and odorous organic compounds from an air stream. The collected contaminant remains in the adsorption bed in the adsorption system, unlike the absorption system, where the collected contaminant is continuously removed by flowing liquid. The fixed-bed adsorber is the most common type of adsorption system. A fixed-bed adsorber can be contained in either a vertical or horizontal cylindrical shell. The adsorbent is arranged in beds or trays in layers about 0.5-inch thick; in multiple-bed systems, one (or more) bed adsorbs vapors while the other bed regenerates.

Adsorption systems are high-efficiency devices. At the beginning of the operation, the efficiency of most adsorbers is near 100%. Efficiency remains high until a breakpoint or breakthrough occurs. Upon adsorbent saturation with adsorbate, contaminant begins to leak out of the bed. This signals that the adsorber should be renewed or regenerated. Advantages include possible recovery of product, excellent control and response to process changes, and the capability of being operated unattended. Their disadvantages include the need for exotic, expensive extraction schemes if product recovery is required, relatively high capital costs, and gas stream prefiltering needs (to remove any particulate capable of plugging the adsorbent bed).

Condensation

Condensation, a process by which condensers remove volatile gases from the contaminant stream and change them into liquid, can be used either for pretreatment to reduce the load problems with other air pollution control equipment or for effectively controlling contaminants in the form of gases and vapors. By increasing the system pressure without a change in temperature or by decreasing the system temperature to its saturation temperature without a pressure change, condensers condense vapors to the liquid phase. The composition of the contaminant gas stream affects condensation. Condensation is hindered when (for some reason) gases present in the stream condense under different conditions than those the equipment was designed to handle. Surface and contact condensers are the two basic types of condensation equipment. A surface condenser, normally a shell-and-tube heat exchanger, uses a cooling medium of air or water, where the vapor to be condensed is separated from the cooling medium by a metal wall. Coolant flows through the tubes while the vapor is passed over and condenses on the outside of the tubes, draining off to storage (USEPA, 1971). A contact condenser resembles a simple spray scrubber. The vapor, cooled by spraying liquid directly on the vapor stream, condenses, and the water and condensate mixture are removed, treated, and disposed of. Contact condensers cost less, are more flexible, and are simpler than surface condensers, as a general rule, but surface condensers require much less water and produce many times less wastewater to be treated than do contact condensers. A wide range of industrial applications can use condensers, including petroleum refining, petrochemical manufacturing, basic chemical manufacturing, dry cleaning, and degreasing.

Combustion

Even though combustion (or incineration) is a major source of air pollution, it is also, if properly operated, a beneficial air pollution control system in which the objective is to convert certain air contaminants (usually CO and hydrocarbons) to innocuous substances such as carbon dioxide and water (USEPA, 1973). Combustion is a chemical process defined as rapid, high-temperature, gas-phase oxidation. The combustion equipment used to control air pollution emissions is designed to push these oxidation reactions as close to complete combustion as possible, leaving a minimum of unburned residue. The operation of any combustion operation is governed by four variables: oxygen, temperature, turbulence, and time. For complete combustion to occur, oxygen must be available and put into contact with sufficient temperature (turbulence) and held at this temperature for a sufficient time. These four variables are not independent—changing one affects the entire process. Equipment used to control waste gases depends on the contaminant being oxidized by combustion and can be divided into three categories: direct-flame combustion (or flaring), thermal combustion (afterburners), or catalytic combustion.

Direct-Flame Combustion (Flaring)

The most commonly used air pollution control devices, direct-flame combustion devices (flares) burn waste gases directly (with or without the addition of a supplementary fuel); they include steam-assisted, air-assisted, and pressure-head types. Flares are normally elevated from 100 to 400 feet, protecting the surroundings from heat and flames. Flares, often designed for steam injection at the flare top, commonly use steam in this application because it provides sufficient turbulence to ensure complete combustion, preventing production of visible smoke or soot. Flares can be noisy, sometimes causing problems for adjacent neighborhoods. Some flares produce oxides of nitrogen, thus creating a new air pollutant.

Thermal Combustion (Afterburners)

Usually the unit of choice in cases where the concentration of combustible gaseous pollutants is too low to make flaring impractical, the thermal incinerator or afterburner is widely used in industry. The thermal combustion system typically operates at high temperatures. The contaminant airstream passes around or through a burner within the thermal incinerator and into a refractory-line residence chamber where oxidation occurs. Flue gas from a thermal incinerator (which is relatively clean) contains recoverable heat energy and is at high temperature.

Catalytic Combustion

Catalytic combustion passes a preheated contaminant-laden gas stream through a catalyst bed (usually thinly coated platinum mesh mat, honeycomb, or other configuration designed to increase surface area). This promotes the oxidation reaction at lower temperatures. The metal catalyst, used to initiate and promote combustion at much lower temperatures than those required for thermal combustion, is often made of metals in the platinum family, which are recognized for their ability to promote low-temperature combustion. Catalytic incineration may require 20 to 50 times less residence time than thermal incineration (see Table 7.3 for other advantages of catalytic incinerators

TABLE 7.3
Advantages of Catalytic over Thermal Incinerators

1. Catalytic incinerators have lower fuel requirements.
2. Catalytic incinerators have lower operating temperatures.
3. Catalytic incinerators have little or no insulation requirements.
4. Catalytic incinerators have reduced fire hazards.
5. Catalytic incinerators have reduced flashback problems.

Source: Adapted from Davis, W.T., Ed., *Air Pollution Engineering Manual*, 2nd ed., John Wiley & Sons, New York, 2000.

over thermal incinerators). Catalytic incinerators normally operate at 700°F to 900°F, a reduced temperature range that realizes a saving in fuel usage and cost. However, this savings may be offset by the cost of the catalytic incinerator itself.

A heat exchanger is an option for systems with heat transfer between two gas streams (recuperative heat exchange). Dilution air, combustion air, and flue gas treatment needs are based on site-specific conditions. Catalyst usefulness, subject to both physical and chemical deterioration, is suppressed by sulfur-containing compounds. Catalyst surfaces must be clean and active for best performance. Catalytic incineration is used in a variety of industries to treat effluent gases, including emissions from paint and enamel bake ovens, asphalt oxidation, coke ovens, formaldehyde manufacture, and varnish cooking.

REMOVAL OF GASEOUS POLLUTANTS: MOBILE SOURCES

Mobile sources of gaseous pollutants include locomotives, ships, airplanes, and automobiles. Worldwide, transportation is a significant source of all major air pollutants emitted to the atmosphere (e.g., 70 to 90% of all carbon monoxide emissions, 45 to 50% of nitrogen oxide emissions, 40 to 50% of total hydrocarbon and volatile organic compound emissions) (Rodrigue, 2017). Automobiles, though, are by far the largest problem, from both a total emissions standpoint and a standpoint of emissions location relative to people. Over 135 million passenger cars were registered in the United States in 2014, and they consumed around 90 billion gallons of fuel (USDOT, 2016). Overall, transportation contributes nearly 30% of the greenhouse gas emissions in the United States. These emissions include carbon monoxide, carbon dioxide, methane, nitrogen oxides, hydrofluorocarbons, and particulates (USEPA, 2017). Emission standards have become increasingly more stringent in the United States because of high levels of pollutant emissions from automobiles; for example, motor vehicle emissions standards forced the development of new control technology to achieve compliance with emission levels set by the Clean Air Act. We can solve mobile source pollution problems by replacing the internal combustion engine (e.g., with electrical power or mass transit) or by the use of direct pollutant control systems. Think of the cultural changes necessary to persuade most Americans to give up their cars and use mass transit. Currently, replacement is not feasible; the technology is still too new. Even if the technology were feasible for replacement, this task would also be inordinately difficult to undertake and incredibly expensive. Direct pollutant control systems (those that control emissions from the crankcase, carburetor, fuel tank, and exhaust) are what, for better or worse, we rely on.

CONTROL OF CRANKCASE EMISSIONS

Crankcase emissions are controlled by a technology called *positive crankcase ventilation* (PCV). In this control technology, hydrocarbon blowby gases (gases that go past the piston rings into the crankcase) are recirculated to the combustion chamber for reburning. The National Air Pollution Control Administration (NAPCA, 1970) estimated that incorporation of the PCV system reduced crankcase hydrocarbon emissions to negligible levels.

CONTROL OF EVAPORATIVE EMISSIONS

Changes in ambient temperatures (diurnal loses), hot soak, and running losses result in evaporative emissions. Diurnal losses are caused by expansion of the air–fuel mixture in a partially filled fuel tank, which expels gasoline vapor into the atmosphere. Hot soak emissions occur after the engine is shut off as heat from the engine causes increased evaporation of fuel. Running (or operating) losses occur when fuel is forced from the fuel tank under the heat of normal operation and during driving

TABLE 7.4
Types of Catalytic Converters

Oxidizing catalytic converters work to accelerate the completion of the oxidation of CO and hydrocarbons so CO is converted to carbon dioxide and water vapor. Platinum and palladium are used as catalysts. These converters can be poisoned by lead; thus, only unleaded gasoline should be used with this type.

Reducing catalytic converters use rhodium and ruthenium to accelerate the reduction of NO_x to N_2.

Three-way catalytic converters are favored by U.S. automobile manufacturers because they enable them to meet compliance requirements of the Clean Air Act. This converter oxidizes hydrocarbons and carbon monoxide to carbon dioxide, while reducing NO_x to N_2. It is effective in controlling emissions and has the advantage of allowing the engine to operate at normal conditions where engine performance and efficiency are greatest.

Source: Adapted from Demmler, A.W., *Automotive Engineering*, 85(3), 29–32, 1977.

as the fuel is heated by the road surface. A direct control measure instituted in 1971 to control hydrocarbon emissions involves the installation of a canister filled with activated charcoal to adsorb hydrocarbon emissions (Perkins, 1974). During high-power operating conditions, adsorbed vapors are purged from charcoal into the engine. Vapor control systems at service stations in California have reduced potential refueling vapor losses.

CATALYTIC CONVERTERS

Beginning in 1975, all new U.S. automobiles were required to be equipped with catalytic converters to meet more restrictive tailpipe emission standards. Current technology uses three types of catalytic converters for this purpose: oxidizing, reducing, and three-way. Table 7.4 lists characteristics of these catalytic converters.

THE BOTTOM LINE

Strict regulation has made strides in controlling emissions; however, urban population centers present special problems for the control of air quality. Though we may be able to accomplish concrete goals of reducing emissions to meet standards, highly populous areas emit more wastes into the air than local conditions can always handle. The eventual goal? To continually work to decrease the need for local air quality alerts for the health and safety of all.

DISCUSSION QUESTIONS

1. With regard to atmospheric air sampling and monitoring, is there a major difference between the two? Explain.
2. If your air sampling equipment does not include a calibration device and you are about to enter a confined space, what would you do? Explain.
3. Is the breathing zone the same for each person? Explain.
4. Is there any advantage to taking grab samples over other types? Explain.
5. The selection of a sampling method depends on several factors. In your opinion, what factor is the most important? Explain.
6. Do you agree that the primary route of entry for particulate matter is inhalation?
7. Should particles smaller that 0.001 μm be treated as particulate matter or as a gas? Explain.
8. Define “end of the pipeline” pollution prevention methods. What alternatives are possible?
9. Why are control methods used to solve air pollution problems, rather than remedial measures?
10. What are the two chief source categories for air pollutants and how are they defined?

11. What two methods of reduction are used? How do control technology and regulation drive them—and each other?
12. What considerations go into decisions for choice of air pollution control equipment? How and why are these considerations important?
13. What physical factors must be considered? Why?
14. What factors affect particulate matter control?
15. What factors affect gaseous pollutant control?

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8 Indoor Air Quality and Mold Control

INTRODUCTION

Recognition that the indoor air environment is not an exact reflection of outdoor conditions has emerged only relatively recently. The impact of cigarette smoking, stove and oven operation, and emanations from certain types of particleboard, cement, and other building materials are often the most significant determinants of indoor air quality. There is a continuing need to characterize human exposures from the standpoint of meeting pertinent ambient and occupational standards as well as in recognition of potential hazardous levels of pollutants that do not have applicable standards. The implications of indoor air concentrations for epidemiological studies, where exposures are based on outdoor measurements, have been recognized and partially investigated (Dockery and Spengler, 1981; Spengler et al., 1979).

Those familiar with *Star Trek* will recognize this most quotable quote: "The air is the air." However, with regard to the air we breathe, few of us realize that we all face a variety of risks to our health as we go about our day-to-day lives (USEPA, 1991). Driving our cars, flying in planes, engaging in recreational activities, and being exposed to environmental pollutants all pose varying degrees of risk. Some risks are simply unavoidable. Some we choose to accept because to do otherwise would restrict out ability to lead our lives the way we want. And some are risks we might decide to avoid if we had the opportunity to make informed choices. Indoor air pollution is one risk that we can do something about.

A growing body of scientific evidence indicates that the air within homes and other buildings can be more seriously polluted than the outdoor air in even the largest and most industrialized cities. Other research indicates that people spend approximately 90% of their time indoors. A type of climate we do not often think about is the indoor microclimate we spend 80% of our time in—at the office or at home (Wadden and Scheff, 1983). For many people, though, the risks to health due to exposure to air pollution may be greater indoors than outdoors (USEPA, 1991). In addition, people who may be exposed to indoor air pollutants for the longest periods of time are often those most susceptible to the effects of indoor air pollution. Such groups include the young, the elderly, and the chronically ill, especially those suffering from respiratory or cardiovascular disease.

The impact of energy conservation on inside environments may be substantial, particularly with respect to decreases in ventilation rates (Hollowell et al., 1979a) and tight buildings constructed to minimize infiltration of outdoor air (Hollowell et al., 1979b; Woods, 1980). The purpose of constructing tight buildings is to save energy—to keep the heated or air conditioned air inside the structure. The problem is that not only are indoor air contaminants within these tight structures trapped within but they can also be concentrated, exposing inhabitants to even more exposure.

What about indoor air quality problems in the workplace? This chapter discusses this pervasive but often overlooked problem, including the basics of indoor air quality (as related to the workplace environment) and the major contaminants that currently contribute to this problem. Moreover, mold and mold remediation, although not new to the workplace, are the new buzzwords gaining the attention of environmental pollution specialists these days. The chapter also briefly discusses exposure to contaminants such as asbestos, silica, lead, and formaldehyde. Various related remediation practices are also discussed.

WHAT IS INDOOR AIR QUALITY?

Indoor air quality refers to the effect, good or bad, of the contents of the air inside a structure on its occupants (Byrd, 2003). Stated differently, indoor air quality, in this text, refers to the quality of the air inside workplaces as represented by the concentrations of pollutants and thermal conditions (temperature and relative humidity) that affect the health, comfort, and performance of employees. Usually, temperature (too hot or too cold), humidity (too dry or too damp), and air velocity (too drafty or too still) are considered comfort rather than indoor air quality issues. Unless they are extreme, these conditions may make someone uncomfortable but will not make a person ill. Other factors affecting employees, such as light and noise, are important indoor environmental quality considerations but are not treated as core elements of indoor air quality problems. Nevertheless, most industrial hygienists must take these factors into account when investigating environmental quality situations.

Good indoor air quality can be considered to be present when the air has no unwanted gases or particles in it at concentrations that will adversely affect someone. Poor indoor air quality can result when any gases or particles are at excessive concentrations so as to affect the satisfaction or health of the occupants (Byrd, 2003). In the workplace, poor indoor air quality may be annoying to only one person; however, at the other end of the spectrum, it could be fatal to all of the occupants in the workplace. The concentration of the contaminant is crucial. Potentially infectious, toxic, allergenic, or irritating substances are always present in the air, but there is nearly always a threshold level below which no effect occurs.

WHY IS INDOOR AIR QUALITY IMPORTANT TO WORKPLACE OWNERS?

Workplace structures (buildings) exist to protect workers from the elements and to otherwise support worker activity. Workplace buildings should not make workers sick, cause them discomfort, or otherwise inhibit their ability to perform. How effectively a workplace building functions to support its workers and how efficiently the workplace building operates to keep costs manageable is a measure of the workplace building's performance.

The growing proliferation of chemical pollutants in industrial and consumer products, the tendency toward tighter building envelopes and reduced ventilation to save energy, and pressures to defer maintenance and other building services to reduce costs have fostered indoor air quality problems in many workplace buildings. Employee complaints of odors, stale and stuffy air and symptoms of illness or discomfort breed undesirable conflicts between workplace occupants and workplace managers. Lawsuits sometimes follow.

If indoor air quality is not well managed on a daily basis, remediation of ensuing problems or resolution in court can be extremely costly. Moreover, air quality problems in the workplace can lead to reduced worker performance. So it helps to understand the causes and consequences of indoor air quality and to manage workplace buildings to avoid these problems.

Worker Symptoms Associated with Poor Air Quality

Worker responses to pollutants, climatic factors, and other stressors such as noise and light are generally categorized according to the type and degree of responses and the time frame in which they occur. Workplace managers should be generally familiar with these categories, leaving detailed knowledge to industrial hygienists (USEPA, 2016):

- *Acute effects*—Acute effects are those that occur immediately (e.g., within 24 hours) after exposure. Chemicals released from building materials may cause headaches, or mold spores may result in itchy eyes and runny noses in sensitive individuals shortly after exposure. Generally, these effects are not long lasting and disappear shortly after exposure ends. However, exposure to some biocontaminants (fungi, bacteria, viruses) resulting from moisture problems, poor maintenance, or inadequate ventilation have been known to cause serious, sometimes life-threatening respiratory diseases that themselves can lead to chronic respiratory conditions.

- *Chronic effects*—Chronic effects are long-lasting responses to long-term or frequently repeated exposures. Long-term exposures to even low concentrations of some chemicals may induce chronic effects. Cancer is the most commonly associated long-term health consequence of exposure to indoor air contaminants. For example, long-term exposures to environmental tobacco smoke, radon, asbestos, and benzene increase cancer risk.
- *Discomfort*—Discomfort is typically associated with climatic conditions but workplace building contaminants may also be implicated. Workers complain of being too hot or too cold or experience eye, nose, or throat irritation because of low humidity. However, reported symptoms can be difficult to interpret. Complaints that the air is "too dry" may result from irritation from particles on the mucous membranes rather than low humidity, or "stuffy air" may mean that the temperature is too warm or there is lack of air movement, or "stale air" may mean that there is a mild but difficult to identify odor. These conditions may be unpleasant and cause discomfort among workers, but there is usually no serious health implication involved. Absenteeism, work performance, and employee morale, however, can be seriously affected when building managers fail to resolve these complaints.
- *Performance effects*—Significant measurable changes in workers' ability to concentrate or perform mental or physical tasks have been shown to result from modest changes in temperature and relative humidity. In addition, recent studies suggest that similar effects are associated with indoor pollution due to a lack of ventilation or the presence of pollution sources. Estimates of performance losses from poor indoor air quality for all buildings suggest a 2 to 4% loss on average. Future research should further document and quantify these effects.

WORKPLACE BUILDING-ASSOCIATED ILLNESSES

The rapid emergence of indoor air quality problems and associated occupant complaints has given rise to terms to describe illnesses or effects particularly associated buildings. These include *sick building syndrome*, *building-related illness*, and *multiple chemical sensitivity* (USEPA, 2016).

Sick Building Syndrome

Sick building syndrome (SBS) is a catch-all term that refers to a series of acute complaints for which there is no obvious cause and where medical tests reveal no particular abnormalities. It describes situations in which more than 20% of the building occupants experience acute health and comfort effects that appear to be linked to time spent in a building because all other probable causes have been ruled out. The 20% figure is arbitrarily set, as there will always be some workers complaining about adverse health effects associated with occupancy of a building; however, a figure higher than 20% indicates that there must be some determinable cause that can be remedied. Symptoms include headaches; eye, nose, and throat irritation; dry cough; dry or itchy skin; dizziness and nausea; difficulty in concentration; fatigue; and sensitivity to odors.

Sick building syndrome is attributed to inadequate ventilation, chemical contaminants from indoor and outdoor sources, and biological contaminants such as molds, bacteria, pollens, and viruses. Increased air tightness of buildings beginning in the 1970s, a result of efforts to reduce energy consumption, has created environmental conditions conducive to the "proliferation of microorganisms [including mold] in indoor environments" (Passon and Mante, 1996). Once growth has occurred, harmful organisms can be spread by improperly designed and maintained ventilation systems (USEPA, 1991). A single causative agent (e.g., contaminant) is seldom identified, and complaints may be resolved when building operational problems or occupant activities identified by investigators are corrected. Increased absenteeism, reduced work efficiency, and deteriorating employee morale are the likely outcomes of SBS problems that are not quickly resolved.

Building-Related Illness

Building-related illness (BRI) refers to a defined illness with a known causative agent resulting from exposure to the building air. Although the causative agent can be chemical (e.g., formaldehyde), it is often biological. Typical sources of biological contaminants are humidification systems, cooling towers, drain pans or filters, other wet surfaces, or water-damaged building material. Symptoms may be specific or mimic symptoms commonly associated with the flu, including fever, chills, and cough. Serious lung and respiratory conditions can occur. Legionnaires' disease, hypersensitivity pneumonitis, and humidifier fever are common examples of building-related illness.

Multiple Chemical Sensitivity

It is generally recognized that some workers can be sensitive to particular agents at levels that do not have an observable effect in the general population. In addition, it is recognized that certain chemicals can be sensitizers in that exposure to the chemical at high levels can result in sensitivity to that chemical at much lower levels. Some evidence suggests that a subset of the worker population may be especially sensitive to low levels of a broad range of chemicals at levels common in today's home and working environments. This apparent condition has come to be known as multiple chemical sensitivity (MCS). Workers reported to have MCS apparently have difficulty being in most buildings. There is significant professional disagreement concerning whether MCS actually exists and what the underlying mechanism might be. Building managers may encounter occupants who have been diagnosed with MCS. Resolution of complaints in such circumstances may or not be possible. Responsibility to accommodate such workers is subject to negotiation and many involve arrangements to work at home or in a different location.

BUILDING FACTORS AFFECTING INDOOR AIR QUALITY

Building factors affecting indoor air quality can be grouped into two factors (USEPA, 2016).

Factors Affecting Indoor Climate

The thermal environment (temperature, relative humidity, and airflow) are important dimensions of indoor air quality for several reasons. First, many complaints of poor indoor air may be resolved by simply altering the temperature or relative humidity. Second, people that are thermally uncomfortable will have a lower tolerance to other building discomforts. Third, the rate at which chemicals are released from building materials is usually higher at higher building temperatures. Thus, if occupants are too warm, it is also likely that they are being exposed to higher pollutant levels.

Factors Affecting Indoor Air Pollution

Much of the building fabric, its furnishings and equipment, its occupants, and the occupants' activities produce pollution. In a well-functioning building, some of these pollutants will be directly exhausted to the outdoors and some will be removed as outdoor air enters that building and replaces the air inside. The air outside may also contain contaminants that will be brought inside in this process. This air exchange is brought about by the mechanical introduction of outdoor air (outdoor air ventilation rate), the mechanical exhaust of indoor air, and the air exchanged through the building envelope (infiltration and exfiltration). Pollutants inside can travel through the building as air flows from areas of higher atmospheric pressure to areas of lower atmospheric pressure. Some of these pathways are planned and deliberate so as to draw pollutants away from occupants, but problems arise when unintended flows draw contaminants into occupied areas. In addition, some contaminants may be removed from the air through natural processes, such as with the adsorption of chemicals by surfaces or the settling of particles onto surfaces. Removal processes may also be deliberately incorporated into the building systems. Air filtration devices, for example, are commonly incorporated into building ventilation systems. Thus, the factors most important to understanding indoor pollution are (1) indoor sources of pollution, (2) outdoor sources of pollution, (3) ventilation parameters, (4) airflow patterns and pressure relationships, and (5) air filtration systems.

TYPES OF POLLUTANTS

Common pollutants or pollutant classes of concern in commercial buildings along with common sources of these pollutants are provided in Table 8.1.

Sources of Indoor Air Pollutants

Air quality is affected by the presence of various types of contaminants in the air. Some are in the form of gases. These would be generally classified as toxic chemicals. The types of interest are combustion products (carbon monoxide, nitrogen dioxide), volatile organic compounds (e.g., formaldehyde, solvents, perfumes and fragrances), and semivolatile organic compounds (pesticides). Other pollutants are in the form of animal dander; soot; particles from buildings, furnishings, and occupants (e.g., fiberglass, gypsum powder, paper dust, lint from clothing, carpet fibers); and dirt (sandy and earthy material), among others. Specific sources for contaminants that result in adverse health effects in the workplace include the workers themselves, who can have contagious diseases or can carry allergens or other agents on their clothing; building compounds containing VOCs, particles, or fibers; contaminated building components that contain allergens, microbial agents, or pesticides; and outdoor air, which can carry microorganisms, allergens, and chemical air pollutants (Burge and Hoyer, 1998).

Table 8.2 identifies indoor sources of contaminants commonly found in the workplace and offers some measures for maintaining control of these contaminants. Table 8.3 identifies common sources of contaminants that are introduced from outside buildings. These contaminants frequently find their way inside through the building shell, openings, or other pathways to the inside. When workers complain of indoor air quality problems, industrial hygienists are called upon to determine if the problem really is an indoor air quality problem. If they determine that some form of contaminant is present in the workplace, proper remedial action is required. This usually includes removing the source of the contamination. Table 8.4 summarizes management protocols for major sources of pollution in buildings.

TABLE 8.1
Indoor Pollutants and Potential Sources

Pollutant or Pollutant Class	Potential Sources
Environmental tobacco smoke	Lighted cigarettes, cigars, pipes
Combustion contaminants	Furnaces, generators, gas or kerosene space heaters, tobacco products, outdoor air, vehicles
Biological contaminants	Wet or damp materials, cooling towers, humidifiers, cooling coils or drain pans, damp duct insulation or filters, condensation, re-entrained sanitary exhausts, bird droppings, cockroaches or rodents, dust mites on upholstered furniture or carpeting, body odors
Volatile organic compounds (VOCs)	Paints, stains, varnishes, solvents, pesticides, adhesives, wood preservatives, waxes, polishes, cleansers, lubricants, sealants, dyes, air fresheners, fuels, plastics, copy machines, printers, tobacco products, perfumes, drycleaned clothing
Formaldehyde	Particleboard, plywood, cabinetry, furniture, fabrics
Soil gases (radon, sewer gas, VOCs, methane)	Soil and rock (radon), sewer drain leak, dry drain traps, leaking underground storage tanks, landfill
Pesticides	Termiticides, insecticides, rodenticides, fungicides, disinfectants, herbicides

TABLE 8.2
Indoor Sources of Contaminants

Common Sources	Mitigation and Control
Housekeeping and Maintenance	
Cleansers	Use low-emitting products.
Waxes and polishes	Avoid aerosols and sprays.
Disinfectants	Dilute products to the proper strength.
Air fresheners	Use proper protocol when diluting and mixing.
Adhesives	Do not overuse; use during unoccupied hours.
Janitor/supply closets	Store products properly with containers closed and lids on tight.
Wet mops	Use exhaust ventilation for storage spaces (eliminate return air).
Drain cleaners	Clean mops; store mop top up to dry.
Vacuuming	Avoid the use of air fresheners; clean and exhaust instead.
Paints and coatings	Use high-efficiency vacuum bags and filters.
Solvents	Use integrated pest management.
Pesticides	
Lubricants	
Occupant-Related Sources	
Tobacco products	Enforce a smoking policy.
Office equipment	Use exhaust ventilation with pressure control for major local sources.
Cooking/microwave use	Use low-emitting art supplies and marking pens.
Art supplies	Avoid paper clutter.
Marking pens	Educate occupants and staff.
Paper products	
Personal products (e.g., perfume)	
Tracked-in dirt or pollen	
Building Uses as Major Sources	
Print/photocopy shop	Use exhaust ventilation and pressure control.
Drycleaning	Use exhaust hoods where appropriate; check hood air flows.
Science laboratory	
Medical office	
Hair or nail salon	
Cafeteria	

(continued)

INDOOR CONTAMINANT TRANSPORT

Contaminants can travel to worker breathing zones by various pathways. Normally, the contaminants travel with the flow of air. Air moves from areas of high pressure to areas of low pressure, which is why controlling workplace air pressure is an integral part of controlling pollution and enhancing building indoor air quality performance. Air movements should be from occupants toward a source and out of the building rather than from the source to the occupants and out the building. Pressure differences will control the direction of air motion and the extent of occupant exposure. *Driving forces* change pressure relationships and create airflow. Common driving forces are identified in Table 8.5.

COMMON AIRFLOW PATHWAYS

Contaminants travel along pathways—sometimes over great distances. Pathways may lead from an indoor source to an indoor location or from an outdoor source to an indoor location. The location experiencing a pollution problem may be close by, in the same area, or in an adjacent area, but

TABLE 8.2 (continued)
Indoor Sources of Contaminants

Common Sources	Mitigation and Control
Building-Related Sources	
Plywood/compressed wood	Use low-emitting sources.
Construction adhesives	Air out an open or ventilated area before installing.
Asbestos products	Increase ventilation rates during and after installing.
Insulation	Keep material dry prior to enclosing.
Wall/floor coverings (vinyl/plastic)	
Carpets and carpet adhesives	
Wet building products	
Transformers	
Upholstered furniture	
Renovation or remodeling	
HVAC Systems	
Contaminated filters	Perform HVAC preventive maintenance.
Contaminated duct linings	Change filter and clean drain pans; provide proper slope and drainage.
Dirty drain pans	Use potable water for humidification.
Humidifiers	Keep duct lining dry; move lining outside of duct if possible.
Lubricants	Fix leaks and clean spills.
Refrigerants	Maintain spotless mechanical rooms (they are not storage areas).
Mechanical room	Avoid backdrafting.
Maintenance activities	Check and maintain flues from boilers to the outside.
Combustion appliances (boilers, furnaces, stoves, generators)	Keep combustion appliances properly tuned.
	Do not allow the use of unvented combustion appliances.
	Perform polluting activities during unoccupied hours.
Moisture	
Mold	Keep building dry.
Vehicles	
Underground or attached garage	Use exhaust ventilation.
	Maintain garage under negative pressure relative to the building.
	Check air-flow patterns frequently.
	Monitor carbon monoxide levels.

it may be a great distance from or on a different floor from a contaminant source. Knowledge of common pathways helps to track down the source and prevent contaminants from reaching building occupants (see Table 8.6).

VENTILATION

Ventilation can be used to either exhaust contaminants from a fixed source or dilute contaminants from all sources within a space. Exhaust and dilution ventilation along with ventilation measurements are discussed later in the text.

MAJOR INDOOR AIR QUALITY CONTAMINANTS

Industrial hygienists spend a large portion of their time working with and mitigating air contaminant problems in the workplace. The list of potential contaminants workers might be exposed to while working is extensive. Other than those poisonous gases and materials that are automatically

TABLE 8.3
Outdoor Sources of Contaminants

Common Sources	Mitigation and Control
Ambient Outdoor Air	
Air quality in the general area	Filter or clean intake air.
Vehicular Sources	
Local vehicular traffic	Locate air intake away from source.
Vehicle idling areas	Require engines to be shut off at loading docks.
Loading docks	Pressurize building or zone.
	Add vestibules or sealed doors near sources.
Commercial or Manufacturing Sources	
Laundry or drycleaning	Locate air intake away from source.
Paint shops	Pressurize building relative to the outdoors.
Restaurants	Consider air cleaning options for outdoor air intakes.
Photo processing	Use landscaping to block or redirect flow of contaminants.
Automotive shops or gas stations	
Electronics manufacturers or assemblers	
Various industrial operations	
Utilities or Public Works	
Utility power plants	Locate air intake away from source.
Incinerators	Pressurize building relative to the outdoors.
Water treatment plants	Consider air cleaning options for outdoor air intakes.
	Use landscaping to block or redirect flow of contaminants.
Agricultural	
Pesticide spraying	Locate air intake away from source.
Processing or packing plants	Pressurize building relative to the outdoors.
Ponds	Consider air cleaning options for outdoor air intakes.
	Use landscaping to block or redirect flow of contaminants.
Construction and Demolition	Pressurize building.
	Use walk-off mats.
Building Exhaust	
Bathroom exhaust	Separate exhaust or relief from air intake.
Restaurant exhaust	Pressurize building.
Air handler relief vent	
Exhaust from major tenant (e.g., drycleaner)	
Water Sources	
Pools of water on roof	Provide proper roof drainage.
Cooling tower mist	Separate air intake from source of water.
	Treat and maintain cooling tower water.
Birds and Rodents	
Fecal contaminants	Bird-proof intake grills.
Bird nesting	Consider vertical grills.
Building Operations and Maintenance	
Trash and refuse areas	Separate source from air intake.
Chemicals, fertilizers, groundskeeping, and storage	Keep source area clean with lids on tight.
Painting, roofing, or sanding	Isolate storage areas from occupied areas.
Ground Sources	
Soil gas	Depressurize soil.
Sewer gas	Seal foundation and penetrations to foundations.
Underground fuel storage tanks	Keep air ducts away from ground sources.

TABLE 8.4
Protocols for Managing Major Sources of Pollution in Buildings

Type of Protocol	Recommended Solution
Remodeling and renovation	*Isolate construction activity from occupants.*
Painting	*Establish a protocol for painting and ensure that the protocol is followed by both in-house personnel and by contractors.* • Use low-VOC-emission, fast-drying paints where feasible. • Paint during unoccupied hours. • Keep lids on paint containers when not in use. • Ventilate the building with significant quantities of outside air during and after painting. • Perform a complete building flush prior to occupancy. • Use more than normal outside air ventilation for some period after occupancy. • Avoid spraying, when possible.
Pest control	*Use or require the use of pest management by pest control contractors in order to minimize the use of pesticides when managing pests.* • Control dirt, moisture, clutter, foodstuff, harborage, and building penetrations to minimize pests. • Use baits and traps rather than pesticide sprays where possible. • Avoid periodic pesticide application for the “prevention” of pests. • Use pesticides only where pests are located. • Use pesticide specifically formulated for the targeted pest. • Apply pesticides only during unoccupied hours. • Ventilate the building with significant quantities of outside air during and after applications. • Perform a complete building flush prior to occupancy. • Use more than normal outside air ventilation for some period after occupancy. • Notify occupants prior to occupation. • If applying outside, keep away from air intake.
Shipping and receiving	*Establish and enforce a program to prevent vehicle contaminants from entering the building.* • Do not allow idling of vehicles at the loading dock. Post signs and enforce the ban. • Pressurize the receiving area relative to the outside to insure that contaminants from the loading area do not enter the building. Use pressurized vestibules and air locks if necessary. • Periodically check the pressure relationships and compliance with the protocol. • Notify delivery company supervisors of policy.
Establish and enforce a smoking policy	*Environmental tobacco smoke (ETS) is a major indoor air contaminant. A smoking policy may take one of two forms:* • A smoke-free policy that does not allow smoking in any part of the building. • A policy that restricts smoking to designated smoking lounges only.
Smoking lounge requirements	*A designated smoking lounge must have the following features to be effective in containing ETS:* • The lounge should be fully enclosed. • The lounge should be sealed off from the return air plenum. • The lounge should have exhaust ventilation directly to the outside at 60 cfm per occupant (using maximum occupancy). • Transfer air from occupied spaces may be used as make-up air. • The lounge should be maintained under negative pressure relative to the surrounding occupied spaces.

TABLE 8.5
Major Driving Forces

Driving Force	Effect
Wind	Positive pressure is created on the windward side causing infiltration, and negative pressure on the leeward size causing exfiltration, although wind direction can be varied due to surrounding structures.
Stack effect	When the air inside is warmer than that outside it rises, sometimes creating a column that rises up stairwells, elevator shafts, vertical pipe chases, etc. This buoyant force of the air results in positive pressure on the higher floors, negative pressure on the lower floors, and a neutral pressure plane somewhere in between.
HVAC/fans	Fans are designed to push air in a directional flow, resulting in positive pressure in front and negative pressure behind the fan.
Flues and exhaust	Exhausted air from a building will reduce the building air pressure relative to the outdoors. Air exhausted will be replaced either through infiltration or through planned outdoor air intake vents.
Elevators	The pumping action of a moving elevator can push air out of or draw air into the elevator shaft as it moves.

TABLE 8.6
Common Airflow Pathways for Contaminants

Common Pathway	Comment
Indoors	
Stairwells, elevator shafts, vertical electrical or plumbing chases	The stack effect brings about air flow by drawing air toward these chases on the lower floors and away from these chases on the higher floors, affecting the flow of contaminants.
Receptacles, outlets, openings	Contaminants can easily enter and exit building cavities and thereby move from space to space.
Duct or plenum	Contaminants are commonly carried by the HVAC system throughout the occupied spaces.
Duct or plenum leakage	Duct leakage accounts for significant unplanned air flow and energy loss in buildings.
Flue or exhaust leakage	Leaks from sanitary exhausts or combustion flues can cause serious health problems.
Room spaces	Air and contaminants move within a room or through doors and corridors to adjoining spaces.
Outdoors to Indoors	
Indoor air intake	Polluted outdoor air or exhaust air can enter the building through the air intake.
Windows or doors	A negatively pressurized building will draw air and outside pollutants into the building through any cracks and crevices or available opening.
Substructure or slab penetrations	Radon and other soil gases and moisture-laden air or microbial-contaminated air often travel through crawlspaces and other substructures into the building.

top priorities for industrial hygienists to investigate and mitigate, there are a few major chemical- and material-derived air contaminants that are considered extremely hazardous. These also attract an industrial hygienist's immediate attention and require remedial actions. This section focuses on asbestos, silica, formaldehyde, and lead as examples of such hazardous contaminants requiring the immediate attention of industrial hygienists.

ASBESTOS EXPOSURE

Asbestos is the name given to a group of naturally occurring minerals widely used in certain products, such as building materials and vehicle brakes, to resist heat and corrosion. Asbestos includes chrysoltile, amosite, crocidolite, tremolite asbestos, anthophyllite asbestos, actinolite asbestos, and any of these materials that have been chemically treated or altered. Typically, asbestos appears as a whitish, fibrous material that may release fibers that range in texture from coarse to silky; however, airborne fibers that can cause health damage may be too small to be seen with the naked eye. An estimated 1.3 million employees in construction and general industry face significant asbestos exposure on the job. Heaviest exposures occur in the construction industry, particularly during the removal of asbestos during renovation or demolition (abatement). Employees are also likely to be exposed during the manufacture of asbestos products (such as textiles, friction products, insulation, and other building materials) and automotive brake and clutch repair work (OSHA, 2002).

The inhalation of asbestos fibers by workers can cause serious diseases of the lungs and other organs that may not appear or manifest themselves until years after the exposure has occurred. For instance, asbestosis can cause a buildup of scar-like tissue in the lungs and result in a loss of lung function that often progresses to disability and death. Smokers are at higher risk of developing some asbestos-related diseases. In addition to asbestosis, exposure to asbestos can cause mesothelioma, which is a cancer affecting the membranes lining the lungs and abdomen; lung cancer; and cancers of the esophagus, stomach, colon, and rectum. The Occupational Safety and Health Administration (OSHA) has issued the following three standards to assist industrial hygienists with compliance and to protect workers from exposure to asbestos in the workplace:

- 29 CFR 1926.1101 covers construction work, including alteration, repair, renovation, and demolition of structures containing asbestos.
- 29 CFR 1915.1001 covers asbestos exposure during work in shipyards.
- 29 CFR 1910.1001 applies to asbestos exposure in general industry, such as exposure during brake and clutch repair, custodial work, and manufacture of asbestos-containing products.

Standards for the construction and shipyard industries classify the hazards of asbestos work activities and prescribe particular requirements for each classification:

- Class I is the most potentially hazardous class of asbestos jobs and involves the removal of thermal system insulation and sprayed-on or troweled-on asbestos-containing surfacing materials or presumed asbestos-containing materials.
- Class II includes the removal of other types of asbestos-containing materials that are not thermal system insulation, such as resilient flooring and roofing materials containing asbestos.
- Class III focuses on repair and maintenance operations where asbestos-containing materials are disturbed.
- Class IV pertains to custodial activities where employees clean up asbestos-containing waste and debris.

There are equivalent regulations in states with OSHA-approved state plans.

Permissible Exposure Limits

Employee exposure to asbestos must not exceed 0.1 fibers per cubic centimeter (f/cm^3) of air, averaged over an 8-hour work shift. Short-term exposure must also be limited to not more than 1 f/cm^3, averaged over 30 minutes. Rotation of employees to achieve compliance with either permissible exposure limit (PEL) is prohibited.

Exposure Monitoring

In construction and shipyard work, unless the industrial hygienist is able to demonstrate that employee exposures will be below the PELs (a "negative exposure assessment"), it is generally a requirement that monitoring for workers in Class I and II regulated areas be conducted. For workers in other operations where exposures are expected to exceed one of the PELs, periodic monitoring must be conducted. In general industry, for workers who may be exposed above a PEL or above the excursion limit, initial monitoring must be conducted. Subsequent monitoring at reasonable intervals must be conducted, and in no case at intervals greater than 6 months for employees exposed above a PEL.

Competent Person

In all operations involving asbestos removal (abatement), employers must name a "competent person" qualified and authorized to ensure worker safety and health, as required by Subpart C, General Safety and Health Provisions for Construction (29 CFR 1926.20). Under the requirements for safety and health prevention programs, the competent person must frequently inspect job sites, materials, and equipment. A fully trained and licensed industrial hygienist often fills this role. In addition, for Class I jobs the competent person must inspect onsite at least once during each work shift and upon employee request. For Class II and III jobs, the competent person must inspect often enough to assess changing conditions and upon employee request.

Regulated Areas

In general industry and construction, regulated areas must be established where the 8-hour TWA or 30-minute excursion values for airborne asbestos exceed the PELs. Only authorized persons wearing appropriate respirators can enter a regulated area. In regulated areas, eating, smoking, drinking, chewing tobacco or gum, and applying cosmetics are prohibited. Warning signs must be displayed at each regulated area and must be posted at all approaches to regulated areas.

Methods of Compliance

In both general industry and construction, employers must control exposures using engineering controls, to the extent feasible. Where engineering controls are not feasible to meet the exposure limit, they must be used to reduce employee exposures to the lowest levels attainable and must be supplemented by the use of respiratory protection.

Respirators

In general industry and construction, the level of exposure determines what type of respirator is required; the standards specify the respirator to be used. Keep in mind that respirators must be used during all Class I asbestos jobs. Refer to 29 CFR 1926.103 for further guidance on when respirators must be worn.

Labels

Caution labels must be placed on all raw materials, mixtures, scrap, waste, debris, and other products containing asbestos fibers.

Protective Clothing

For any employee exposed to airborne concentrations of asbestos that exceed the PEL, the employer must provide and require the use of protective clothing such as coveralls or similar full-body clothing, head coverings, gloves, and foot coverings. Wherever the possibility of eye irritation exists, face shields, vented goggles, or other appropriate protective equipment must be provided and worn.

Training

For employees involved in each identified work classification, training must be provided. The specific training requirements depend on the particular class of work being performed. In general industry, training must be provided to all employees exposed above a PEL. Asbestos awareness training must also be provided to employees who perform housekeeping operations covered by the standard. Warning labels must be placed on all asbestos products, containers, and installed construction materials when feasible.

Recordkeeping

The employer must keep an accurate record of all measurements taken to monitor employee exposure to asbestos. This record is to include the date of measurement, operation involving exposure, sampling and analytical methods used, and evidence of their accuracy; number, duration, and results of samples taken; type of respiratory protective devices worn; name and Social Security number; and the results of all employee exposure measurements. This record must be kept for 30 years.

Hygience Facilities and Practices

Clean change rooms must be furnished by employers for employees who work in areas where exposure is above the TWA or excursion limit. Two lockers or storage facilities must be furnished and separated to prevent contamination of the employees' street clothes by protective work clothing and equipment. Showers must be furnished so that employees may shower at the end of the work shift. Employees must enter and exit the regulated area through the decontamination area. The equipment room must be supplied with impermeable, labeled bags and containers for the containment and disposal of contaminated protective clothing and equipment. Lunchroom facilities for those employees must have a positive-pressure, filtered air supply and be readily accessible to employees. Employees must wash their hands and face prior to eating, drinking, or smoking. The employer must ensure that employees do not enter lunchroom facilities with protective work clothing or equipment unless surface fibers have been removed from the clothing or equipment. Employees may not smoke in work areas where they are occupationally exposed to asbestos.

Medical Exams

In general industry, exposed employees must have a preplacement physical examination before being assigned to an occupation exposed to airborne concentrations of asbestos at or above the action level or the excursion level. The physical examination must include chest x-ray, medical and work history, and pulmonary function tests. Subsequent exams must be given annually and upon termination of employment, although chest x-rays are required annually only for older workers whose first asbestos exposure occurred more than 10 years ago. In construction, examinations must be made available annually for workers exposed above the action level or excursion limit for 30 or more days per year or who are required to wear negative pressure respirators; chest x-rays are at the discretion of the physician.

SILICA EXPOSURE

Crystalline silica (SiO_2) is a major component of the Earth's crust. In pure, natural form, SiO_2 crystals are minute, very hard, translucent, and colorless. Most mined minerals contain some SiO_2. "Crystalline" refers to the orientation of SiO_2 molecules in a fixed pattern as opposed to a nonperiodic, random molecular arrangement defined as amorphous (e.g., diatomaceous earth). Silica exposure occurs in a wide variety of settings, such as mining, quarrying, and stone-cutting operations; ceramics and vitreous enameling; and in the use of filters for paints and rubber. The wide use and multiple applications of silica in industrial applications combine to make silica a major occupational health hazard that can lead to death. Silicosis is a disabling, nonreversible, and sometimes fatal lung

DID YOU KNOW?

Crystalline silica is a common mineral found in the Earth's crust. It occurs primarily as quartz and is a major component of the sand, clay, and stone materials used to make such everyday products as concrete, brick, and glass.

DID YOU KNOW?

Respirable crystalline silica is small enough to enter the gas-exchange regions of the lungs if inhaled; this includes particles with aerodynamic diameters less than approximately 10 micrometers (μm).

disease caused by overexposure to respirable crystalline silica. More than a million U.S. workers are exposed to crystalline silica, and each year more than 250 die from silicosis (see Table 8.7). There is no cure for the disease, but it is 100% preventable if employers, workers, and health professionals work together to reduce exposures.

Silica Exposure During Hydraulic Fracturing

The U.S. Department of Labor identified exposure to airborne silica as a health hazard to workers conducting some hydraulic fracturing operations during recent field studies (OSHA, 2012). Hydraulic fracturing, or "fracking," is a process used to stimulate well production in the oil and gas industry. It is not a new process, but its use has increased significantly in the last 10 years because of new horizontal drilling, multistage fracking (or "completions") technologies that improve access to natural gas and oil deposits. It involves pumping large volumes of water and sand into a well at high pressure to fracture shale and other tight formations, allowing oil and gas to flow into the well.

Recent field studies showed that workers may be exposed to dust with high levels of respirable crystalline silica during hydraulic fracturing, and this is where occupational health and safety professionals and industrial hygiene practitioners come in. Because federal, state, and local officials began paying particular attention to fracking operations not only for environmental issues but also for worker safety and health, fracking companies came to understand that it is necessary to make use of employee safety and health professionals, including industrial hygienists, to monitor and sample fracking sites to ensure worker safety and health. Seven primary sources of silica dust exposure during hydraulic fracturing operations have been identified (OSHA, 2012):

- Dust ejected from thief hatches (access ports) on top of the sane movers during refilling operations while the machines are running (hot loading)
- Dust ejected and pulsed through open side-fill ports on the sand movers during refilling operations
- Dust generated by onsite vehicle traffic
- Dust released from the transfer belt under the sand movers
- Dust created as sand drops into, or is agitated in, the blender hopper and on transfer belts
- Dust released from the operation of transfer belts between the sand mover and the blender
- Dust released from the top of the end of the sand transfer belt (dragon's tail) on sand movers

DID YOU KNOW?

The OSHA general industry PEL for quartz, the common form of crystalline silica found in sand, is an 8-hour time-weighted average exposure to respirable dust calculated from the following formula.

$$\text{PEL} = 10\ \text{mg/m}^3/(\%\ \text{silica} + 2)$$

The PEL is approximately equal to 0.1 mg/m^3 for pure quartz silica. The PEL is outlined in 29 CFR 1910.1000, Table Z-3. If other forms of crystalline silica are present, the PEL calculation must be modified per Table Z-3. The NIOSH recommended exposure limit (REL) is a fixed value of 0.05 mg/m^3.

TABLE 8.7
Deaths from Silica in the Workplace

Occupation	Proportionate Mortality Ratio (PMR)[a]
Miscellaneous metal and plastic machine operators	168.44
Hand molders and shapers, except jewelers	64.12
Crushing and grinding machine operators	50.97
Hand molding, casting, and forming occupations	35.70
Molding and casting machine operators	30.60
Mining machine operators	19.61
Mining occupations (not elsewhere classified)	15.33
Construction trades (not elsewhere classified)	14.77
Grinding, abrading, buffing, and polishing machine operators	8.47
Heavy equipment mechanics	7.72
Miscellaneous material moving equipment operators	6.92
Millwrights	6.56
Crane and tower operators	6.02
Brick masons and stone masons	4.71
Painters, construction and maintenance	4.50
Furnace, kiln, oven operators, except food	4.10
Laborers, except construction	3.79
Operating engineers	3.56
Welders and cutters	3.01
Machine operators, not specified	2.86
Not specified mechanics and repairers	2.84
Supervisors, production occupations	2.73
Construction laborers	2.14
Machinists	1.79
Janitors and cleaners	1.78

Industry	Proportionate Mortality Ratio (PMR)[a]
Metal mining	69.51
Miscellaneous nonmetallic mineral and stone products	55.31
Nonmetallic mining and quarrying, except fuel	49.77
Iron and steel foundries	31.15
Pottery and related products	30.73
Structural clay products	27.82
Coal mining	9.26
Blast furnaces, steelworks, rolling and finishing mills	6.49
Miscellaneous fabricated metal products	5.87
Miscellaneous retail stores	4.63
Machinery, except electrical, (not elsewhere classified)	3.96
Other primary metal industries	3.63
Industrial and miscellaneous chemicals	2.72
Not specified manufacturing industries	2.67
Construction	1.82

Sources: OSHA, *Deaths from Silica in the Workplace*, Occupational Safety and Health Administration, Washington, DC, 2015 (https://www.osha.gov/dsg/etools/silica/determine_exposure/silicadeaths/silicadeaths.html).

[a] Observed number of deaths from silicosis per occupation divided by expected number of deaths. A value of 1 indicates no additional risk; a value of 10 indicates a risk 10 times greater than the normal risk of silicosis.

Guidelines for Control of Occupational Exposure to Silica

In accordance with the Occupational Safety and Health Administration's standard for air contaminants (29 CFR 1910.1000), employee exposure to airborne crystalline silica must not exceed an 8-hour time-weighted average (TWA) limit as stated in 29 CFR 1910.1000, Table Z-3, or a limit set by a state agency whenever a state-administered occupational safety and health plan is in effect. As mandated by OSHA, the first mandatory requirement is that employee exposure be eliminated through the implementation of feasible engineering controls (e.g., dust suppression, ventilation). After all such controls are implemented and they do not control to the permissible exposure, each employer must rotate its employees to the extent possible in order to reduce exposure. Only when all engineering or administrative controls have been implemented, and the level of respirable silica still exceeds permissible exposure limits, may an employer rely on a respirator program pursuant to the mandatory requirements of 29 CFR 1910.134. Generally, where working conditions or other practices constitute recognized hazards likely to cause death or serious physical harm, they must be corrected.

FORMALDEHYDE EXPOSURE

Formaldehyde (HCHO) is a colorless, flammable gas with a pungent, suffocating odor. Formaldehyde is common to the chemical industry. It is the most important aldehyde produced commercially and is used in the preparation of urea-formaldehyde and phenol-formaldehyde resins. It is also produced during the combustion of organic materials and is a component of smoke. The major sources in workplace settings are in manufacturing processes (used in the paper, photographic, and clothing industries) and building materials. Building materials may contain phenol, urea, thiourea, or melamine resins that contain HCHO. Degradation of HCHO resins can occur when these materials become damp from exposure to high relative humidity, if the HCHO materials are saturated with water during flooding, or when leaks occur. The release of HCHO occurs when the acid catalysts involved in the resin formulation are reactivated. When temperatures and relative humidity increase, outgassing increases (OSHA, 2011; Washington State Department of Health, 2003).

Formaldehyde exposure is most common through gas-phase inhalation; however, it can also occur through liquid-phase skin absorption. Workers can be exposed during direct production, treatment of materials, and production of resins. Healthcare professionals, pathology and histology technicians, and teachers and students who handle preserved specimens are potentially at high risk. Studies indicate that formaldehyde is a potential human carcinogen. Airborne concentrations above 0.1 ppm can cause irritation of the eyes, nose, and throat. The severity of irritation increases as the concentration increases; at 100 ppm it is immediately dangerous to life and health. Dermal contact causes various skin reactions, including sensitization, which might force persons thus sensitized to find other work. OSHA requires that the employer conduct initial monitoring to identify all employees who are exposed to formaldehyde at or above the action level or short-term exposure-limit (STEL) and to accurately determine the exposure of each employee so identified. If the exposure level is maintained below the STEL and the action level, employers may discontinue exposure monitoring until there is a change that could affect exposure levels. The employer must also monitor employee exposure promptly upon receiving reports of formaldehyde-related signs and symptoms.

With regard to exposure control, the best prevention is provided by source control whenever possible. The selection of HCHO-free or low-emitting products, such as exterior-grade plywood, which use phenol HCHO resins for indoor use is the best starting point. Secondary controls include filtration, sealants, and fumigation treatments. Filtration can be achieved using selected adsorbents. Sealants involve coating the materials in question with two or three coats of nitrocellulose varnish or water-based polyurethane. Three coats of these materials can reduce outgassing by as much as 90%. Training is required at least annually for all employees exposed to formaldehyde concentrations of 0.1 ppm or greater. The training will increase employees' awareness of specific hazards in their workplace and of the control measures employed. The training also will assist successful medical surveillance and medical removal programs. These provisions will only be effective if employees know what signs or symptoms are related to the health effects of formaldehyde and are periodically encouraged to do learn them.

LEAD EXPOSURE

Lead has been poisoning workers for thousands of years. Most occupational over-exposures to lead have been found in the construction trades, such as plumbing, welding, and painting. In plumbing, soft solder (banned for many uses in the United States), used chiefly for soldering tinplate and copper pipe joints, is an alloy of lead and tin. The use of lead-based paint in residential applications has been banned, but because lead-based paint inhibits the rusting and corrosion of iron and steel it is still used on construction projects. Significant lead exposures can also arise from removing paint from surfaces previously coated with lead-based paint. According to OSHA 93-47, the operations that generate lead dust and fumes include the following:

- Flame-torch cutting, welding, the use of heat guns, or sanding, scraping, and grinding of lead-based painted surfaces during repair, reconstruction, dismantling, and demolition work
- Abrasive blasting of structures containing lead-based paints
- Use of torches and heat guns, and sanding, scraping, and grinding of lead-based painted surfaces during remodeling or abating lead-based paint
- Maintaining process equipment or exhaust duct work

Health Effects of Lead

Lead can enter the body through several routes of entry. When absorbed into the body in certain doses, lead is a toxic substance. Lead can be absorbed into the body by inhalation and ingestion. Except for certain organic lead compounds not covered by OSHA's lead standard (29 CFR 1926.62), such as tetraethyl lead, when scattered in the air as a dust, fume, or mist lead can be absorbed into the body by inhalation. A significant portion of the lead that can be inhaled or ingested gets into the blood stream. Once in the blood stream, lead is circulated throughout the body and stored in various organs and tissues. Some of this lead is quickly filtered out of the body and excreted, but some remains in the blood and other tissues. As exposure to lead continues, the amount stored in the body will increase if more lead is being absorbed than is being excreted. Cumulative exposure to lead, which is typical in construction settings, may result in damage to the blood, nervous system, kidneys, bones, heart, and reproductive system and contributes to high blood pressure. Some of the symptoms of lead poisoning include the following:

- Poor appetite
- Dizziness
- Pallor
- Headache
- Irritability or anxiety
- Constipation
- Sleeplessness
- Weakness
- Insomnia
- "Lead line" in gums
- Fine tremors
- Hyperactivity
- Wrist drop (weakness of extensor muscles)
- Excessive tiredness

- Numbness
- Muscle and joint pain or soreness
- Nausea
- Reproductive difficulties

Lead Standard Definitions

The OSHA lead standard defines the following terms:

- *Action level* is the employee exposure, without regard to the use of respirators, to an airborne concentration of lead of 30 micrograms per cubic meter of air (30 µg/m^3), averaged over an 8-hour period.
- *Permissible exposure limit (PEL)* is the concentration of airborne lead to which an average person may be exposed without harmful effects. OSHA has established a PEL of 50 micrograms per cubic meter of air (50 µg/m^3) averaged over an 8-hour period. If an employee is exposed to lead for more than 8 hours in any work day, the permissible exposure limit, a time-weighted average (TWA) for that day should be reduced according to the following formula:

  $$\text{Maximum permissible limit } (\mu g/m^3) = 400 \times \text{Hours worked in the day.}$$

  When respirators are used to supplement engineering and administrative controls to comply with the PEL and all the requirements of the lead standard's respiratory protection rules have been met, employee exposure, for the purpose of determining whether the employer has complied with the PEL, may be considered to be at the level provided by the protection factor of the respirator for those periods the respirator is worn. Those periods may be averaged with exposure levels during periods when respirators are not worn to determine the employee's daily TWA exposure.
- *µg/m^3* is micrograms per cubic meter of air. A microgram is 1 millionth of a gram. There are 454 grams in a pound.

Worker Lead Protection Program

The employer is responsible for the development and implementation of a worker lead protection program. This program is essential to minimizing worker risk of lead exposure. The most effective way to protect workers is to minimize exposure through the use of engineering controls and good work practices. At a minimum, the following elements should be included in the employer's worker protection program for employees exposed to lead:

- Hazard determination, including exposure assessment
- Engineering and work practice controls
- Respiratory protection
- Protective work clothing and equipment (PPE)
- Housekeeping
- Hygiene facilities and practices
- Medical surveillance and provisions for medical removal
- Employee information and training
- Signs
- Recordkeeping

MOLD CONTROL

Molds can be found almost anywhere; they can grow on virtually any organic substance, as long as moisture and oxygen are present. The earliest known writings that appear to discuss mold infestation and remediation are found in Leviticus, Chapter 14, Old Testament. Where is mold typically found?

Name the spot or place; mold has been found growing in office buildings, schools, automobiles, private homes, and any location where water and organic matter are left unattended. Mold is not a new issue—just one that, until recently, has received little attention by regulators in the United States. That is, there are no state or federal statutes or regulations regarding molds and indoor air quality.

Molds reproduce by making spores that usually cannot be seen without magnification. Mold spores waft through the indoor and outdoor air continually. When mold spores land on a damp spot indoors, they may begin growing and digesting whatever they are growing on in order to survive. Molds generally destroy the things they grow on (USEPA, 1991).

The key to limiting mold exposure is to prevent the germination and growth of mold. Because mold requires water to grow, it is important to prevent moisture problems in buildings. Moisture problems can have many causes, including uncontrolled humidity. Some moisture problems in workplace buildings have been linked to changes in building construction practices beginning in the 1970s. Some of these changes have resulted in buildings that are tightly sealed and lack adequate ventilation, potentially leading to moisture buildup. Building materials, such as drywall, may not allow moisture to escape easily. Moisture problems may also be due to roof leaks, landscaping, or gutters that direct water into or under the building, as well as by unvented combustion appliances. Delayed maintenance or insufficient maintenance is also associated with moisture problems in buildings. Moisture problems in temporary structures have frequently been associated with mold problems.

Building maintenance personnel, architects, and builders need to know effective means of avoiding mold growth that might arise from maintenance and construction practices. Locating and cleaning existing growths are also paramount to reducing the health effects of mold contamination. Using proper cleaning techniques is important because molds are incredibly resilient and adaptable (Davis, 2001).

Molds can elicit a variety of health responses in humans. The extent to which an individual may be affected depends on that person's state of health, susceptibility to disease, the organisms with which they came in contact, and the duration and severity of exposure (Ammann, 2000). Some people experience temporary effects that disappear when they vacate infested areas (Burge, 1997). In others, the effects of exposure may be long term or permanent (Yang, 2001). It should be noted that systemic infections caused by molds are not common. Normal, healthy individuals can resist systemic infection from airborne molds. Those at risk for system fungal infection are severely immunocompromised individuals such as those with HIV/AIDS, individuals who have had organ or bone marrow transplants, and persons undergoing chemotherapy.

In 1994, an outbreak of the mold *Stachybotrys chartarum* in Cleveland, Ohio, was believed by some to have caused pulmonary hemorrhage in infants. Sixteen of the infants died. The CDC sponsored a review of the cases and concluded that the scientific evidence provided did not warrant the conclusion that inhaled mold was the cause of illness in the infants; however, the panel also stated that further research was warranted, as the study design for the original research appeared to be flawed (CDC, 1999). Below is a list of mold components known to elicit a response in humans:

- *Volatile organic compounds*—"Molds produce a large number of volatile organic compounds. These chemicals are responsible for the musty odors produced by growing molds" (McNeel and Kreutzer, 1996). VOCs also provide the odor in cheeses, and the "off" taste of mold-infested foods. Exposure to high levels of volatile organic compounds affects the central nervous system, producing such symptoms as headaches, attention deficit, inability to concentrate, and dizziness (Ammann, 2000). The specific contribution of mold volatile organic compounds to building-related health problems has not yet been studied (McNeel and Kreutzer, 1996), but mold volatile organic compounds are likely responsible for only a small fraction of total VOCs indoors (Davis, 2001).
- *Allergens*—Because of the presence of allergens on mold spores, all molds have the potential to cause an allergic reaction in susceptible humans (Rose, 1999). Allergic reactions are believed to be the most common exposure reaction to molds. These reactions

can range from mild, transitory responses such as runny eyes, runny nose, throat irritation, coughing, and sneezing to more severe, chronic illnesses such as sinusitis and asthma (Ammann, 2000).
- *Mycotoxins*—These natural organic compounds are capable of initiating a toxic response in vertebrates (McNeel and Kreutzer, 1996). Some molds are capable of producing mycotoxins. Molds known to potentially produce mycotoxins and which have been isolated in infestations causing adverse health effects include certain species of *Acremonium*, *Alternaria*, *Aspergillus*, *Caldosporium*, *Chaetomium*, *Fusarium*, *Paecilomyces*, *Penicillium*, *Stachybotrys*, and *Trichoderma* (Yang, 2001). Although a certain type of mold or mold strain type may have the genetic potential for producing mycotoxins, specific environmental conditions are believed to be necessary for the mycotoxins to be produced. In other words, although a given mold might have the potential to produce mycotoxins, it will not produce them if the appropriate environmental conditions are not present (USEPA, 1991). Currently, the specific conditions that cause mycotoxin production are not fully understood. The USEPA recognizes that mycotoxins have a tendency to concentrate in fungal spores and that there is limited information currently available regarding the process involved in fungal spore release. As a result, research is being conducted to determine the environmental conditions required for the sporulation, emission, aerosolization, dissemination, and transport of *Stachybotrys* into the air (CDC, 2012; USEPA, 2017).

Mold Prevention

The key to mold control is moisture control; in other words, solve moisture problems before they become mold problems. Several mold prevention tips are listed below (USEPA, 2001):

- Fix leaky plumbing and leaks in the building envelope as soon as possible.
- Watch for condensation and wet spots. Fix sources of moisture problems as soon as possible.
- Prevent moisture due to condensation by increasing surface temperature or reducing the moisture level in air (humidity). To increase surface temperature, insulate or increase air circulation. To reduce the moisture level in air, repair leaks, increase ventilation (if outside air is cold and dry), or dehumidify (if outdoor air is warm and humid).
- Keep heating, ventilation, and air conditioning (HVAC) drip pans clean, flowing properly, and unobstructed.
- Perform regular HVAC inspections and maintenance as scheduled.
- Vent moisture-generating appliances, such as dryers, to the outside where possible.
- Maintain a low indoor humidity, below 60% relative humidity (RH) but ideally 30 to 50%, if possible.
- Clean and dry wet or damp spots within 48 hours.
- Do not let foundations stay wet. Provide drainage and slope the ground away from the foundation.

Mold Remediation

At the present time, there are no standardized recommendations for mold remediation; however, the USEPA is working on guidelines. There are certain aspects of mold cleanup, though, that have been agreed upon by many practitioners in the field. A common-sense approach should be taken when assessing mold growth. For example, it is generally believed small amounts of growth, such as those commonly found on shower walls, pose no immediate health risk to most individuals. Persons with respiratory problems, a compromised immune system, or fragile health should not participate in cleanup operations. Cleanup crews should be properly attired. Mold should not be allowed to touch bare skin. Eyes and lungs should be protected from aerosol exposure. Adequate ventilation should be provided while, at the same time, containing the infestation in an effort to avoid spreading mold to other areas. The source of moisture must be stopped and all areas infested with mold thoroughly cleaned. If thorough cleaning is not possible due to the nature of the material (porous vs. semi- and nonporous), all contaminated areas should be removed. Safety tips that should be followed when remediating moisture and mold problems include the following (USEPA, 2001):

- Do not touch mold or moldy items with bare hands.
- Do not get mold or mold spores in your eyes.
- Do not breathe in mold or mold spores.
- Consider using personal protective equipment (PPE) when disturbing mold. The minimum PPE is a respirator, gloves, and eye protection.

Mold Cleanup Methods

A variety of mold cleanup methods are available for remediating damage to building materials and furnishings caused by moisture control problems and mold growth. These include wet vacuum, damp wipe, HEPA vacuum, and the removal of damaged materials and sealing them off in plastic bags. The specific method or group of methods used will depend on the type of material affected (USEPA, 2001).

Checklist for Mold Remediation

1. Investigate and evaluate moisture and mold problems.
    - Assess size of moldy area (square feet).
    - Consider the possibility of hidden mold.
    - Fix small mold and moisture problems before they become large problems.
    - Select a remediation manager for medium- or large-sized mold problem.
    - Investigate areas associated with occupant complaints.
    - Identify sources or causes of water or moisture problems.
    - Note type of water-damaged materials (wallboard, carpet, etc.).
    - Check inside air ducts and air handling unit.
    - Throughout the process, consult a qualified professional if necessary or desired.
2. Communicate with building occupants at all stages of process, as appropriate.
    - Designate a contact person for questions and comments about medium- or large-scale remediation as needed.
3. Plan the remediation.
    - Adapt or modify remediation guidelines to fit the situation; use professional judgment.
    - Plan to dry wet, nonmoldy materials within 48 hours to prevent mold growth.
    - Select cleanup methods for moldy items.
    - Select personal protective equipment (PPE).
    - Select containment equipment; protect building occupants.
    - Select remediation personnel who have the experience and training needed to implement the remediation plan and use PPE and containment as appropriate.
4. Remediate moisture and mold problems.
    - Fix the moisture problem and implement a repair or maintenance plan.
    - Dry wet, non-moldy materials within 48 hours to prevent mold growth.
    - Clean and dry moldy materials.
    - Discard moldy porous items that cannot be cleaned (USEPA, 2001).

INDOOR AIR QUALITY EQUATIONS

A few of the basic, standard equations used in indoor air quality computations are provided in this section.

PERCENTAGE OF OUTSIDE AIR IN THE AIR SUPPLY

$$\% \text{ Outside air} = T_{RA} - T_{MA}/T_{RA} - T_{OA} \tag{8.1}$$

where

T_{RA} = Temperature of return air (dry-bulb).
T_{MA} = Temperature of mixed return and outside air (dry-bulb).
T_{OA} = Temperature of outdoor air (dry-bulb).

OUTDOOR AIR VOLUME FLOW RATE

$$Q_{OA} = 13{,}000n/C_{indoors} - C_{OA} \tag{8.2}$$

where

Q_{OA} = Approximate volume flow rate of outdoor air (cfm).
n = Number of people working in an office complex (with ~7 people per 1000 ft^2 of office space).
$C_{indoors}$ = Measured concentration of CO_2 in the office air after a long period of occupancy time, such as near lunch or near the end of the day (ppm).
C_{OA} = Concentration of CO_2 in the outdoor air (ppm).

AIR CHANGES PER HOUR, OUTDOOR AIR

$$N = \ln(C_i - C_O) - \ln(C_A - C_O)/\text{hr} \tag{8.3}$$

where

N = Air exchange, air changes per hour.
ln = Natural log.
C_i = Concentration of CO_2 at start of test.
C_O = Outdoor CO_2 concentration, about 330 ppm.
C_A = Concentration of CO_2 at end of test.

DISCUSSION QUESTIONS

1. Is sick building syndrome real? Explain.
2. What is the difference between sick building syndrome and building-related illness? Is there really a difference?
3. Sick building syndrome has been compared to silicosis, macrophagic myofascitis, Gulf War syndrome, and post-vaccination phenomena. What do you think?
4. Asbestos exposure can be deadly. Should any use of asbestos be prohibited? Explain.
5. Do you think the crisis involving lead in the drinking water in Flint, Michigan, has focused public attention on the hazards of lead ingestion or lead vapor inhalation?

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Section III

Water

I am the daughter of Earth and Water,
And the nursling of the Sky;
I pass through the pores of the ocean and shores;
I change, but I cannot die.

—Percy Bysshe Shelley, poet (1792–1872)

9 Water

The average American uses more than 180 gallons of fresh, clean water a day, while many rural villagers in the Third World nations spend up to 6 hours a day obtaining their water from distant, polluted streams. Nearly 10 million people die each year as a result of intestinal diseases caused by unsafe water. While the magnitude of water use in most Western countries gives the appearance of an unlimited supply, it is only an illusion. In the 30-year period between 1950 and 1980, the U.S. population grew by 50 percent. During the same time period, water consumption increased by 150 percent. The Water Resources Council projects that of the 106 water supply regions in the United States, water supplies to 17 of them will be seriously inadequate in the next decades.

Boyce (1997)

What do Rome's aqueducts, Napoleon's death, and the pilgrimage site of Lourdes have in common? All involve water: the leading ingredients of our bodies, essential for our daily lives, and the subject of innumerable struggles. Even if you prefer to drink wine—it's mostly water anyway.

—Jared Diamond, scientist and author

WATER: EARTH'S BLOOD

We can think of Earth (and the environmental systems that make the Earth a living planet) as analogous to the human body. In reality, Earth and the human body are similar in ways we don't normally consider. For example, we can portray Earth as a combination of three active phases—gases, liquids, and solids—and we can portray the human body in much the same way (that is, as a compilation of gases, liquids, and solids). We can say that the human body (in its gaseous phase) makes direct contact with the atmosphere, directly consuming air. Most of the gases found in the atmosphere are also found on the Earth (especially in soil), but at different concentrations, of course. The gaseous concentrations in the materials of Earth are normally regulated by the diffusion of oxygen into soil and of carbon dioxide from soil (i.e., soil respiration). Doesn't the human body also respire?

The human body has a solid phase, of course. Although the human body typically consists of approximately 60% water, the bone, tissue, cartilage, muscle, tendon, and sinew alone or in combination provide the solid substance upon which the human body is formed. We normally think of the Earth as a rotating body of solids: iron mostly, but with several other elements blended, mixed, and collated within its structure. We can say that the solid phase of Earth is its body, its muscle, its tendons, the very sinews that hold the entire mass together in structural form.

The human body's liquid phase is a combination of water, blood, and other vital liquid chemical substances. This liquid phase is, of course, essential for all humans and other forms of life. In particular, blood sustains human life. The human body's 60 to 100 trillion cells simply cannot survive without blood, without the daily supply of nutrients such as the amino acids and glucose that blood supplies. Human blood also functions to remove wastes such as carbon dioxide and ammonia. At the center of the human blood system is the heart, which keeps the blood moving along its predetermined circular path. Circulation of the blood is so important that if the heart discontinues beating for only a few minutes we die. This vital pump, the heart, pumps its life-sustaining liquid through blood vessels, arteries, arterioles, and capillaries to all reaches of the human body; without blood in those further reaches, those extremities die.

Earth also has its own blood supply: water. Without water, Earth simply becomes another moon, a sterile, desolate, gray hunk of orbiting rock. Water is Earth's blood, and comparison of the cycle of human blood to Earth's blood cycle is really not a stretch. Water circulates like human blood courtesy of the hydrologic cycle, Earth's blood pump. In its own way, Earth even has veins, arteries, arterioles, and capillaries. The pump, the hydrologic cycle, precipitates rainfall, snow, sleet, and hail. In turn (gravity being what it is), this liquid falls to Earth, where it either runs off or is taken in by Earth's soil. Once absorbed, water, like human blood in our bodies, circulates within the Earth's body. Earth-absorbed water either evaporates back to the atmosphere or continues to circulate within Earth's body. Sometimes its circulation route leads it through Earth's veins, arteries, arterioles, and capillaries (cracks, seams, crevices, capillaries, etc.) to the water table, where it moves slowly (maybe a foot per year, maybe more)—but move it does. Eventually this groundwater supply will resurface in the oceans, rivers, lakes, and streams and then evaporate, pumped back into the atmosphere. Earth's blood follows other veins, arteries, arterioles, and capillaries. These other vessels are contained within plant life, of course. Once within a plant, Earth's blood continues to circulate, nourish, and eventually transpire back to the atmosphere, where the cycle continues, repeating itself as the water is pumped through Earth's air to Earth's body.

WATER: FACTS AND PROSE

Let's look at some basic concepts or facts about water—facts that we may or may not be familiar with:

- Life as we know it cannot exist without water. A lack of water first enervates, then prostrates, then kills. Most of us are familiar with this fact.
- When literally dying from lack of water, any fear of drowning in the first river, lake, stream, or deep depression containing water that we stumble upon leaves us instantly. Why? Simply, we do not fear drowning when we intend to drink it all—every last drop.
- The leading cause of accidental death in desert regions is drowning.
- In a rainstorm, we know that when lightning streaks like gunfire through clouds dense as wool and volleys of thunder roar like cannonballs tumbling down a stone staircase, shaking air permeated with the smell of ozone, that rain—hard rain, rain that splatters on rock like pellets, knocking berries off junipers, leaves off trees, limbs off oaks—is on its way, driven by wind perhaps capable of knocking down the oak itself.
- Some people choose to eat fiber only. Some eat red meat, some eat fish only, and some eat no meat at all. Some eat all and any form of chocolate, and some eat no form of any candy or sugar product. Some drink coffee, some people drink only tea, and some people drink no beverage containing any form or semblance of caffeine. But everyone on Earth drinks water.
- The history of water is burdened with conflict and myth, belief and knowledge, principles and commerce.
- Water can both quench our thirst and kill us.
- Some view water as a fountain of youth, the mother of health and wealth, a provider of miraculous cures, and a magic weight-reducing elixir.
- Sick water is the single leading source of mortality in the Third World.
- Many feel that water is a public good that should never be barcoded.
- Many feel water is a free commodity that belongs to all (including animals and microbes), but have you counted the number of public drinking fountains lately? Fountains are disappearing quickly, right along with public telephones.

The bottom line is that there is no life without water. We, and every living organism, must have drinking water available in one form or another and from all sources available (see Figure 9.1). When summing up the preceding, who better than Shakespeare?

FIGURE 9.1 Taking advantage of a temporary watering hole. (Illustration by F.R. Spellman and Kathern Welsh.)

> Blow, winds, and crack your cheeks! Rag! Blow!
> You cataracts and hurricanes, spout
> Till you have drench'd our steeples, drown'd the cocks!
> Your sulphurous and thought-executing fires,
> Vaunt-couriers to oak-cleaving thunderbolts,
> Sing my white head! And thou all-shaking thunder
> Smite flat the thick rotundity o' the world!
>
> **—*King Lear*, Act III, Scene II**

These are things we know or can imagine about water, about rain, about the results of water or rain events. We know these things—some through instinct, some through experience. We have knowledge of many facts concerning water, but of course there is much more that we do not know about water that we *should* know. Most important, though, as our Native American friends would tell us if we bothered to ask, is that we need to learn to respect water because water is the essence of life.

Now let's take a look at some other facts about water that some of us might not be familiar with at all but should be:

- If we took all the available supplies of water on Earth from every ocean, every lake, every stream, every river, every brook, every well, every tiny puddle, and from the atmosphere itself, the quantity would all add up to an overwhelming volume of more than 333 million cubic miles, making water the most common substance on Earth.
- Of this 333 million cubic miles of water, about 97% (or about 323 million cubic miles) is salty, residing mostly in the oceans but also in glaciers and ice caps. Note that, although saltwater is more plentiful than freshwater, freshwater is what concerns us in this text. Saltwater fails the most vital test: It does not provide us the vital refreshment we require.

- Freshwater makes up only a small fraction of the Earth's water, about 3%. Only 1% of Earth's water is usable by humans. Freshwater is contained in lakes, rivers, streams, and bays, as well as in the atmosphere and under the ground.
- Most living organisms depend on water for survival. Human bodies are about 60% water. To survive, we need to take in about 2-1/2 liters of water a day; 1-1/2 liters come from the liquids we drink and the rest from the water content in our foods. We put our lives in jeopardy if we lose 12% or more of our body water.

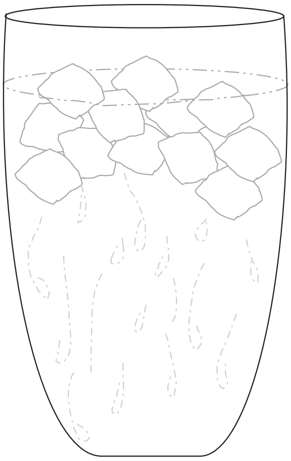

FIGURE 9.2 A glass of drinking water.

WATER: THE BASICS[*]

Unless you are thirsty, in real need of refreshment, when you look at that glass of water shown in Figure 9.2 you might wonder what could be more boring. The curious might want to know more about the physical and chemical properties of water that make it so unique and necessary for living things. Pure water is virtually colorless and has no taste or smell, but the hidden qualities of water make it a most interesting subject. When the uninitiated become initiated to the wonders of water, one of the first surprises is that the total quantity of water on Earth is much the same now as it was more than 3 or 4 billion years ago, when the 330 million cubic miles of it were first formed. Ever since then, the water reservoir has gone round and round, building up, breaking down, cooling, and then warming. Water is very durable but remains difficult to explain, because it has never been isolated in a completely undefiled state. Remember, water is special, strange, and different.

HOW SPECIAL, STRANGE, AND DIFFERENT IS WATER?

Have you ever wondered about the nutritive value of water? Well, the fact is water has no nutritive value. Yet, it is the major ingredient of all living things. Consider yourself, for example. Think of what you need to survive—just to survive. Food? Air? PS4? Netflix? Water? Naturally, water is on your list and is the focus of this text. Water is of major importance to all living things; up to 90% of the body weight of some organisms is water. Up to 60% of the entire human body is water; the brain is composed of 70% water, the lungs are nearly 90% water, and about 83% of our blood is water. It digests our food, transports waste, and controls body temperature. Each day humans must replace 2-1/2 liters of water, some through drinking and the rest from the foods we eat.

There wouldn't be any you, me, or Lucy the dog without the existence of an ample liquid water supply on Earth. The unique qualities and properties of water are what make it so important and basic to life. The cells in our bodies are full of water. The excellent ability of water to dissolve so many substances allows our cells to use valuable nutrients, minerals, and chemicals in biological processes. Water's "stickiness" (from surface tension) plays a part in our body's ability to transport these materials all through ourselves. The carbohydrates and proteins that our bodies use as food are metabolized and transported by water in the bloodstream. No less important is the ability of water to transport waste material out of our bodies.

Chemically, water is hydrogen oxide; however, on more advanced analysis, it turns out to be a mixture of more than 30 possible compounds. In addition, all of its physical constants are abnormal (strange). Water is used to fight forest fires; yet, we spray water on coal in a furnace to make it burn

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[*] Adapted from Spellman, F.R., *The Science of Water*, 3rd ed., CRC Press, Boca Raton, FL, 2015.

DID YOU KNOW?

All of these water molecules attracting each other means they tend to clump together. This is why water drops are, in fact, drops! If it wasn't for some of Earth's forces, such as gravity, a drop of water would be ball shaped—a perfect sphere. Even if it doesn't form a perfect sphere on Earth, we should be happy water is sticky.

better. At a temperature of 2900°C, some substances that contain water cannot be forced to part with it; yet, others that do not contain water will liberate it when even slightly heated. When liquid, water is virtually incompressible; as it freezes, it expands by an eleventh of its volume. For these reasons, and for many others, we can truly say that water is special, strange, and different.

CHARACTERISTICS OF WATER

Up to this point, many things have been said about water; however, it has not been said that water is plain. This is because nowhere in nature is plain water to be found. Here on Earth, with a geologic origin dating back over 3 to 5 billion years, water found in even its purest form is still composed of many constituents. You probably know that the chemical description of water is H_2O—that is, one atom of oxygen bound to two atoms of hydrogen. The hydrogen atoms are attached to one side of the oxygen atom, resulting in a water molecule having a positive charge on the side where the hydrogen atoms are and a negative charge on the other side, where the oxygen atom is. Because opposite electrical charges attract, water molecules tend to attract each other, making water kind of "sticky" in that the hydrogen atoms (positive charge) attract the oxygen side (negative charge) of a different water molecule.

Along with H_2O molecules, hydrogen (H^+), hydroxyl (OH^-), sodium, potassium, and magnesium, other ions and elements are present. Additionally, water contains dissolved compounds, including various carbonates, sulfates, silicates, and chlorides. Rainwater, often assumed to be the equivalent of distilled water, is not immune to contamination as it descends through the atmosphere. The movement of water across land contributes to its contamination, as it takes up dissolved gases such as carbon dioxide and oxygen and a multitude of organic substances and minerals leached from the soil. Don't let that crystal-clear lake or pond fool you. It is not filled with water alone but instead is composed of a complex mix of chemical ingredients far exceeding the brief list presented here; it is a special medium in which highly specialized life can occur.

How important is water to life? To answer this question all we need to do is take a look at the common biological cell. It easily demonstrates the importance of water to life. Living cells are comprised of a number of chemicals and organelles within a liquid substance, the cytoplasm, and the cell's survival may be threatened by changes in the proportion of water in the cytoplasm. This change in the proportion of water in the cytoplasm can occur through desiccation (evaporation), oversupply, or the loss of either nutrients or water to the external environment. A cell that is unable to control and maintain homeostasis (i.e., the correct equilibrium or proportion of water) in its cytoplasm may be doomed—it may not survive.

DID YOU KNOW?

Water is called the "universal solvent" because it dissolves more substances than any other liquid. This means that wherever water goes, either through the ground or through our bodies, it takes along valuable chemicals, minerals, and nutrients.

INFLAMMABLE AIR + VITAL AIR = WATER

In 1783, in England, Henry Cavendish, a brilliant chemist and physicist, was investigating electric current. Specifically, Cavendish was passing electric current through a variety of substances to see what happened. Eventually, he got around to water. He filled a tube with water and sent his current through it. The water vanished. To say that Cavendish was flabbergasted by the results of this experiment would be a mild understatement. "The tube has to have a leak in it," he reasoned. He repeated the experiment again—same result. Then again—same result. The fact is he made the water disappear again and again. Actually, what Cavendish had done was convert the liquid water to its gaseous state—into an invisible gas. When Cavendish analyzed the contents of the tube, he found it contained a mixture of two gases, one of which was *inflammable air* and the other a heavier gas. This heavier gas had only been discovered a few years earlier by his colleague, the English chemist and clergyman Joseph Priestly, who, finding that it kept a mouse alive and supported combustion, called it *vital air*.

JUST TWO H'S AND ONE O

Cavendish had been able to separate the two main constituents that make up water. All that remained was for him to put the ingredients back together again. He accomplished this by mixing a measured volume of inflammable air with different volumes of its vital counterpart and setting fire to both. He found that most mixtures burned well enough, but when the proportions were precisely two to one, there was an explosion and the walls of his test tubes were covered with liquid droplets. He quickly identified these as water. Cavendish made an announcement: Water was not water. Moreover, water is not just an odorless, colorless, and tasteless substance that lay beyond the reach of chemical analysis. Water is not an element in its own right, but a compound of two independent elements, one a supporter of combustion and the other combustible. When united, these two elements become the preeminent quencher of thirst and flames. It is interesting to note that, a few year later, the great French genius Antoine Lavoisier tied the compound neatly together by renaming the ingredients *hydrogen*—"the water producer"—and *oxygen*. In a fitting tribute to his guillotined corpse (he was a victim of the French Revolution), his tombstone carried a simple and telling epitaph, a fitting tribute to the father of a new age in chemistry—*just two H's and one O.*

SOMEWHERE BETWEEN 0° AND 105°

We take water for granted. Every high-school student knows that water is a chemical compound of two simple and abundant elements. And yet scientists continue to argue the merits of rival theories on the structure of water. The fact is we still know little about water; for example, we don't know how water works. Part of the problems lies with the fact that no one has ever seen a water molecule. It is true that we have theoretical diagrams and equations. We also have a disarmingly simple formula—H_2O. The reality, however, is that water is very complex. X-rays, for example, have shown that the atoms in water are intricately laced. It has been said over and over again that water is special, strange, and different. Water is also almost indestructible. Sure, we know that electrolysis can separate water atoms, but we also know that once they get together again they must be heated up to more than 2900°C to separate again.

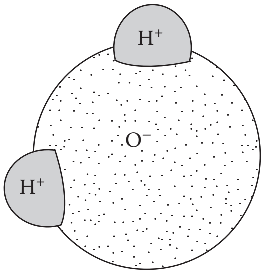

FIGURE 9.3 Molecule of water.

Water is also idiosyncratic. This can be seen in the way in which the two atoms of hydrogen in a water molecule (see Figure 9.3) take up a very precise and strange (different) alignment to each other. Not all angles of 45°, 60°, or 90°—oh, no, not water. Remember, water is different. The two hydrogen atoms always come to rest at an angle of approximately 105° from each other, making all diagrams of their attachment to the larger oxygen atom look like Mickey Mouse ears on a very round head (see Figure 9.3, and remember that everyone's favorite mouse is mostly water, too). This 105° relationship makes water lopsided, peculiar, and eccentric—it breaks all the rules. You're not surprised, are you? One thing is certain, however; this 105° angle is crucial to all life as we know it. Thus, the answer to why water is special, strange, different—and vital—lies somewhere between 0° and 105°.

PHYSICAL PROPERTIES OF WATER

Water has several unique physical properties:

- Water is unique in that it is the only natural substance found in all three states—liquid, solid (ice), and gas (steam) at the temperatures normally found on Earth. Earth's water is constantly interacting, changing, and in motion.
- Water freezes at 32°F and boils at 212°F at sea level, but it boils at 186.4°F at 14,000 feet. In fact, water's freezing and boiling points are the baseline by which temperature is measured: 0° on the Celsius scale is the freezing point of water, and 100° is the boiling point of water. Water is unusual in that the solid form, ice, is less dense than the liquid form, which is why ice floats.
- Water has a high specific heat index. This means that water can absorb a lot of heat before it begins to get hot. This is why water is valuable to industries and in your car's radiator as a coolant. The high specific heat index of water also helps regulate the rate at which air changes temperature, which is why the temperature change between seasons is gradual rather than sudden, especially near the oceans.
- Water has a very high surface tension. In other words, water is sticky and elastic and tends to clump together in drops rather than spread out in a thin film. Surface tension is responsible for capillary action (discussed in detail below), which allows water (and its dissolved substances) to move through the roots of plants and through the thin blood vessels in our bodies.

Here is a quick rundown of some of the properties of water:

- Weight = 8.33 lb/gal or 0.036 lb/in.^3
- Weight at 32°F = 62.416 lb/ft^3
- Weight at 100°F = 61.998 lb/ft^3
- Density at 39.2°F = 1 g/cm^3
- Density at 212°F = 0.95865 g/cm^3
- 1 gallon = 4 quarts = 8 pints = 128 ounces = 231 in.^3
- 1 liter = 0.2642 gallons = 1.0568 quarts = 61.02 in.^3
- 1 million gallons = 3.069 acre-feet = 133,685.64 ft^3

CAPILLARY ACTION

If we were to mention the term *capillary action* to the average man or woman on the street, they might instantly nod their heads and respond that their bodies are full of them—that capillaries are the tiny blood vessels that connect the smallest arteries and the smallest of the veins. This would be true, of course, but in the context of water science capillary action is something different than capillary action in the human body.

Even if you've never heard of capillary action, it is still important in your life. Capillary action is important for moving water (and all of the things that are dissolved in it) around. It is defined as the movement of water within the spaces of a porous material due to the forces of adhesion, cohesion, and surface tension. Surface tension is a measure of the strength of the water's surface film. The attraction between the water molecules creates a strong film that, among other common liquids, is only surpassed by that of mercury. This surface tension permits water to hold up substances heavier and denser than itself. A steel needle carefully placed on the surface of that glass of water will float. Some aquatic insects such as the water strider rely on surface tension to walk on water.

Capillary action occurs because water is sticky, thanks to the forces of cohesion (water molecules like to stay closely together) and adhesion (water molecules are attracted and stick to other substances). So, water tends to stick together, as in a drop, and it sticks to glass, cloth, organic tissues, and soil. Dip a paper towel into a glass of water and the water will climb up the paper towel. In fact, it will keep climbing up the towel until the pull of gravity is too much for it to overcome.

WATER CYCLE

The natural *water cycle* or *hydrological cycle* is the means by which water in all three forms—solid, liquid, and vapor—circulates through the biosphere. The water cycle is all about describing how water moves above, on, and through the Earth. Much more water, however, is in storage for long periods of time than is actually moving through the cycle. The storehouses for the vast majority of all water on Earth are the oceans. It is estimated that of the 333,000,000 cubic miles of the world's water supply, about 321,000,000 cubic miles are stored in oceans. That is about 96.5%. It is also estimated that the oceans supply about 90% of the evaporated water that goes into the water cycle.

Water—lost from the Earth's surface to the atmosphere either by evaporation from the surface of lakes, rivers, and oceans or through the transpiration of plants—forms clouds that condense to deposit moisture on the land and sea. Evaporation from the oceans is the primary mechanism supporting the surface-to-atmosphere portion of the water cycle. Note, however, that a drop of water may travel thousands of miles between the time it evaporates and the time it falls to Earth again as rain, sleet, or snow. The water that collects on land flows to the ocean in streams and rivers or seeps into the Earth, joining groundwater. Even groundwater eventually flows toward the ocean for recycling (see Figure 9.4). The cycle constantly repeats itself, a cycle without end.

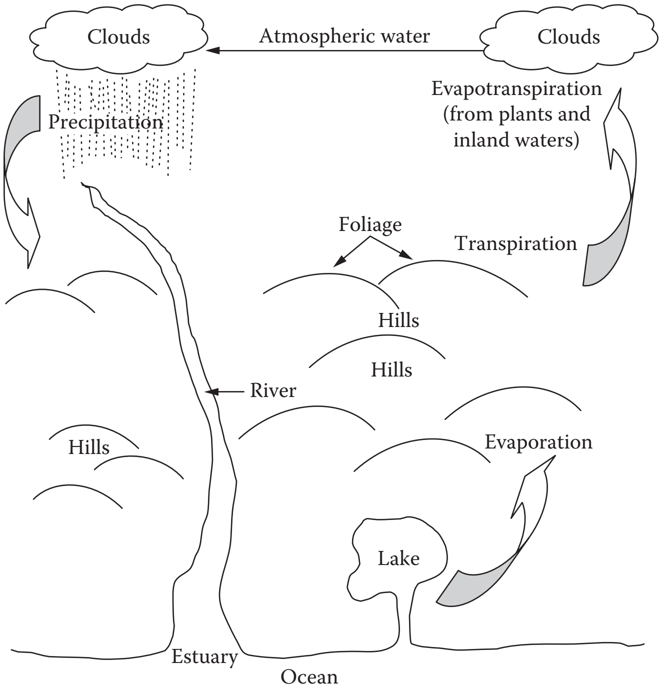

FIGURE 9.4 The water cycle.

DID YOU KNOW?

How long water that falls from the clouds takes to return to the atmosphere varies tremendously. After a short summer shower, most of the rainfall on land can evaporate into the atmosphere in only a matter of minutes. A drop of rain falling on the ocean may take as long as 37,000 years before it returns to the atmosphere, and some water has been in the ground or caught in glaciers for millions of years.

DID YOU KNOW?

Only about 2% of the water absorbed into plant roots is used in photosynthesis. Nearly all of it travels through the plant to the leaves, where transpiration to the atmosphere begins the cycle again.

SPECIFIC WATER MOVEMENTS

After having reviewed the water cycle in very simple terms to provide foundational information, it is important to point out that the actual movement of water on Earth is much more complex. Three different methods of transport are involved in this water movement: *evaporation*, *precipitation*, and *runoff*. Evaporation of water is a major factor in hydrologic systems. Evaporation is a function of temperature, wind velocity, and relative humidity. Evaporation (or vaporization), as the name implies, is the formation of vapor. Dissolved constituents such as salts remain behind when water evaporates. Evaporation of the surface water of oceans provides most of the water vapor. It should be pointed out, however, that water can also vaporize through plants, especially from leaf surfaces. This process is called *evapotranspiration*. Plant transpiration is pretty much an invisible process—because the water is evaporating from the leaf surfaces, you cannot just go out and see the leaves breathe. During a growing season, a leaf will transpire many times more water than its own weight. A large oak tree can transpire 40,000 gallons (151,000 liters) per year (USGS, 2006).

The amount of water that plants transpire varies greatly geographically and over time (USGS, 2006). A number of factors determine transpiration rates:

- *Temperature*—Transpiration rates go up as the temperature goes up, especially during the growing season, when the air is warmer due to stronger sunlight and warmer air masses.
- *Relative humidity*—As the relative humidity of the air surrounding the plant rises, the transpiration rate falls. It is easier for water to evaporate into drier air than into more saturated air.
- *Wind and air movement*—Increased movement of the air around a plant will result in a higher transpiration rate.
- *Soil-moisture availability*—When moisture is lacking, plants can begin to senesce (i.e., age prematurely, which can result in leaf loss) and transpire less water.
- *Type of plant*—Plants transpire water at different rates. Some plants that grow in arid regions, such as cacti and succulents, conserve precious water by transpiring less water than other plants.

DID YOU KNOW?

It may surprise you that ice can also vaporize without melting first; however, this *sublimation* process is slower than vaporization of liquid water.

DID YOU KNOW?

The annual evaporation from ocean and land areas is the same as the annual precipitation.

Evaporation rates are measured with evaporation pans. These evaporation pans provide data that indicate the atmospheric evaporative demand of an area and can be used to estimate (1) the rates of evaporation from ponds, lakes, and reservoirs; and (2) evapotranspiration rates. It is important to note that several factors affect the rate of pan evaporation. These factors include the type of pan, type of pan environment, method of operating the pan, exchange of heat between pan and ground, solar radiation, air temperature, wind, and temperature of the water surface (Jones, 1992).

Precipitation includes all forms in which atmospheric moisture descends to Earth—rain, snow, sleet, and hail. Before precipitation can occur, the water that enters the atmosphere by vaporization must first condense into a liquid (clouds and rain) or solid (snow, sleet, and hail) before it can fall. This vaporization process absorbs energy. This energy is released in the form of heat when the water vapor condenses. A good example of this phenomenon is the heat lost when water evaporates from your skin, making you feel cold.

Runoff is the flow back to the oceans of the precipitation that falls on land. This journey to the oceans is not always unobstructed—flow back may be intercepted by vegetation (from which it later evaporates), a portion is held in depressions, and a portion infiltrates into the ground. A part of the infiltrated water is taken up by plant life and returned to the atmosphere through evapotranspiration, while the remainder either moves through the ground or is held by capillary action. Eventually, water drips, seeps, and flows its way back into the oceans.

Assuming that the water in the oceans and ice caps and glaciers is fairly constant when averaged over a period of years, the water balance of the Earth's surface can be expressed by the relationship water lost = water gained (Turk and Turk, 1988).

Q AND Q FACTORS

Whereas drinking water practitioners must have a clear and complete understanding of the natural water cycle, they also must, as previously mentioned, factor in the two major considerations of quality and quantity—the *Q and Q factors*. They are responsible for (1) providing a *quality* potable water supply—one that is clean, wholesome, and safe to drink; and (2) finding a water supply available in adequate *quantities* to meet the anticipated demand.

To meet the Q and Q requirements of a potential water supply, the drinking water practitioner (whether it be the design engineer, community planner, plant manager, plant administrator, plant engineer, or other responsible person in charge) must determine the answers to a number of questions, including the following:

DID YOU KNOW?

Two central facts important to our discussion of freshwater supplies are that (1) water is very much a local or regional resource, and (2) problems of its shortage or pollution are equally local problems. Human activities affect the quantity of water available at a locale at any time by changing either the total volume that exists there or aspects of quality that restrict or devalue it for a particular use. Thus, the total human impact on water supplies is the sum of the separate human impacts on the various drainage basins and groundwater aquifers. In the global system, the central, critical fact about water is the natural variation in its availability (Meyer, 1997). Simply put—*not all lands are watered equally.*

DID YOU KNOW?

Drinking water practitioners are wise to direct their attention toward considering point 7, simply because public buy-in for any proposed drinking water project that involves new construction or retrofitting, expansion, or upgrade of an existing facility is essential to ensure that necessary financing is forthcoming. In addition to the finances required for any type of waterworks construction project, public and financial support is also required to ensure the safe operation, maintenance, and control of the entire water supply system. The acronym POTW stands for "*publicly* owned treatment works," and the public foots the bills.

1. Does a potable water supply exist nearby with the capacity to be distributed in sufficient quantity and pressure at all times?
2. Will constructing a centralized treatment and distribution system for the entire community be best, or would using individual well supplies be better?
3. If a centralized water treatment facility is required, will the storage capacity at the source as well as at intermediate points of the distribution system maintain the water pressure and flow (quantity) within the conventional limits, particularly during loss-of-pressure events, such as major water-main breaks, rehabilitation of the existing system, or major fires?
4. Can a planned preventive maintenance program or one that is already in place for the distribution system be properly implemented and controlled at the optimum level possible?
5. Is the type of water treatment process selected in compliance with federal and state drinking water standards?
6. When the source and treatment processes are selected, has the optimum hydraulic design of the storage, pumping, and distribution network been determined to ensure that sufficient quantities of water can be delivered to consumers at adequate pressures?
7. Have community leaders and consumers (the general public) received continuing and realistic information about the functioning of the proposed drinking water service?
8. Does planning include steps to ensure elimination of waste, leakages, and unauthorized consumption?
9. Does the water works or proposed water works physical plant include adequate laboratory facilities to ensure proper monitoring of water quality?
10. Are procedures in place to evaluate specific problems, such as lead content in the distribution system and at the consumer's faucet or suspected contamination due to cross-connection potentials?
11. Is a cross-connection control program in place to make sure that the distribution system (in particular) is protected from plumbing errors and illegal connections that may lead to injection of nonpotable water into public or private supplies of drinking water?
12. Are waterworks operators and laboratory personnel properly trained and licensed?
13. Are waterworks managers properly trained and licensed?
14. Are proper operating records and budgetary records kept?

DID YOU KNOW?

The primary concern for drinking water practitioners involved with securing an appropriate water supply, treatment process, and distribution system must be the protection of public health. Contaminants must be eliminated or reduced to a safe level to minimize menacing waterborne diseases (to prevent another Milwaukee *Cryptosporidium* event, for example) and to avoid long-term or chronic injurious health effects.

DID YOU KNOW?

Industrywide operational experience has shown that the cost per cubic foot, cubic meter, liter, or gallon of water delivered to the customer has steadily increased because of manpower, automation, laboratory, and treatment costs. To counter these increasing costs, treatment works must meter consumers, measure the water supply flow, and evaluate the entire system annually.

DID YOU KNOW?

Water from a river or a lake usually requires more extensive treatment than groundwater does to remove bacteria and suspended particles.

DID YOU KNOW?

Some waterworks facilities routinely perform laboratory work; however, water pollution control technologists must ensure that the waterworks laboratory or other laboratory used is approved by the appropriate health authority. Keep in mind that the laboratory selected to test and analyze the waterworks samples must be able to analyze chemical, microbiologic, and radionuclide parameters.

SOURCES OF WATER

Approximately 333 million cubic miles of water cover or reside within the planet, and the oceans contain about 97% of all water on Earth. The other 3% is freshwater: (1) snow and ice on the surface represent about 2.25% of the freshwater, (2) usable groundwater is approximately 0.3%, and (3) surface freshwater accounts for less than 0.5%. In the United States, for example, average rainfall is approximately 2.6 feet (a volume of 5900 km^3). Of this amount, approximately 71% evaporates (about 4200 km^3), and 29% goes to stream flow (about 1700 km^3). Beneficial freshwater uses include manufacturing, food production, domestic and public needs, recreation, hydroelectric power production, and flood control. Stream flow withdrawn annually is about 7.5% (440 km^3). Irrigation and industry use almost half of this amount (3.4%, or 200 km^3/year). Municipalities use only about 0.6% (35 km^3/year) of this amount.

Historically, in the United States, water usage has increased; for example, 180 billion gallons per day of water were used in 1950. By 1975, water use had increased to 420 billion gallons per day. However, water usage today is estimated to be about 355 billion gallons per day, which is actually the lowest level since before 1970. Of that, 306 billion gallons per day are freshwater (Maupin et al., 2014). The primary sources of freshwater include the following:

- Captured and stored rainfall in cisterns and water jars
- Groundwater from springs, artesian wells, and drilled or dug wells
- Surface water from lakes, rivers, and streams
- Desalinized seawater or brackish groundwater
- Reclaimed wastewater

Current federal drinking water regulations define three distinct and separate sources of freshwater: surface water, groundwater, and groundwater under the direct influence of surface water (GUDISW). This last classification is the result of the Surface Water Treatment Rule (SWTR). The conditions that define GUDISW, while specific, are not obvious. This classification is discussed in detail later.

WATERSHEDS

Watershed protection is one of the barriers in the multiple-barrier approach to protecting source water. In fact, watershed protection is the primary barrier, the first line of defense against contamination of drinking water at its source.

Multiple-Barrier Concept of Protection

On August 6, 1996, during the Safe Drinking Water Act Reauthorization signing ceremony, President Bill Clinton stated: “A fundamental promise we must make to our people is that the food they eat and the water they drink are safe.” No rational person could doubt the importance of the promise made in this statement. The Safe Drinking Water Act (SDWA), passed in 1974, amended in 1986, and reauthorized in 1996, gives the U.S. Environmental Protection Agency (USEPA) the authority to set drinking water standards. This document is important for many reasons, but is even more important because it describes how USEPA establishes these standards. Drinking water standards are regulations that USEPA sets to control the level of contaminants in the nation’s drinking water. These standards are part of the Safe Drinking Water Act’s multiple-barrier approach to drinking water protection. The multiple-barrier approach includes the following elements:

1. *Assessing and protecting drinking water sources*, which means doing everything possible to prevent microbes and other contaminants from entering water supplies. Minimizing human and animal activity around our watersheds is one part of this barrier.
2. *Optimizing treatment processes*, which provides a second barrier. This usually means filtering and disinfecting the water. It also means making sure that the people who are responsible for our water are properly trained and certified and knowledgeable about the public health issues involved.
3. *Ensuring the integrity of distribution systems*, which consists of maintaining the quality of water as it moves through the system on its way to the customer’s tap.
4. *Effecting correct cross-connection control procedures*, which is a critical element in the multiple-barrier approach because the greatest potential hazard in water distribution systems is associated with cross-connections to nonpotable waters. Many connections exist between potable and nonpotable systems (e.g., every drain in a hospital constitutes such a connection), but cross-connections are those through which backflow can occur (Angele, 1974).
5. *Continuous monitoring and testing of the water before it reaches the tap* are essential in the multiple-barrier approach. Specific procedures to follow if potable water ever fails to meet quality standards should be included.

With the involvement of the USEPA, local governments, drinking water utilities, and citizens, these multiple barriers ensure that the tapwater in the United States and territories is safe to drink. Simply, the multiple-barrier approach is a holistic one for water management that begins at the source and continues through treatment, disinfection, and distribution. The bottom line on the multiple-barrier approach to protecting the watershed can best be summed up in the following (Spellman, 2003): “Ideally, under the general concept of ‘quality in means quality out,’ a protected watershed ensures that surface runoff and inflow to the source waters occur within a pristine environment.”

Watershed Management[*]

Water regulates population growth, influences world health and living conditions, and determines biodiversity. For thousands of years, people have tried to control the flow and quality of water. Water provided resources and a means of transportation for development in some areas. Even today, the

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[*] Much of the information provided in this section is adapted from Viessman, Jr., W., Water management issues for the nineties, *Water Resource Bulletin*, 26(6), 883–981, 1991.

DID YOU KNOW?

Integrated water management means putting all of the pieces together, including the social, environmental, and technical aspects.

presence or absence of water is critical in determining how we can use land. Yet, despite this long experience in water use and water management, humans often fail to manage water well. Sound water management was pushed aside during rapid, never-ending economic development in many countries. Often, optimism about the applications of technology (e.g., dam building, wastewater treatment, irrigation measures) exceeded concerns for, or even interest in, environmental shortcomings. Pollution was viewed as the inevitable consequence of development, the price that must be paid to achieve economic progress.

Clearly, we have reached the stage of our development when the need for management of water systems is apparent, beneficial, and absolutely imperative. Land use and activities in the watershed directly impact raw water quality. Effective watershed management improves raw water quality, controls treatment costs, and provides additional health safeguards. Depending on goals, watershed management can be simple or complex.

This section discusses the need for watershed management on a multiple-barrier basis and provides a brief overview of the range of techniques and approaches that can be used to investigate the biophysical, social, and economic forces affecting water and its use. Water utility directors are charged with providing potable water in a quantity and quality to meet the public's demand. They are also charged with providing effective management of the entire water supply system, and such management responsibility includes proper management of the relevant watershed.

Remarkable consensus exists among worldwide experts over the current issues confronted by waterworks managers and others. These issues include the following:

1. *Water availability, requirements, and use*
   - Protection of aquatic and wetland habitat
   - Management of extreme events (droughts, floods, etc.)
   - Excessive extractions from surface and groundwater
   - Global climate change
   - Safe drinking water supply
   - Waterborne commerce
2. *Water quality*
   - Coastal and ocean water quality
   - Lake and reservoir protection and restoration
   - Water quality protection, including effective enforcement of legislation
   - Management of point- and nonpoint-source pollution
   - Impacts on land, water, and air relationships
   - Health risks
3. *Water management and institutions*
   - Coordination and consistency
   - Capturing a regional perspective
   - Respective roles of federal and state or provincial agencies
   - Respective roles of projects and programs
   - Economic development philosophy that should guide planning
   - Financing and cost sharing
   - Information and education
   - Appropriate levels of regulation and deregulation

TABLE 9.1
Land Use Directly Impacts Water Quality

Source	Sediment	Nutrients	Viruses, Bacteria	Trihalomethane (THM)	Iron (Fe) and Manganese (Mn)
Urban	✓	✓	✓	✓	✓
Agriculture	✓	✓	✓	✓	✓
Logging	✓	✓	—	✓	✓
Industrial	✓	✓	—	✓	✓
Septic tanks	—	✓	✓	✓	—
Construction	✓	✓	—	—	—

Source: Spellman, F.R., *Handbook for Waterworks Operator Certification*, CRC Press, Boca Raton, FL, 2001.

  - Water rights and permits
  - Infrastructure
  - Population growth

4. *Water resources planning, including the following:*
    - Consideration of the watershed as an integrated system
    - Planning as a foundation for, not a reaction to, decision making
    - Establishment of dynamic planning processes incorporating periodic review and redirection
    - Sustainability of projects beyond construction and early operation
    - A more interactive interface between planners and the public
    - Identification of sources of conflict as an integral part of planning
    - Fairness, equity, and reciprocity among affected parties

WATER QUALITY IMPACTS

Generally, in a typical river system, water quality is impacted by about 60% nonpoint-source pollution, 21% municipal discharge, 18% industrial discharge, and about 1% sewer overflows. Of the nonpoint-source pollution, about 67% is from agriculture, 18% is urban, and 15% comes from other sources. Land use directly impacts water quality. The impact of land use on water quality is clearly evident in Table 9.1. From the point of view of waterworks operators, water quality issues caused by nutrient contamination can be summarized quite simply:

Nutrients + Algae = Taste and odor problems
Nutrients + Algae + Macrophytes + Decay = Trihalomethane (THM) precursors

WATERSHED PROTECTION AND REGULATIONS

The Clean Water Act (CWA) and Safe Drinking Water Act (SDWA) address source water protection. Implementation of regulatory compliance requirements (with guidance provided by the U.S. Department of Health) is left up to state and local health department officials. Water protection regulations in force today provide not only guidance and regulation for watershed protection but also additional options for those tasked with managing drinking water utilities.

The typical drinking water utility that provides safe drinking water to the consumer has two choices in water pollution control: (1) keep it out or (2) take it out. The “keep it out” part pertains to effective watershed management. In contrast, contaminants that have found their way into the water supply must be removed by treatment, which is the "take it out" part. Obviously, utility directors and waterworks managers are concerned with controlling treatment costs. An effective watershed management program can reduce treatment costs by reducing source water contamination. The "take it out" option is much more expensive and time consuming than keeping it out in the first place. Proper watershed management also works to maintain consumer confidence. If the consumer is aware that the water source from the area's watershed is of the highest quality, then, logically, confidence in the quality of the water is high. High-quality water also works directly to reduce public health risks.

WATERSHED PROTECTION PLANS

Watershed protection begins with planning. The watershed protection plan includes several responsibilities:

- Inventory and characterize water sources.
- Identify pollutant sources.
- Assess vulnerability of intake.
- Establish program goals.
- Develop protection strategies.
- Implement program.
- Monitor and evaluate program effectiveness.

RESERVOIR MANAGEMENT PRACTICES

To ensure an adequate and safe supply of drinking water for a municipality, watershed management includes proper reservoir management practices. These practices include proper lake aeration, harvesting, dredging, and use of algicide. Water quality improvements from lake aeration include reduced iron, manganese, phosphorus, ammonia, and sulfide content. Lake aeration also reduces capital and operation costs for water supply treatment. Algicide treatment controls algae, which in turn reduces taste and odor problems. The drawback of using algicides is that they are successful for only a brief period.

POTABLE WATER

Because of huge volume and flow conditions, the quality of natural water cannot be modified significantly within the body of water. Accordingly, humans must augment Nature's natural purification processes with physical, chemical, and biological treatment procedures. Essentially, this quality control approach is directed to the water withdrawn from a source to be treated for a specific use.

WHAT IS POTABLE WATER?

Potable water is water fit for human consumption and domestic use; it is sanitary and normally free of minerals, organic substances, and toxic agents in excess of reasonable amounts for domestic usage in the area served and normally adequate in quantity for the minimum health requirements of the persons served. With regard to a potential potable water supply, the key words, as previously mentioned, are *quality* and *quantity*. Obviously, if we have a water supply that is unfit for human consumption, we have a quality problem. If we do not have an adequate supply of quality water, we have a quantity problem. In this section on potable water, the focus is on surface water and groundwater hydrology and the mechanical components associated with the collection and conveyance of water from its source to the public water supply system for treatment. Well supplies are also discussed.

KEY DEFINITIONS

Annular space—The space between the casing and the wall of the hole.

Aquifer—A porous, water-bearing geologic formation.

Caisson—Large pipe placed in a vertical position.

Cone of depression—As the water in a well is drawn down, the water near the well drains or flows into it. The water will drain farther back from the top of the water table into the well as drawdown increases.

Confined aquifer—An aquifer that is surrounded by formations of less permeable or impermeable material.

Contamination—The introduction into water of toxic materials, bacteria, or other deleterious agents that make the water unfit for its intended use.

Drainage basin—An area from which surface runoff or groundwater recharge is carried into a single drainage system. It is also referred to as a *catchment area*, *watershed*, or *drainage area*.

Drawdown—The distance or difference between the static level and the pumping level. When the drawdown for any particular capacity well and rate pump bowls is determined, the pumping level is known for that capacity. The pump bowls are located below the pumping level so they will always be underwater. When the drawdown is fixed or remains steady, the well is then furnishing the same amount of water as is being pumped.

Groundwater—Subsurface water occupying a saturated geological formation from which wells and springs are fed.

Hydrology—The applied science pertaining to properties, distribution, and behavior or water.

Impermeable—Refers to a material or substance that does not allow water to pass through.

Overland flow—The movement of water on and just under the Earth's surface.

Permeable—Refers to a material or substance that allows water to pass through.

Porosity—The ratio of pore space to total volume; that portion of a cubic foot of soil that is air space and could therefore contain moisture.

Precipitation—The process by which atmospheric moisture is discharged onto the Earth's crust in the form of rain, snow, hail, and sleet.

Pumping level—The level at which the water stands when the pump is operating.

Radius of influence—The distance from the well to the edge of the cone of depression; the radius of a circle around the well from which water flows into the well.

Raw water—Untreated water to be used after treatment for drinking water.

Recharge area—An area from which precipitation flows into underground water sources.

Specific yield—The geologist's measure of the capacity of a given well and the production of a given water-bearing formation; it is expressed as gallons per minute per foot of drawdown.

Spring—A surface feature where, without the help of humans, water issues from rock or soil onto the land or into a body of water, with the place of issuance being relatively restricted in size.

Static level—The height to which the water will rise in the well when the pump is not operating.

Surface runoff—The amount of rainfall that passes over the surface of the Earth.

Surface water—The water on the Earth's surface as distinguished from water underground (groundwater).

Unconfined aquifer—An aquifer that sits on an impervious layer but is open on the top to local infiltration. The recharge for an unconfined aquifer is local. It is also called a *water table aquifer.*

Water rights—The rights, acquired under the law, to use the water accruing in surface or groundwater for a specified purpose in a given manner and usually within the limits of a given time period.

Water table—The average depth or elevation of the groundwater over a selected area; the upper surface of the zone of saturation, except where that surface is formed by an impermeable body.
Watershed—A drainage basin from which surface water is obtained.

SURFACE WATER AND GROUNDWATER SOURCES

What are our sources for potable water? Our public water is provided by a groundwater or surface water source, because these two sources are, indeed, the primary sources of most water supplies. From the earlier discussion of the hydrological or water cycle, we know that from whichever of the two sources we obtain our drinking water, the source is constantly being replenished (we hope) with a supply of freshwater. This water cycle phenomenon was best summed up by Heraclitus of Ephesus, who said, "You could not step twice into the same rivers; for other waters are ever flowing on to you." Following is a discussion about the primary duties of the drinking water practitioner (and humankind in general)—to find and secure a source of potable water for human use.

LOCATION! LOCATION! LOCATION!

In the real estate business, location is everything. The same can be said about sources of water. In fact, the presence of water defines "location" for communities. Although communities differ widely in character and size, all have the common concerns of finding water for industrial, commercial, and residential use. Freshwater sources that can provide stable and plentiful supplies for a community do not always occur where we wish. Simply put, on land, the availability of a regular supply of potable water is the most important factor affecting the presence—or absence—of many life forms. A map of the world immediately shows us that surface waters are not uniformly distributed over the surface of the Earth. The United States has rivers, lakes, and streams on only about 4% of its surface. The heaviest populations of life forms, including humans, are found in regions of the United States (and the rest of the world) where potable water is readily available, because lands barren of water simply cannot support large populations. One thing is certain: If a local supply of potable water is not readily available, the locality affected will seek a source. This is readily apparent (absolutely crystal clear), for example, when one studies the history of water procurement, such as from the Owens Valley region for communities located within the Los Angeles Basin. The history of the procurement of water from Owens Valley and its transportation of via aqueduct to Los Angeles was well documented by Mark Reisner in his seminal work, *Cadillac Desert*, in which he described the diversion of water from Owens Valley as having been accomplished by "chicanery, subterfuge … and a strategy of lies."

HOW READILY AVAILABLE IS POTABLE WATER?

Approximately 333 million cubic miles of water comprise Earth's entire water supply. Although this supply of water provides us indirectly with freshwater through evaporation from the oceans, only about 3% of this massive amount of water is actually fresh, and most of this minute percentage of

DID YOU KNOW?

Only 3.8 inches of rain falls on Las Vegas in an average year. That is comparable to Riyadh in Saudi Arabia or Villa Cisneros in the Western Sahara. It takes more water by a factor of two or three times to live in the southwestern United States than anywhere else in the country, mostly because of grass, air-conditioning, malls, swimming pools, and golf courses. A householder in Las Vegas uses three times as much water as an average consumer in an eastern state (Ward, 2002).

TABLE 9.2
World Water Distribution

Location	Percent (%) of Total
Land areas (total)	2.8
Freshwater lakes	0.009
Saline lakes and inland seas	0.008
Rivers (average instantaneous volume)	0.0001
Soil moisture	0.005
Groundwater (above depth of 4000 m)	0.61
Ice caps and glaciers	2.14
Atmosphere (water vapor)	0.001
Oceans	97.2
Total all locations (rounded)	100

Source: USGS, *Water Science in Schools*, U.S. Geological Survey, Washington, D.C., 2006.

freshwater is locked up in polar ice caps and glaciers. The rest is held in lakes or flows through soil and in river and stream systems. Less than 1% of Earth's freshwater is available for human consumption (see Table 9.2 for the distribution of Earth's water supply). We see from Table 9.2 that the major sources of drinking water are surface water, groundwater, and GUDISW (i.e., springs or shallow wells).

SURFACE WATER AS A SOURCE OF POTABLE WATER

Again, surface water is water that is open to the atmosphere and results from overland flow (i.e., runoff that has not yet reached a definite stream channel). Put a different way, surface water is the result of surface runoff. For the most part, however, surface water (as used in the context of this text) refers to water flowing in streams and rivers, as well as water stored in natural or artificial lakes, manmade impoundments such as lakes made by damming a stream or river, springs that are affected by a change in level or quantity, shallow wells that are affected by precipitation, wells drilled next to or in a stream or river, rain catchments, and muskeg and tundra ponds. Specific sources of surface water include the following:

- Rivers
- Streams
- Lakes
- Impoundments (manmade lakes made by damming a river or stream)
- Very shallow wells that receive input via precipitation
- Springs affected by precipitation (flow or quantity directly dependent upon precipitation)
- Rain catchments (drainage basins)
- Tundra ponds or muskegs (peat bogs)

DID YOU KNOW?

Surface waters are not uniformly distributed over the Earth's surface. In the United States, for example, only about 4% of the landmass is covered by rivers, lakes, and streams. The volumes of these freshwater sources depend on geographic, landscape, and temporal variations and on the impact of human activities.

DID YOU KNOW?

Many people probably have an overly simplified idea that precipitation falls on the land, flows overland (runoff), and runs into rivers, which then empty into the oceans. That is an oversimplification because rivers also gain and lose water to the ground. Still, it is true that much of the water in rivers comes directly from runoff from the land surface (i.e., surface runoff).

Surface water has advantages as a source of potable water. Surface water sources are usually easy to locate, unlike groundwater. Finding surface water does not take a geologist or hydrologist, and normally it is not tainted with minerals precipitated from the Earth's strata. Ease of discovery aside, surface water also presents some disadvantages in that surface water sources are easily contaminated (polluted) with microorganisms that can cause waterborne diseases (anyone who has suffered from "hiker's disease" or "hiker's diarrhea" can attest to this) and chemicals that enter from surrounding runoff and upstream discharges. Water rights can also present problems.

Most surface water is the result of surface runoff. The amount and flow rate of this surface water are highly variable due to human interferences (influences) and natural conditions. In some cases, surface water quickly runs off land surfaces. From a water resources standpoint, this is generally undesirable, because quick runoff does not provide enough time for the water to infiltrate the ground and recharge groundwater aquifers. Surface water that quickly runs off land also causes erosion and flooding problems. Probably the only good thing that can be said about surface water that runs off quickly is that it usually does not have enough contact time to increase its mineral content. Slow surface water runoff has all the opposite effects. Drainage basins collect surface water and direct it on its gravitationally influenced path to the ocean. The drainage basin is normally characterized as an area measured in square miles, acres, or sections. Obviously, if a community is drawing water from a surface water source, the size of its drainage basin is an important consideration. Surface water runoff, like the flow of electricity, flows or follows the path of least resistance. Surface water within the drainage basin normally flows toward one primary watercourse (e.g., river, stream, brook, creek), unless some manmade distribution system (canal or pipeline) diverts the flow.

Surface water runoff depends on several factors, including the following:

- *Rainfall duration*—Even a light, gentle rain, if it lasts long enough, can, with time, saturate soil and allow runoff to take place.
- *Rainfall intensity*—With increased rainfall intensity, the surface of the soil can quickly become saturated. This saturated soil can hold no more water; as more rain falls and water builds up on the surface, surface runoff occurs.
- *Soil moisture*—The amount of existing moisture in the soil has a definite impact on surface runoff. Soil already wet or saturated from a previous rain causes surface runoff to occur sooner than if the soil were dry. Surface runoff from frozen soil can be up to 100% of snow melt or rain runoff because frozen ground is basically impervious.
- *Soil composition*—The composition of the surface soil directly affects the amount of runoff; for example, hard rock surfaces, obviously, result in 100% runoff. Clay soils have very small void spaces that swell when wet; the void spaces close and do not allow infiltration. Coarse sand possesses large void spaces that allow water to flow through easily, which produces the opposite effect, even in a torrential downpour.
- *Vegetation cover*—Groundcover limits runoff. Roots of vegetation and pine needles, pine cones, leaves, and branches create a porous layer (a sheet of decaying natural organic substances) above the soil. This porous, organic sheet readily allows water into the soil. Vegetation and organic waste also act as cover to protect the soil from hard, driving rains,

which can compact bare soils, close off void spaces, and increase runoff. Vegetation and groundcover work to maintain the infiltration and water-holding capacity of the soil and also work to reduce soil moisture evaporation.

- *Ground slope*—When rain falls on steeply sloping ground, 80% or more may become surface runoff. Gravity moves the water down the surface more quickly than it can infiltrate the surface. Water flow off flat land is usually slow enough to provide opportunity for a higher percentage of the rainwater to infiltrate the ground.
- *Human influences*—Various human activities have a definite impact on surface water runoff. Most human activities tend to increase the rate of water flow; for example, canals and ditches are usually constructed to provide steady flow, and agricultural activities generally remove groundcover that would work to retard the runoff rate. At the opposite extreme, dams are generally built to retard the flow of runoff.

Paved streets, tarmac, paved parking lots, and buildings are impervious to water infiltration, greatly increasing the amount of stormwater runoff from precipitation events. These manmade surfaces (which work to hasten the flow of surface water) often cause flooding to occur, sometimes with devastating consequences. In badly planned areas, even relatively light precipitation can cause local flooding. Impervious surfaces not only present flooding problems but also do not allow water to percolate into the soil to recharge groundwater supplies—a potentially devastating blow to a location's water supply.

ADVANTAGES AND DISADVANTAGES OF SURFACE WATER

The biggest advantage of using a surface water supply as a water source is that these sources are readily located; finding surface water sources does not demand sophisticated training or equipment. Many surface water sources have been used for decades or even centuries, and considerable data are available on the quantity and quality of the existing water supply. Surface water is also generally softer (not mineral laden), which makes its treatment much simpler.

The most significant disadvantage of using surface water as a water source is pollution. Surface waters are easily contaminated with microorganisms that cause waterborne diseases and with chemicals that enter the river or stream from surface runoff and upstream discharges. Another problem with many surface water sources is turbidity, which fluctuates with the amount of precipitation. Increases in turbidity increase treatment costs and operator time. Surface water temperatures can be a problem, because they fluctuate with ambient temperature, making it difficult to maintain consistent water quality at a waterworks plant. The process of drawing water from a surface water supply might also present problems; intake structures may clog or become damaged from winter ice, or the source may be so shallow that it completely freezes in the winter. Water rights cause problems, too—removing surface water from a stream, lake, or spring requires a legal right. The lingering, seemingly unanswerable question is who owns the water? Using surface water as a source means that the purveyor is obligated to meet the requirements of the Surface Water Treatment Rule and the Interim Enhanced Surface Water Treatment Rule (IESWTR). Note that the IESWTR applies only to large public water systems (PWSs) that serve more than 10,000 people. The IESWTR tightened controls on disinfection byproducts (DBPs) and turbidity and regulates *Cryptosporidium*.

DID YOU KNOW?

The area that directly influences the quantity and quality of surface water is called the *drainage basin* or *watershed*.

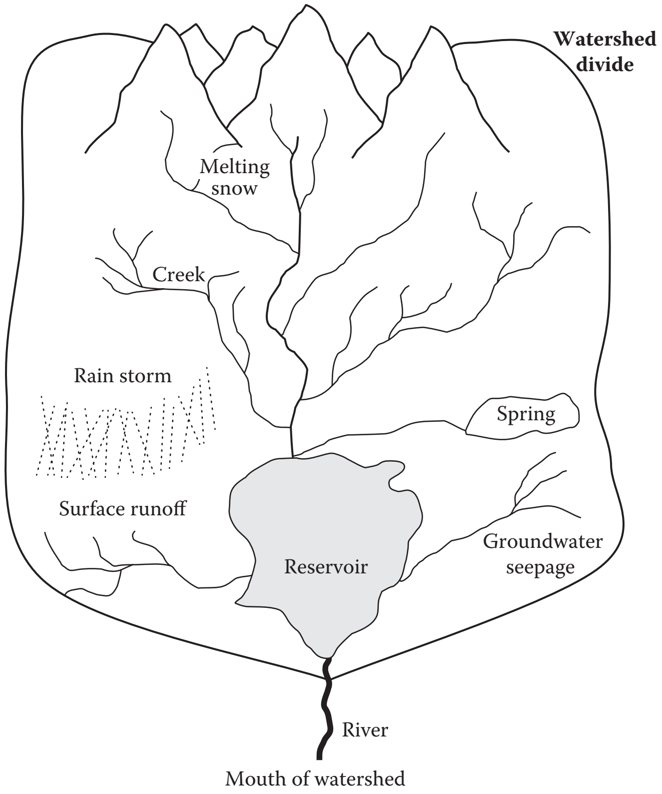

FIGURE 9.5 Watershed.

SURFACE WATER HYDROLOGY

To properly manage and operate water systems, it is important to have a basic understanding of the movement of water and the factors that affect water quality and quantity—in other words, *hydrology*. A discipline of applied science, hydrology includes several components, such as the physical configuration of the watershed, the geology, soils, vegetation, nutrients, energy, wildlife, and the water itself. The area from which surface water flows is called a *drainage basin* or *catchment area*. With a surface water source, this drainage basin is most often called, in nontechnical terms, a *watershed*. When dealing with groundwater, we call this area a *recharge area*.

When we trace on a map the course of a major river from its meager beginnings along its seaward path, it is readily apparent that its flow becomes larger and larger. Every tributary adds to its size, and between tributaries the river grows gradually due to overland flow entering it directly (see Figure 9.5). Not only does the river grow, but its entire watershed or drainage basin, basically the land it drains into, also grows in the sense that it embraces an ever larger area. The area of the watershed is commonly measured in square miles, sections, or acres. When taking water from a surface water source, knowing the size of the watershed is desirable.

RAW WATER STORAGE

Raw water (i.e., water that has not been treated) is stored for single or multiple uses, such as navigation, flood control, hydroelectric power, agriculture, water supply, pollution abatement, recreation, and flow augmentation. The primary reason for storing water is to meet peak demands or to store water to meet demands when the flow of the source is below the demand. Raw water is stored in natural storage sites (such as lakes, muskeg, and tundra ponds) or in manmade storage areas such as dams. Manmade dams are either masonry or embankment dams. If embankment dams are used, they are typically constructed of local materials with an impermeable clay core.

SURFACE WATER QUALITY

Surface waters should be of adequate quality to support aquatic life and be aesthetically pleasing; in addition, waters used as sources of supply should be treatable by conventional processes to provide potable supplies that can meet drinking water standards. Many lakes, reservoirs, and rivers are maintained at a quality suitable for swimming, water skiing, and boating, as well as for drinking water.

Whether the surface water supply is taken from a river, stream, lake, spring, impoundment, reservoir, or dam, surface water quality varies widely, especially in rivers, streams, and small lakes. These water bodies are susceptible not only to waste discharge contamination but also to *flash contamination* (which occurs almost immediately and not necessarily over time). Lakes are subject to summer/winter stratification (turnover) and to algal blooms. Pollution sources include runoff (agricultural, residential, and urban), spills, municipal and industrial wastewater discharges, and recreational users, as well as natural occurrences. Surface water supplies are difficult to protect from contamination and must always be treated.

Public water systems must comply with applicable federal and state regulations and must supply the quantity and quality of water required, which includes providing proper treatment and hiring competent and qualified waterworks operators. The USEPA's regulatory requirements state that all public water systems using any surface or groundwater under the direct influence of surface water must disinfect and may be required by the state to filter it, unless the water source meets certain requirements and site-specific conditions. Treatment technique requirements are established in lieu of maximum contaminant levels (MCLs) for *Giardia*, viruses, heterotrophic plate count bacteria, *Legionella*, and turbidity. Treatment must achieve at least 99.9% (3-log) removal or inactivation of *Giardia lamblia* cysts and 99.9% removal or inactivation of viruses.

GROUNDWATER

Earth possesses an unseen ocean, a hidden resource. This ocean, unlike the surface oceans that cover most of the globe, is freshwater, the groundwater that lies contained in aquifers beneath Earth's crust. This gigantic water source forms a reservoir that feeds all the natural fountains and springs of Earth. But, how does water travel into the aquifers that lie under the Earth's surface?

Groundwater sources are replenished from a percentage of the average approximately 3 feet of water that falls to Earth each year on every square foot of land. Water falling to Earth as precipitation follows three courses. Some runs off directly to rivers and streams (roughly 6 inches of that 3-foot yearly total), eventually working its way back to the sea. Evaporation and transpiration through vegetation take up about 2 feet. The remaining 6 inches of water seep into the ground, entering and filling every interstice, each hollow and cavity. Gravity pulls water toward the center of the Earth. That means that water on the surface will try to seep into the ground below it. Although groundwater accounts for only one-sixth of the total 1,680,000 miles of water, if we could spread out this water over the land it would blanket it to a depth of 1000 feet.

Part of the precipitation that falls on land infiltrates the land surface, percolates downward through the soil under the force of gravity, and becomes groundwater. Groundwater, like surface water, is extremely important to the hydrological cycle and to our water supplies. Almost half of the people in the United States drink public water obtained from groundwater supplies. Overall, more water exists as groundwater than surface water in the United States, including the water in the Great Lakes, but sometimes pumping it to the surface is not economical, and in recent years pollution of groundwater supplies from improper disposal has become a significant problem.

AQUIFERS

We find groundwater in saturated layers called *aquifers* under the surface of the Earth. Because aquifers do not lend themselves to brief, simple, and neat definitions, a flexible hierarchy of terms is used to describe and discuss them. The terms that are used for water-yielding rocks from largest (regional) to smallest (local) are *aquifer system*, *aquifer*, and *zone* (Lohman et al., 1972; Miller, 1986; Poland et al., 1972). Be advised that parallelism between the hierarchy of terms for water-yielding rocks and rock-stratigraphic terms—aquifer system (group), aquifer (formation), and zone (member)—should be avoided because water-yielding rocks can cross the boundaries of geologic units or constitute only a part of a geological unit. Best usage may be determined by the scale of the investigation, analysis, or research effort. For example, at the local scale an aquifer system could be determined totally within a single formation, and at the regional scale a formation or group could be totally within and only a part of a single aquifer or an aquifer system. The point is that aquifer nomenclature must remain flexible to meet a variety of hydrogeologic scales and settings (USGS, 1986). Although complete agreement on the exact meaning of the terms *aquifer*, *aquifer system*, *zone*, and *confining unit* has not been achieved, a brief discussion of these terms is provided here to give readers a common reference base.

It has been said that the term *aquifer* probably has more shades of meaning than any other term used in hydrology (Freeze and Cherry, 1979). It can mean different things to different people and different things to the same person at different times (USGS, 1986). Meinzer (1923) defined an aquifer as:

> A rock formation or stratum that will yield water in sufficient quantity to be of consequence as a source of supply is called an "aquifer," or simply a "water-bearing formation," "water-bearing stratum," or "water-bearer." … It is water bearing not in the sense of holding water but in the sense of carrying or conveying water.

Later, Meinzer's definition of an aquifer was refined somewhat (Lohman et al., 1972):

> A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Both of these definitions imply that the aquifer is bounded by or is included within the formations (or strata), but the concept of the aquifer extending across formational boundaries is not indicated explicitly. However, since the late 1970s, studies of regional aquifers that may cover hundreds of thousands of square miles have been made. Results from several of the studies have shown that regional aquifers may include numerous formations and rock types and that the aquifers may cut across formational and lithologic boundaries so that no one formation is completely representative of the aquifer. With regard to regional scope, the shape and the boundaries of permeable rocks that form the aquifer have greater importance to understanding the flow system than do the individual formation boundaries. Due to advances in the hydrogeology discipline, less emphasis is being placed on the term *formation* and more on *permeable rocks*. An example of this refined definition is "a body of rock that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs (Bates and Jackson, 1980).

Professional hydrogeologists have learned the fine points of these definitions but have made it their goal to map and describe an aquifer by delineating permeable rocks within. In like manner, detailed knowledge of the stratigraphic units and post-depositional process, such as solution, cementation, folding, and faulting, are essential to determining where the boundaries of the aquifer are located and understanding the flow system. Also, hydraulic properties of the aquifer, such as hydraulic conductivity and storage coefficient, usually are not determined directly but are estimated by indirect means, including the following:

- Aquifer tests
- Analyses of drill cuttings and cores
- Borehole geophysical logging
- Surface geophysical surveys

In many situations, hydrologic estimates and extrapolations can be made on the basis of rock type alone without any determination of hydrologic properties; for example, a widespread, thick clay separating two sand units tentatively could be designated as a confining unit on the basis of geologists' logs and borehole geophysical logs alone without any hydrologic data (USGS, 1986).

Aquifer Systems

Aquifer system has been defined as (Poland et al., 1972):

> A heterogeneous body of intercalated permeable and poorly permeable material that functions regionally as a water-yielding hydraulic unit; it comprises two or more permeable beds (aquifers) separated at least locally by aquitards (confined units) that impede groundwater movement but do not greatly affect the regional hydraulic continuity of the system.

The definition could be more general if the term *aquifers* was used in place of *permeable beds*. "Bed" implies a single stratigraphic unit, whereas the individual aquifer could include or cross many "beds." Also, *confining unit* could be used instead of *aquitard* (a term that implies a sealed, leakproof unit) because the definition of a confining unit is broad enough to include varying degrees of leakiness (USGS, 1986).

Zone

When it is convenient or necessary to delineate a particular hydrologic characteristic to subdivide an aquifer the term *zone* is often used. A good example is the Fernandina permeable zone, which is a high-permeability subunit of the Lower Floridan aquifer (Miller, 1986). The zone consists of vuggy (i.e., a cavity in rock), locally cavernous limestone and is traceable for as far as 100 miles in coastal Georgia and Florida. The permeability of the zone greatly exceeds that of most of the lower Floridan aquifer (USGS, 1986).

Confining Unit

Confining unit is a term that supplants the terms *aquiclude*, *aquitard*, and *aquifuge* (Lohman et al., 1972). It is defined as a body of impermeable material stratigraphically adjacent to one or more aquifers. In nature, however, its hydraulic conductivity may range from nearly zero to some value distinctly lower than that of the aquifer. Its conductivity relative to that of the aquifer it confines should be specified or indicated by a suitable modifier such as slightly permeable or moderately permeable.

Although hydrogeologists continue to use the descriptive term of *confining bed*, they prefer to use the term *confining unit*, which is more general and appropriate especially where more than a single bed makes up the confining unit. In addition, bed is not correct usage for a thick sequence of stratigraphic units that could be of member or formation rank. Bed is particularly inappropriate when used for intrusive igneous rocks beneath an aquifer (USGS, 1986).

It is important to point out that confining units do not entirely confine the water within them; they leak. Under natural conditions, they contribute significant amounts of water to the aquifers they confine, and even larger quantities of water when heads are lowered in the aquifer by pumping. In locations where withdrawals from aquifers have caused large declines in head, considerable amounts of water may be derived from water stored in the confining unit—the water will leak out. In their definitions related to studies of the mechanics of aquifer systems and land subsidence due to fluid withdrawal, Poland et al. (1972) retained the terms *aquiclude* and *aquitard*. An aquiclude was

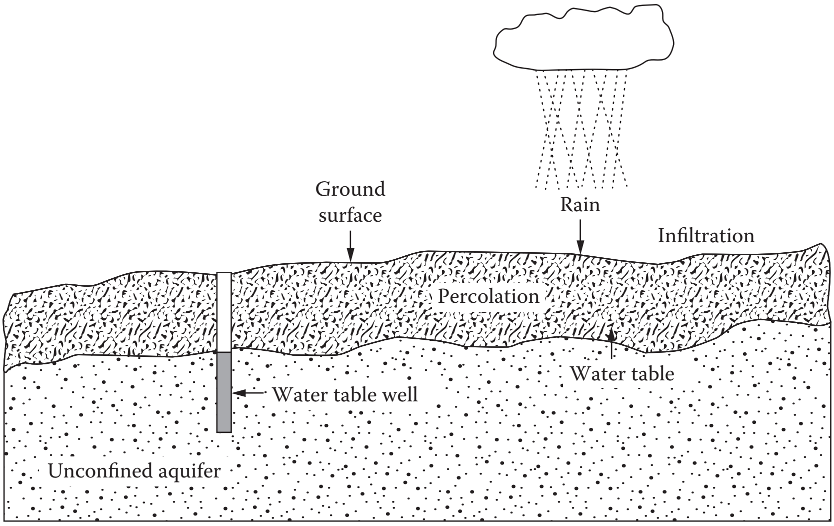

FIGURE 9.6 Unconfined aquifer. (From Spellman, F.R., *Stream Ecology and Self-Purification*, CRC Press, Boca Raton, FL, 1996. With permission.)

defined as a body of saturated but relatively impermeable material that is characterized by very low values of *leakance* (the ratio of vertical hydraulic conductivity to thickness) and transmits negligible inter-aquifer flow. An aquitard is a saturated poorly permeable unit that has values of leakance that range from relatively low to high. Where an aquitard is sufficiently thick, it may form an important groundwater storage unit (USGS, 1986).

Types of Aquifers

Three types of aquifers exist: unconfined, confined, and springs. Aquifers are made up of a combination of solid material such as rock and gravel and open spaces called *pores*. Regardless of the type of aquifer, the groundwater in the aquifer is in a constant state of motion. This motion is caused by gravity or by pumping.

The actual amount of water in an aquifer depends on the amount of space available between the various grains of material that make up the aquifer. The amount of space available is called *porosity*. The ease of movement through an aquifer is dependent on how well the pores are connected; for example, clay can hold a lot of water and has high porosity, but the pores are not connected, so water moves through the clay with difficulty. The ability of an aquifer to allow water to infiltrate is referred to as its *permeability*.

The *zone of saturation* lies just under the Earth's surface in an unconfined aquifer (see Figure 9.6). The top of the zone of saturation is the *water table*, and this type of aquifer is often called a *water table aquifer*. An unconfined aquifer is dependent on local precipitation for recharge. Unconfined aquifers are a primary source of shallow well water. Because these wells are shallow they are not desirable as a public drinking water source. They are subject to local contamination from hazardous and toxic materials; fuel, oil, septic tanks, and agricultural runoff contribute to increased levels of nitrates and microorganisms. These wells may be classified as GUDISW and therefore require treatment for control of microorganisms.

A confined aquifer is sandwiched between two impermeable layers that block the flow of water. The water in a confined aquifer is under hydrostatic pressure, and it does not have a free water table (see Figure 9.7). Confined aquifers are referred to as *artesian aquifers*. Wells drilled into artesian aquifers are *artesian wells* and commonly yield large quantities of high-quality water. An artesian well is any well where the water in the well casing would rise above the saturated strata. Wells in

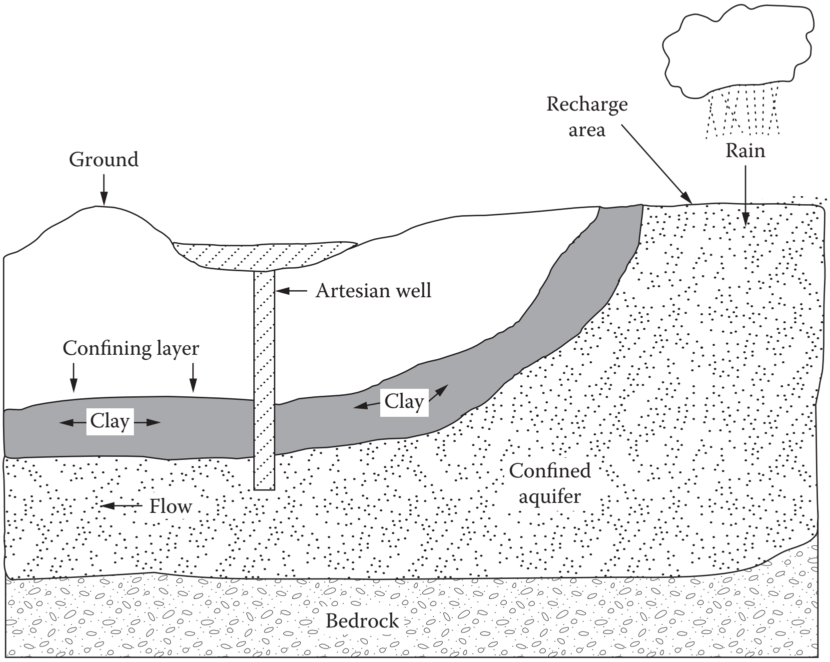

FIGURE 9.7 Confined aquifer. (From Spellman, F.R., *Stream Ecology and Self-Purification*, CRC Press, Boca Raton, FL, 1996. With permission.)

confined aquifers are deep wells and are not generally affected by local hydrological events. A confined aquifer is recharged by rain or snow in the mountains where the aquifer lies close to the surface of the Earth. Because the recharge area is some distance from areas of possible contamination, the possibility of contamination is usually very low; however, once contaminated, confined aquifers may take centuries to recover.

Groundwater naturally exits the Earth's crust in areas called springs. The water in a spring can originate from a water table aquifer or from a confined aquifer. Only water from a confined spring is considered desirable for a public water system.

GROUNDWATER QUALITY

Generally, groundwater possesses high chemical, bacteriological, and physical quality. When pumped from an aquifer composed of a mixture of sand and gravel, groundwater is often used without filtration if it is not directly influenced by surface water. It can also be used without disinfection if it has a low coliform count; however, groundwater can become contaminated. Groundwater can become contaminated when septic systems fail, saltwater intrudes, improper disposal of wastes occurs, improperly stockpiled chemicals leach, underground storage tanks leak, hazardous materials spill, fertilizers and pesticides are misplaced, and mines are improperly abandoned.

To understand how an underground aquifer becomes contaminated, we must understand what occurs when pumping is taking place within the well. When groundwater is removed from its underground source (i.e., from the water-bearing stratum) via a well, water flows toward the center of the well. In a water table aquifer, this movement causes the water table to sag toward the well. This sag is the *cone of depression*. The shape and size of the cone depend on the relationship between the pumping rate and the rate at which water can move toward the well. If the rate is high, the cone is shallow, and its growth stabilizes. The area that is included in the cone of depression is the *cone of influence*, and any contamination in this zone will be drawn into the well.

DID YOU KNOW?

Groundwater quality is influenced by the quality of its source. Changes in source waters or degraded quality of source supplies may seriously impair the quality of the groundwater supply.

GROUNDWATER UNDER THE DIRECT INFLUENCE OF SURFACE WATER

Groundwater under the direct influence of surface water (GUDISW) is not classified as a groundwater supply. A supply designated as GUDISW must be treated under the state's surface water rules rather than the groundwater rules. The Surface Water Treatment Rule of the Safe Drinking Water Act requires each site to determine which groundwater supplies are influenced by surface water (e.g., when surface water can infiltrate a groundwater supply and could contaminate it with *Giardia*, viruses, turbidity, and organic material from the surface water source). To determine whether a groundwater supply is under the direct influence of surface water, the USEPA has developed procedures that focus on significant and relatively rapid shifts in water quality characteristics, including turbidity, temperature, and pH. When these shifts can be closely correlated with rainfall or other surface water conditions, or when certain indicator organisms associated with surface water are found, the source is said to be under the direct influence of surface water.

PERPETUAL MOTION

Almost all groundwater is in constant motion through the pores and crevices of the aquifer in which it occurs. The water table is rarely level; it generally follows the shape of the ground surface. Groundwater flows in the downhill direction of the sloping water table. The water table sometimes intersects low points of the ground, where it seeps out into springs, lakes, or streams. Usual groundwater sources include wells and springs that are not influenced by surface water or local hydrologic events.

As a potable water source, groundwater has several advantages over surface water. Unlike surface water, groundwater is not easily contaminated. Groundwater sources are usually lower in bacteriological contamination than surface waters. Groundwater quality and quantity usually remain stable throughout the year. In the United States, groundwater is available in most locations. As a potable water source, groundwater does present some disadvantages compared to surface water sources. Operating costs are usually higher, because groundwater supplies must be pumped to the surface. Any contamination is often hidden from view. Removing any contaminants is very difficult. Groundwater often has high mineral levels and thus an increased level of hardness because it is in contact longer with minerals. Near coastal areas, groundwater sources may be subject to saltwater intrusion.

It is important to point out that our freshwater supplies are constantly renewed through the hydrological cycle, but the balance between the normal ratio of freshwater to saltwater is not subject to our ability to change. As our population grows and we move into lands without ready freshwater supplies, we place ecological strains upon those areas and on their ability to support life. Communities that build in areas without an adequate local water supply are at risk in the event of an emergency. Proper attention to our surface and groundwater sources, including remediation, pollution control, and water reclamation and reuse, can help to ease the strain, but technology cannot fully replace adequate local freshwater supplies, whether from surface or groundwater sources.

WELL SYSTEMS

The most common method for withdrawing groundwater is to penetrate the aquifer with a vertical well, then pump the water up to the surface. In the past, when someone wanted a well, they simply dug (or hired someone to dig) and hoped (gambled) that they would find water in a quantity suitable for their needs. Today, in most locations in the United States, for example, developing a well supply usually involves a more complicated step-by-step process. Local, state, and federal requirements specify the actual requirements for development of a well supply in the United States. The standard sequence for developing a well supply is generally a seven-step process:

1. *Application*—Depending on location, standard procedure is filling out and submitting an application (to the applicable authorities) to develop a well supply.
2. *Well site approval*—Once the application has been made, local authorities check various local geological and other records to ensure that the siting of the proposed well coincides with mandated guidelines for approval.
3. *Well drilling*—The well is drilled.
4. *Preliminary engineering report*—After the well is drilled and the results documented, a preliminary engineering report is made on the suitability of the site to serve as a water source. This procedure involves performing a pump test to determine if the well can supply the required amount of water. The well is generally pumped for at least 6 hours at a rate equal to or greater than the desired yield. A stabilized drawdown should be obtained at that rate, and the original static level should be recovered within 24 hours after pumping stops. During this test period, samples are taken and tested for bacteriological and chemical quality.
5. *Submission of documents for review and approval*—The application and test results are submitted to an authorized reviewing authority that determines if the well site meets approval criteria.
6. *Construction permit*—If the site is approved, a construction permit is issued.
7. *Operation permit*—When the well is ready for use, an operation permit is issued.

WATER USE

In the United States, rainfall averages approximately 4250 × 10^9 gal/day. About two-thirds of this rainfall returns to the atmosphere through evaporation directly from the surface of rivers, streams, and lakes and transpiration from plant foliage. This leaves approximately 1250 × 10^9 gal/day to flow across or through the Earth to the sea.

It has been estimated that water use in the United States in 2010 was about 355 billion gallons per day (abbreviated Bgal/day), which was 13% less than in 2005. Freshwater withdrawals were 306 Bgal/day, or 86% of total withdrawals; saline water withdrawals were 48.3 Bgal/d, or 14% of total withdrawals. Fresh surface water withdrawals (230 Bgal/d) were almost 15% less than in 2005, and fresh groundwater withdrawals (76.0 Bgal/d) were about 4% less than in 2005. Total saline groundwater withdrawals in 2010 (3.29 Bgal/d) were primarily for mining use (Maupin et al., 2014).

Thermoelectric power and irrigation were the two largest uses of water in 2010, although total withdrawals for both were notably less than in 2005. Only mining and aquaculture had larger withdrawals in 2010 compared to 2005. Thermoelectric power, irrigation, and public supply withdrawals accounted for 90% of total water withdrawals in 2010. Withdrawals for thermoelectric power were 161 Bgal/d in 2010, the lowest level since before 1970. Surface water withdrawals accounted for more than 99% of total thermoelectric power withdrawals, and 73% of these withdrawals were from freshwater sources (Maupin et al., 2014).

Irrigation withdrawals in 2010 were 115 Bgal/d in 2010, the lowest level since before 1965, despite a growing number of acreage being irrigated. Irrigation withdrawals (all freshwater) accounted for 38% of total freshwater withdrawals for all uses; however, irrigation freshwater withdrawals represented 61% of total freshwater withdrawals for all uses *excluding* thermoelectric power. Surface water withdrawals (65.9 Bgal/d) accounted for 57% of the total irrigation withdrawals, about 12% less than in 2005. In 2010, groundwater withdrawals for irrigation were 49.5 Bgal/d. The number of acres irrigated using sprinkler and microirrigation systems continues to increase and accounted for 58% of total irrigated lands in 2010 (Maupin et al., 2014).

Public supply withdrawals in 2010 were 42.0 Bgal/d, or 5% less than in 2005. This drop in usage represented the first decline in public supply withdrawals since reporting began in 1950. Public supply withdrawals in 2010 accounted for 14% of total freshwater withdrawals for all uses and 22% of freshwater withdrawals for all uses *excluding* thermoelectric power. The number of people who received potable water from public supply facilities in 2010 was 268 million, or about 86% of the total U.S. population (Maupin et al., 2014).

Self-supplied domestic withdrawals were 3.60 Bgal/d, or 3% less than in 2005. More than 98% of the self-supplied domestic withdrawals were from groundwater sources. Self-supplied industrial withdrawals were 15.9 Bgal/d in 2010, a 12% decline from 2005 that continued the downward trend since a peak of 47 Bgal/d in 1970. Total self-supplied industrial withdrawals were 4% of total withdrawals for all uses, but 8% of total withdrawals for all uses *excluding* thermoelectric power (Maupin et al., 2014).

Total aquaculture withdrawals were 9.42 Bgal/d in 2010. Total mining withdrawals in 2010 were 5.32 Bgal/d; mining withdrawals accounted for the largest percentage increase in water use between 2005 and 2010. Livestock withdrawals in 2010 were 2.00 Bgal/d (Maupin et al., 2014).

In 2010, more than 50% of the total withdrawals in the United States could be attributed to 12 states. California accounted for about 11% of the total withdrawals and 10% of freshwater withdrawals, predominantly for irrigation. Texas accounted for about 7% of total withdrawals, primarily for thermoelectric power, irrigation, and public supply. Florida accounted for 18% of total saline surface water withdrawals, mostly for thermoelectric power. Oklahoma and Texas together accounted for about 70% of the total saline groundwater withdrawals, mostly for mining (Maupin et al., 2014).

In this text, our primary focus on water use is with regard to municipal applications. Municipal water demand is usually classified according to the nature of the user:

- *Domestic*—Domestic water is supplied to houses, schools, hospitals, hotels, restaurants, etc., for culinary, sanitary, and other purposes. Use varies with the economic level of the consumer, the range being 20 to 100 gal/capita/day. It should be pointed out that these figures include water used for watering gardens and lawns and washing cars.
- *Commercial and industrial*—Commercial and industrial water is supplied to stores, offices, and factories. The importance of commercial and industrial demand is based, of course, on whether there are large industries that use water supplied from the municipal system. These large industries demand a quantity of water directly related to the number of persons employed, to the actual floor space or area of each establishment, and to the number of units manufactured or produced. Industry in the United States uses an average of 150 Bgal/day of water each day.
- *Public use*—Public use water is the water furnished to public buildings and used for public services. This includes water for schools, public buildings, fire protection, and flushing streets.
- *Loss and waste*—Water that is lost or wasted (i.e., unaccounted for) is attributable to leaks in the distribution system, inaccurate meter readings, and unauthorized connections. Loss and waste of water can be expensive. In order to reduce loss and waste, a regular program that includes maintenance of the system and replacement or recalibration of meters is required (McGhee, 1991).

THE BOTTOM LINE

Water is not an infinite resource. As population grows, the demand for water seems to grow threefold in comparison. The problem is, with a finite water supply available, we literally cannot afford to waste a drop of it—but we do. Water, to most of us is a substance so common we think of it as unlimited, that we can do as we wish with it, including abusing it, polluting it, damming it, diverting it, and throwing out the water with the garbage, or, worse yet, throwing the garbage into the water. This is what we do to our water—the finite resource we cannot live without. The question becomes why? Why do we ignore water? Why do we pollute it? Do we and should we care?

DISCUSSION QUESTIONS

1. Discuss the concept of the hydrogeologic cycle as a pump.
2. What are the chief differences between surface water and groundwater? Why are these distinctions important?
3. Describe the hydrogeologic cycle. How could pollutants enter the cycle at every stage?
4. How does the hydrogeologic cycle work to cleanse water?
5. Discuss global water distribution. How does water supply affect local populations?

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10 Water Pollution

Water—the ace of elements. Water dives from the clouds without parachute, wings or safety net. Water runs over the steepest precipice and blinks not a lash. Water is buried and rises again; water walks on fire and fire gets the blisters. Stylishly composed in any situation—solid, gas, or liquid—speaking in penetrating dialects understood by all things—animal, vegetable or mineral—water travels intrepidly through four dimensions, sustaining, destroying, and creating. Always in motion, ever-flowing (whether at stream rate or glacier speed), rhythmic, dynamic, ubiquitous, changing and working its changes, a mathematics wrong side out, a philosophy in reverse, the ongoing odyssey of water is virtually irresistible.

Robbins (1976)

The American economy's ultimate purpose is to produce more consumer goods.

—President Eisenhower's Council of Economic Advisors (1953)

For the first time in the history of the world, every human being is now subjected to contact with dangerous chemicals, from the moment of conception until death.

Carson (1962)

Please … understand that the important thing is not to listen to what I say but to look at the facts—the science—and ask: Is there anything?

—Frank R. Spellman

Case Study 10.1. Get the Lead Out

"Momma, this water is dirty!" "Momma, this water is smelly!" "Momma, this water tastes yucky!" "Momma, I drank the water and now I feel icky!" Does this refrain sound at all familiar to you? Is it something you've ever heard a child utter? In modern countries, such as the United States, has this refrain ever even been spoken? Well, let's have a conversation about this issue.

Most likely, this refrain does not sound familiar to you. It's possible that you've heard it, but you may not have heard it spoken in English. Such complaints may be spoken in any of many different languages and too often are heard in underdeveloped nations. Underdeveloped nation? What exactly is an underdeveloped nation? In keeping with Voltaire and his famous saying, "If you wish to converse with me, please define your terms," and for our purposes here, let's define the term as a nation that, because of several possible conditions, is lacking access to job opportunities, food, healthcare, education, housing, and—most importantly in the real world and in this book—safe drinking water (the key word being *safe*). It has been estimated that 780 million people do not have access to an improved drinking water source and that over 800,000 children younger than 5 years of age perish each year from diarrhea, mostly in underdeveloped countries. But, what is an improved drinking water source? The World Health Organization/UNICEF Joint Monitoring Programme for Water Supply and Sanitation has defined "improved" water sources as follows (WHO/UNICEF, 2017):

- Piped water into a dwelling; water can be drawn from a common household tap (see Figure 10.1)
- Piped water into a yard/plot

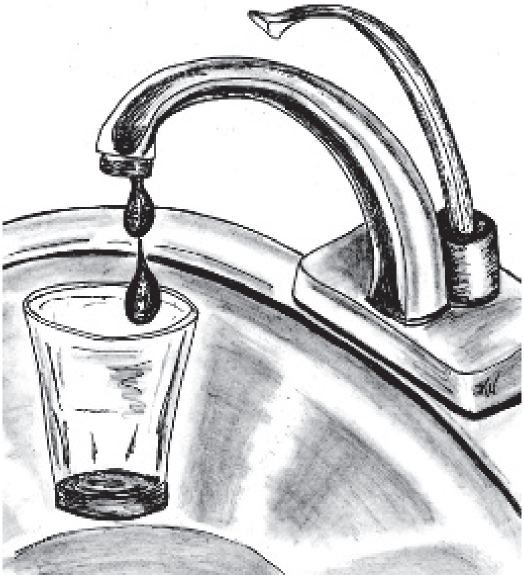

FIGURE 10.1 Kitchen tap, an improved drinking water source. (Illustration by F.R. Spellman and Kathern Welsh.)

- Public taps/standpipes
- Tubewells/boreholes
- Protected dug wells
- Protected springs
- Rainwater collection (see Figure 10.2)
- Bottled water, if the secondary source used by the household for cooking and personal hygiene is improved

FIGURE 10.2 Rainwater collection. (Illustration by F.R. Spellman and Kathern Welsh.)

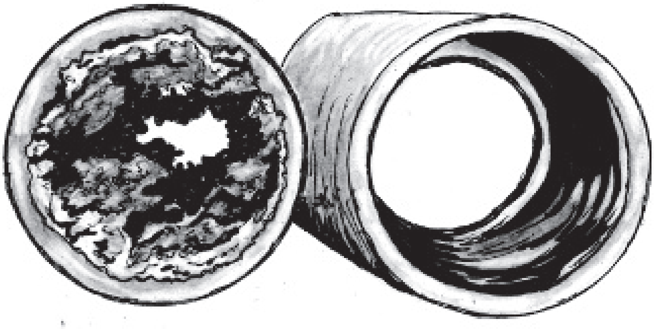

FIGURE 10.3 The water pipe shown on the left is indicative of scaling, corrosion, and buildup; the corrosive (improperly treated) water can easily cause built-up materials to leach into water flowing inside the pipe. The pipe on the right is how a standard water pipe should appear. (Illustration by F.R. Spellman and Kathern Welsh.)

Water sources that are not considered "improved" include the following:

- Unprotected dug wells
- Unprotected springs
- Vendor-provided water
- Cart with a small tank/drum
- Bottled water, if the secondary source used by the household for cooking and personal hygiene is unimproved
- Tanker-truck
- Surface water

It should be clear now as to what an improved drinking water source is and what an unimproved source is. So, getting back to our earlier question, are complaints about drinking water only heard in underdeveloped countries? Unfortunately, no. They can be heard even in this country, depending on geographical location and personal circumstance. Your experience with the tap water from your own kitchen sink is probably okay, but consider the residents of Flint, Michigan, for example. Many readers are no doubt familiar with the Flint, Michigan, fiasco, but for those of you who are not, let's summarize. In April 2014, Flint changed its water source from treated Detroit Water and Sewerage Department water, which was sourced from the Detroit River and Lake Huron, to water from the Flint River, a very corrosive water source. The city experienced a series of problems with the new drinking water source that culminated in the discovery of lead contamination, a grave public health hazard. Flint River water that was treated improperly (or not treated at all) caused lead, scale, and who knows what else that had built up in the aging pipes (see Figure 10.3) to leach into the water supply, causing extremely elevated levels of lead, a heavy metal neurotoxin. It is estimated that, in Flint, somewhere between 6000 and 12,000 children have been exposed to tap water, a supposedly improved water source, with high levels of lead. These lead levels were high enough to cause a range of serious health issues (United Way, 2016). Due to the change in water source, the percentage of Flint children with elevated blood lead levels may have raised from about 2.5% in 2013 to as much as 5% in 2015 (Hanna-Attisha et al., 2015). Some speculate that the water change may have caused an outbreak of Legionnaires' disease in the county that killed 10 people and made more than 70 people ill.

The experience of Flint's lead-contaminated water supply suggests that children's complaints about the water they are drinking could actually be heard here in the United States. This, of course, raises other questions. Are there other, as yet undiscovered cities in the United States distributing contaminated water? Without a doubt, due to this country's aging infrastructure. Many water distribution systems are more than 100 years old and in dire need of upgrading. The main problem is money. Replacing old and deteriorating distribution systems is not cheap. When city managers, city councils, and utility directors are advised that they need to upgrade their water system to the tune of millions of dollars, they immediately ask, "Where would we get the money to do that?" If they contemplate raising funds by making rate payers pay the bill, their political careers or appointed positions will quickly be over. Well, how about the states and federal government? Can't they come up with the funds needed to upgrade such critical infrastructure? Again, though, their answer is, "Where would we get the money to do that?" Unfortunately, no action can be expected until a Flint-type event occurs, one that has a highly emotional impact because of potential damage to children and others. The press would have to be all over the situation, and the politicians would have to point fingers here, there, and everywhere (except toward themselves).

Funding that is difficult or impossible to find to retrofit aging municipal water distribution systems is one thing, but allowing what occurred in Flint is an entirely different matter. After my years of teaching undergraduate- and graduate-level environmental health courses, including waterworks operation, as well as short courses in water and wastewater treatment at Virginia Tech for operators and for those seeking licensure as operators, I was totally surprised by what happened in Flint, Michigan. Water operators, water administrators, waterworks managers, waterworks environmental engineers, and other waterworks personnel know that incoming water must be sampled and tested for quality. Moreover, during the treatment of water as it flows from unit process to unit process, it must be sampled and tested. At the completion of treatment and prior to discharge to the distribution system the treated water must be sampled and treated again. This sequence of sampling and treating is not just nice to do; it is not just best practices—it is the absolute law of the land, and there is a distinct moral obligation to provide the best and safest drinking water possible. What exactly occurred at Flint may never be fully revealed; however, one thing is absolutely certain—people did not do what they were trained and obligated to do. They did not deliver safe drinking water to the consumer. And, because of their incompetence, violation of law, or just plan stupidity or immorality, we are now likely to hear, "Get the lead out of the water, please!"

INTRODUCTION

Water covers almost three-quarters of the Earth's surface. Although it is our most abundant resource, water is present on Earth in only a thin film, and almost 97% of it is saltwater. Earth's water performs many functions essential to life on Earth: helping to maintain climate, diluting environmental pollution, and, of course, supporting all life. Freshwater sources include groundwater and surface water. In this chapter, we focus on surface water—rivers, lakes, streams, wetlands, and coastal waters. More specifically, we focus our attention on surface water pollution; however, we limit our discussion to only the freshwater bodies upon which life is so dependent. Later in the chapter we discuss groundwater pollution.

Most human settlements evolved and continue to develop along the shores of many freshwater bodies, mainly rivers. The obvious reason for this is threefold: accessibility, a plentiful source of drinking water, and, later, a source of energy (water power) for our earliest machines. When human populations began to spread out and leave the watercourses, we found that some areas have too little water and others too much. Human beings (being the innovative and destructive creatures we are) have, with varying degrees of success, attempted to correct these imbalances by capturing freshwater in reservoirs behind dams, transferring freshwater in rivers and streams from one area to another, tapping underground supplies, and endeavoring to reduce water use, waste, and contamination. Water pollution can be defined in a general way as the presence of unwanted substances in water beyond levels acceptable for health or aesthetics. In some of these efforts to modify Nature we have been successful; in others (when gauged against the current condition of our water supplies) we are still learning—and we have much more to learn. Unfortunately, only a small proportion (about 0.5%) of all water on Earth is found in lakes, rivers, streams, or in the atmosphere. Even this small amount, though, is more than enough, if it is kept free of pollution and distributed evenly, to provide for the drinking, food preparation, and agricultural needs of all Earth's people. We simply need to learn how to better manage and conserve the freshwater readily available to us.

SURFACE WATER

Precipitation that does not infiltrate into the ground or return to the atmosphere is surface water. When the water is freshly fallen and still mobile, not having yet reached a body of water, we call it *runoff*—water that flows into nearby lakes, wetlands, streams, rivers, and reservoirs. Before continuing our discussion of surface water, let us review the basic concepts of the hydrological cycle. Actually a manifestation of an enormous heat engine, the water cycle raises water from the oceans in warmer latitudes by a prodigious transformation of solar energy. Transferred through the atmosphere by the winds, the water is deposited far away over sea or land. Water taken from the Earth's surface to the atmosphere (either by evaporation from the surface of lakes, rivers, streams, and oceans or through transpiration of plants) forms clouds that condense to deposit moisture on the land and sea as rain or snow. The water that collects on land flows back to the oceans in streams and rivers. The water that we see is surface water. The U.S. Environmental Protection Agency (USEPA) defines surface water as all water open to the atmosphere and subject to runoff. Surface freshwater can be broken down into four components: lakes, rivers and streams, estuaries, and wetlands.

Limnology is the study of bodies of open freshwater (lakes, rivers, and streams) and of their plant and animal biology and physical properties. Freshwater systems are grouped or classified as either lentic or lotic. Lentic (*lenis*, for "calm") systems are represented by lakes, ponds, impoundments, reservoirs, and swamps—standing water systems. Lotic (*lotus*, for "washed") systems are represented by rivers, streams, brooks, and springs—running water systems. On occasion, distinguishing between these two different systems is difficult. In old, wide, and deep rivers where water velocity is quite low, for example, the system becomes similar to that of a pond. Surface water (produced by melting snow or ice or from rainstorms) always follows the path of least resistance. In other words, water doesn't run uphill. Beginning with droplets and ever increasing, runoff is carried by rills, rivulets, brooks, creeks, streams, and rivers from elevated land areas that slope down toward one primary water course—a topographically defined drainage area. Drainage areas, known as *watersheds* or *drainage basins*, are surrounded by a ridge of high ground called the *watershed divide*. Watershed divides separate drainage areas from each other.

LENTIC (STANDING OR STILL) WATER SYSTEMS

Natural lentic water systems include lakes, ponds, bogs, marshes, and swamps. Other standing freshwater bodies, including reservoirs, oxidation ponds, and holding basins, are usually constructed. Use of the term "still water" can be deceiving. Consider the following.

Still Water[*]

Consider a river pool, isolated by fluvial processes and time from the main stream flow. We are immediately struck by one overwhelming impression: It appears so still … so very still … still enough to soothe us. The river pool provides a kind of poetic solemnity, if only at the pool's surface. No words of peace, no description of silence or motionless can convey the perfection of this place, in this moment stolen out of time.

We ask ourselves, "The water is still, but does the term 'still' correctly describe what we are viewing? Is there any other term we can use besides 'still'? Is there any other kind of still?" Yes, of course, we know many ways to characterize still. For sound or noise, "still" can mean inaudible, noiseless, quiet, or silent. With movement (or lack of movement), still can mean immobile, inert, motionless, or stationary. And this is how the pool appears to the casual visitor, at least on the surface. The visitor sees no more than water and rocks.

The rest of the pool? We know very well that a river pool is more than just a surface. How does the rest of the pool (the subsurface, for example) fit the descriptors we tried to use to characterize its surface? Maybe they fit, maybe they don't. In time, we will go beneath the surface, through the liquid mass, to the very bottom of the pool to find out. For now, remember that images retained from first glances are almost always incorrectly perceived, incorrectly discerned, and never fully understood.

On second look, we see that the fundamental characterization of this particular pool's surface is correct enough. Wedged in a lonely riparian corridor—formed by river bank on one side and sand bar on the other—between a youthful, vigorous river system at its lower end and a glacier- and artesian-fed lake at its headwater end, almost entirely overhung by mossy old Sitka spruce, the surface of the large pool, at least at this particular location, is indeed still. In the proverbial sense, the pool's surface is as still and as flat as a flawless sheet of glass.

The glass image is a good one, because, like perfect glass, the pool's surface is clear, crystalline, unclouded, definitely transparent, yet perceptively deceptive, as well. The water's clarity, accentuated by its bone-chilling coldness, is apparent at close range. Farther back, we see only the world reflected in the water—the depths are hidden and unknown. Quiet and reflective, the polished surface of the water perfectly reflects in mirror-image reversal the spring greens of the forest at the pond's edge, without the slightest ripple. Up close, though, looking straight into the bowels of the pool, we are struck by the water's transparency. In the motionless depths, we do not see a deep, slow-moving reach with a muddy bottom typical of a river or stream pool; instead, we clearly see the warm variegated tapestry of blues, greens, and blacks stitched together with threads of fine, warm-colored sand that carpets the bottom, at least 12 feet below. Still waters can run deep.

No sounds emanate from the pool. The motionless, silent water does not, as we might expect, lap against its bank or bubble or gurgle over the gravel at its edge. Here, the river pool, held in temporary bondage, is patient, quiet, waiting, withholding all signs of life from its surface visitor.

Then the reality check: This stillness, like all feelings of calm and serenity, could be fleeting, momentary, temporary, you think. And you would be correct, of course, because there is nothing still about a healthy river pool. At this exact moment, true clarity is present, it just needs to be perceived … and it will be.

We toss a small stone into the river pool and watch the concentric circles ripple outward as the stone drops through the clear depths to the pool bottom. For a brief instant, we are struck by the obvious: The stone sinks to the bottom, following the laws of gravity, just as the river flows according to those same inexorable laws—downhill in its search for the sea. As we watch, the ripples die away, leaving as little mark as the usual human lifespan creates in the record of the Earth, then disappears as if it had never been. Now the river water is as before, still. At the pool's edge, we look down through the massy depth to the very bottom—the substrate.

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[*] This section is adapted from Spellman, F.R., *The Science of Water*, 3rd ed., CRC Press, Boca Raton, FL, 2015.

We determine that the pool bottom is not flat or smooth, but instead is pitted and mounded occasionally with discontinuities. Gravel mounds alongside small corresponding indentations—small, shallow pits—make it apparent to us that gravel was removed from the indentations and piled into slightly higher mounds. From our topside position, as we look down through the cool, quiescent liquid, the exact height of the mounds and the depth of the indentations are difficult for us to judge; our vision is distorted by several feet of water.

We can detect, near the low gravel mounds (where female salmon buried their eggs and where their young grow until they are old enough to fend for themselves) and actually through the gravel mounds, movement, water flow, an upwelling of groundwater. This water movement explains our ability to see the variegated color of pebbles. The mud and silt that would normally cover these pebbles has been washed away by the water's subtle, inescapable movement. Obviously, in the depths, our still water is not as still as it first appeared.

The slow, steady, inexorable flow of water in and out of the pool, along with the upflowing of groundwater through the pool's substrate and through the salmon redds (nests) is only a small part of the activities occurring within the pool, including the air above it, the vegetation surrounding it, and the damp bank and sandbar forming its sides.

Let's get back to the pool itself. If we could look at a cross-sectional slice of the pool, at the water column, the surface of the pool may carry those animals that can literally walk on water. The body of the pool may carry rotifers and protozoa and bacteria—tiny microscopic animals—as well as many fish. Fish will also inhabit hidden areas beneath large rocks and ledges to escape predators. Going down farther in the water column, we come to the pool bed. This is called the *benthic zone*, and certainly the greatest number of creatures lives here, including larvae and nymphs of all sorts, worms, leeches, flatworms, clams, crayfish, dace, brook lampreys, sculpins, suckers, and water mites.

We need to go down even farther, down into the pool bed, to see the whole story. How far this goes and what lives here, beneath the water, depend on whether it is a gravelly bed or a silty or muddy one. Gravel will allow water, with its oxygen and food, to reach organisms that live underneath the pool. Many of the organisms that are found in the benthic zone may also be found underneath, in the *hyporheal zone*. But, to see the rest of the story, we need to look at the pool's outlet and where its flow enters the main river. This is the riffles—shallow places where water runs fast and is disturbed by rocks. Only organisms that cling very well, such as net-winged midges, caddisflies, stoneflies, some mayflies, dace, and sculpins, can spend much time here, and the plant life is restricted to diatoms and small algae. Riffles are a good place for mayflies, stoneflies, and caddisflies to live because they offer plenty of gravel to hide in.

At first, we struggled to find the words to describe the river pool. Eventually, we settled on "still waters." We did this because of our initial impression and because of our lack of understanding—lack of knowledge. Even knowing what we know now, we might still describe this river pool as still waters; however, in reality, we must call the pool what it really is: a dynamic habitat. This is true, of course, because each river pool has its own biological community, all members interwoven with each other in complex fashion, all depending on each other. Thus, our river pool habitat is part of a complex, dynamic ecosystem. On reflection, we realize, moreover, that anything dynamic certainly cannot be accurately characterized as "still," including our river pool.

LOTIC (FLOWING) WATER SYSTEMS

Earlier, we compared the human circulatory system to the Earth's water circulation system. The hydrological cycle pumps water as our hearts pump blood, continuously circulating water through air, water bodies, and various vessels. As our blood vessels are essential to the task of carrying blood throughout our bodies, water vessels (rivers) carry water, fed by capillary creeks, brooks, streams, rills, and rivulets. Consider the following account of stream genesis.

Stream Genesis[*]

Early in the spring, on a snow- and ice-covered high alpine meadow, the water cycle continues. The main component of the cycle—water—has been held in reserve, literally frozen over the long, dark winter months. Now, though, because of the longer, warmer spring days, the sun is higher, more direct, and of longer duration, and the frozen masses of water respond to the increased warmth. The melt begins with a single drop, then two, then more. As the snow and ice melt, the drops of water join a chorus that continues apparently unending; they fall from ice-bound lips to the bare rock and soil terrain below.

The terrain on which the snowmelt falls is not like glacial till, which is an unconsolidated, heterogeneous mixture of clay, sand, gravel, and boulders dug out, ground out, and exposed by the force of a huge, slow, inexorably moving glacier. Instead, this soil and rock ground is exposed to the falling drops of snowmelt because of a combination of wind and the tiny, enduring force exerted by drops of water as season after season they collide with the thin soil cover, exposing the intimate bones of the Earth.

Gradually, the single drops increase to a small rush—they join to form a splashing, rebounding, helter-skelter cascade, many separate rivulets that trickle, then run their way down the face of the granite mountain. At an indented ledge halfway down the mountain slope, a pool forms whose beauty, clarity, and sweet iciness provide the visitor with an incomprehensible, incomparable gift—a blessing from Earth.

The mountain pool fills slowly, tranquil under the blue sky, reflecting the pines, snow and sky around and above it, an open invitation to lie down and drink and to peer into the glass-clear, deep phantom blue–green eye, so clear that it seems possible to reach down over 50 feet and touch the very bowels of the mountain. The pool has no transition from shallow margin to depth; it is simply deep and pure. As the pool fills with more melt water, we wish to freeze time, to hold this place and this pool in its perfect state forever, it is such a rarity to us in our modern world. However, this cannot be, as Mother Nature calls, prodding, urging. For a brief instant, the water laps in the breeze against the outermost edge of the ridge, then a trickle flows over the rim. The giant hand of gravity reaches out and tips the overflowing melt onward and it continues the downward journey, following the path of least resistance to its next destination, several thousand feet below.

When the overflow, still high in altitude but with its rock-strewn bed bent downward, toward the sea, meets the angled, broken rocks below, it bounces, bursts, and mists its way against steep, V-shaped walls that form a small valley, carved out over time by water and the forces of the Earth. Within the valley confines, the melt water has grown from drops to rivulets to a small mass of flowing water. It flows through what is at first a narrow opening, gaining strength, speed, and power as the V-shaped valley widens to form a U shape. The journey continues as the water mass picks up speed and tumbles over massive boulders, and then slows again.

At a larger but shallower pool, waters from higher elevations have joined the main body—from the hillsides, crevices, springs, rills, and mountain creeks. At the influent poolsides, all appears peaceful, quiet, and restful, but not far away, at the effluent end of the pool, gravity takes control again. The overflow is flung over the jagged lip, and cascades downward several hundred feet, where the waterfall again brings its load to a violent, mist-filled meeting.

The water separates and joins repeatedly, forming a deep, furious, wild stream that calms gradually as it continues to flow over lands that are less steep. The waters widen into pools overhung by vegetation, surrounded by tall trees. The pure, crystalline waters have become progressively discolored on their downward journey, stained brown–black with humic acid, and literally filled with suspended sediments; the once-pure stream is now muddy.

The mass divides and flows in different directions over different landscapes. Small streams divert and flow into open country. Different soils work to retain or speed the waters, and in some places the waters spread out into shallow swamps, bogs, marshes, fens, or mires. Other streams

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[*] This section is adapted from Spellman, F.R., *The Science of Water*, 3rd ed., CRC Press, Boca Raton, FL, 2015.

pause long enough to fill deep depressions in the land and form lakes. For a time, the water remains and pauses in its journey to the sea, but this is only a short-term pause, because lakes are only a short-term resting-place in the water cycle. The water will eventually move on, by evaporation or seepage into groundwater. Other portions of the water mass stay with the main flow, and the speed of flow changes to form a river, which braids its way through the landscape, heading for the sea. As it changes speed and slows the river bottom changes from rock and stone to silt and clay. Plants begin to grow, stems thicken, and leaves broaden. The river is now full of life and the nutrients necessary to sustain life. As the river courses onward, though, it meets its destiny when the flowing rich mass slows at last and finally spills into the sea.

SETTING THE STAGE

Before we discuss surface water pollution, we must define several important terms related to water pollution. One of these is point source. A *point source*, as defined by the Clean Water Act (CWA), is any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation (CAFO), or vessel or other floating craft, from which pollutants are discharged. For example, the outfalls of industrial facilities or wastewater treatment plants are point sources. Figure 10.4 shows a common type of end-of-the pipe point source. A *nonpoint source*, in contrast, is more widely dispersed. An example of a nonpoint source of pollution is rainwater carrying topsoil (sediments), animal waste (feces), and chemical contaminants into a stream. Nonpoint-source pollution includes water runoff from farming, urban areas, forestry, and construction activities. Nonpoint sources represent the largest source of water pollution, contributing an estimated 70% or more of the contamination in quality-impaired surface waters. Note that atmospheric deposition of pollutants is also a nonpoint source of acid, nutrients, metals, and other airborne pollutants.

Another important term associated with nonpoint sources is *runoff*, which is a nonpoint source that originated on land. The USEPA considers polluted runoff to be the most serious water pollution problem in the United States. Runoff occurs because of human intervention with landscapes. When land is disturbed by parking lots, tarmac, roads, factories, homes, and buildings, rainwater is not free to percolate through the soil, which absorbs and detoxifies many pollutants. Instead, when there is little if any soil, contaminated rainwater runs off into area water bodies, polluting them.

FIGURE 10.4 An example of end-of-pipe point-source pollution. (Illustration by F.R. Spellman and Kathern Welsh.)

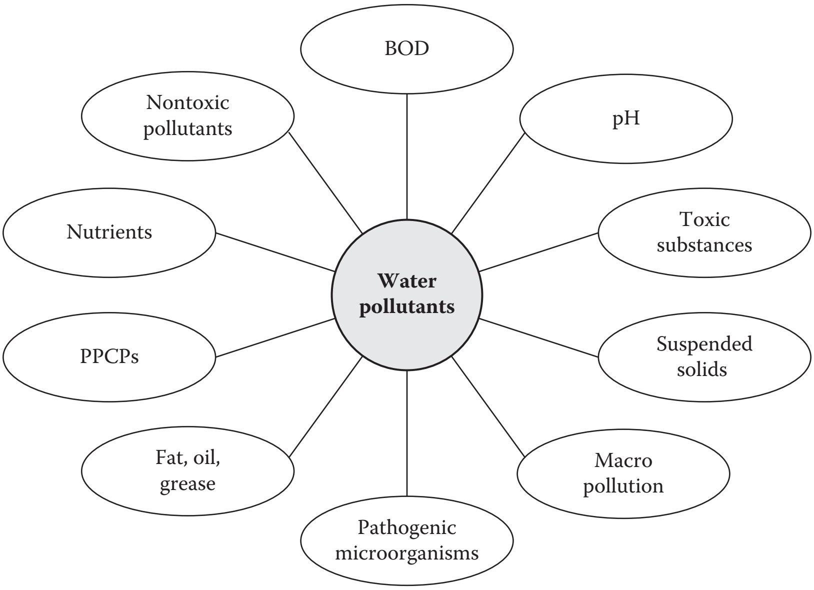

FIGURE 10.5 General water pollutants.

SURFACE WATER POLLUTANTS

Surface water pollutants can harm aquatic life, threaten human health, or result in the loss of recreational or aesthetic potential. Surface water pollutants come from industrial sources, nonpoint sources, municipal sources, background sources, and other/unknown sources. The eight chief pollutants (Figure 10.5) are biochemical oxygen demand (BOD); nutrients (see Case Study 10.2); suspended solids; pH; fats, oil, and grease (FOG); pathogenic microorganisms; toxic pollutants; and nontoxic pollutants.

Case Study 10.2. Good Science vs. "Feel Good" Science

Environmental policymakers in the Commonwealth of Virginia came up with what is called the Lower James River Tributary Strategy on the subject of nitrogen (a nutrient) from the Lower James River and other tributaries contaminating the Lower Chesapeake Bay Region. When in excess, nitrogen is a pollutant. Some "theorists" jumped on nitrogen as being the cause of a decrease in the oyster population in the Lower Chesapeake Bay Region. Oysters are important to the local region. They are important for economical and other reasons. From an environmental point of view, oysters are important to the Lower Chesapeake Bay Region because they have worked to maintain relatively clean Bay water in the past. Oysters are filter-feeders. They suck in water and its accompanying nutrients and other substances. The oyster sorts out the ingredients in the water and uses those nutrients it needs to sustain its life. Impurities (pollutants) are aggregated into a sort of ball that is excreted by the oyster back into the James River.

You must understand that there was a time, not all that long ago (maybe 50 years ago), when oysters thrived in the Lower Chesapeake Bay. Because the oysters were so abundant, these filter-feeders were able to take in turbid Bay water and turn it almost clear in a matter of three days. (How could anyone dredge up, clean, and then eat such a wonderful natural vacuum cleaner?)

Of course, this is not the case today. The oysters are almost all gone. Where did they go? Who knows? The point is that they are no longer thriving, no longer colonizing the Lower Chesapeake Bay Region in numbers they did in the past. Thus, they are no longer providing economic stability to watermen; moreover, they are no longer cleaning the Bay.

Ah! But don't panic! The culprit is at hand; it has been identified. The "environmentalists" know the answer. They say it has to be nutrient contamination—namely, nitrogen is the culprit. Right?

Not so fast.

A local sanitation district and a university in the Lower Chesapeake Bay region formed a study group to formally, professionally, and scientifically study this problem. Over a five-year period, using biological nutrient removal (BNR) techniques at a local wastewater treatment facility, it was determined that the effluent leaving the treatment plant and entering the Lower James River consistently contained below 8 mg/L nitrogen (a relatively small amount) for five consecutive years.

The first question is: Has the water in the Chesapeake Bay become cleaner, clearer because of the reduced nitrogen levels leaving the treatment plant?

The second question is: Have the oysters returned?

Answers to both questions, respectively: no; not really.

Wait a minute. The environmentalists, the regulators, and other well-meaning interlopers stated that the problem was nitrogen. If nitrogen levels have been reduced in the Lower James River, shouldn't the oysters start thriving, colonizing, and cleaning the Lower Chesapeake Bay again?

You might think so, but they are not. It is true that the nitrogen level in the wastewater effluent was significantly lowered through treatment. It is also true that a major point source contributor of nitrogen was reduced with a corresponding decrease in the nitrogen level in the Lower Chesapeake Bay.

If the nitrogen level has decreased, then where are the oysters?

A more important question is: What is the real problem?

The truth is that no one at this point in time can give a definitive answer to this question.

Back to the original question: Why has the oyster population decreased?

One theory states that because the tributaries feeding the Lower Chesapeake Bay (including the James River) carry megatons of sediments into the bay (stormwater runoff, etc.), they are adding to the Bay's turbidity problem. When waters are highly turbid, oysters do the best they can to filter out the sediments but eventually they decrease in numbers and then fade into the abyss.

Is this the answer? That is, is the problem with the Lower Chesapeake Bay and its oyster population related to turbidity?

Only solid, legitimate, careful scientific analysis may provide the answer.

One thing is certain; before we leap into decisions that are ill-advised, that are based on anything but sound science, and that "feel" good, we need to step back and size up the situation. This sizing-up procedure can be correctly accomplished only through the use of scientific methods.

Don't we already have too many dysfunctional managers making too many dysfunctional decisions that result in harebrained, dysfunctional analysis—and results?

Obviously, there is no question that we need to stop the pollution of Chesapeake Bay.

However, shouldn't we replace the timeworn and frustrating position that "we must start somewhere" with good common sense and legitimate science?

The bottom line: We shouldn't do anything to our environment until science supports the investment. Shouldn't we do it right?

BIOCHEMICAL OXYGEN DEMAND

Organic matter (dead plants and animal debris; wild animal and bird feces), human sewage, food-processing wastes, chemical plant wastes, slaughterhouse wastes, pulp- and paper-making wastes, and tannery wastes discharged to a water body are degraded by oxygen-requiring microorganisms. The amount of oxygen consumed during microbial utilization of organics is called the biochemical oxygen demand (BOD). BOD is classified as a *conventional pollutant* because it is amendable to treatment by a municipal sewage treatment plant. Although some natural BOD is almost always present, BOD is often an indication of the presence of sewage and other organic waste. High levels of BOD can deplete the oxygen in water. Fish and other aquatic organisms present in such waters with low oxygen conditions may die.

NUTRIENTS

Elements such as carbon, nitrogen, phosphorus, sulfur, calcium, iron, potassium, manganese, cobalt, and boron are called *nutrients* (or biostimulants); they are essential to the growth and reproduction of aquatic plants and animals that depend on the surrounding water to provide their nutrients. Just as too much of any good thing can have serious side affects for all of us, so is the case with too many nutrients in water. For example, when fertilizers composed of nutrients enter surface water systems, over-enrichment with nitrogen and phosphorus may result. A rich supply of such nutrients entering a lake may hasten *eutrophication*, which the USEPA defines as a process during which a lake evolves into a bog or marsh and eventually disappears. Excess nutrients also can stimulate a very abundant dense growth of aquatic plants (bloom), especially algae. Again, the two nutrients that concern us in this text are nitrogen and phosphorus.

Nitrogen

Nitrogen (N_2) is an extremely stable gas and is the primary component of the Earth's atmosphere (78%). The nitrogen cycle is composed of four processes. Three of these processes—fixation, ammonification, and nitrification—convert gaseous nitrogen into usable chemical forms. The fourth process—denitrification—converts fixed nitrogen back to the unusable gaseous nitrogen state. Nitrogen occurs in many forms in the environment and takes part in many biochemical reactions. Major sources of nitrogen include runoff from animal feedlots, fertilizer runoff from agricultural fields, municipal wastewater discharges, and certain bacteria and blue–green algae that obtain nitrogen directly from the atmosphere. Certain forms of acid rain can also contribute nitrogen to surface waters.

Nitrogen in water is commonly found in the form of nitrate (NO_3), the presence of which indicates that the water may be contaminated with sewage. Nitrates can also enter the groundwater from chemical fertilizers used in agricultural areas. Excessive nitrate concentrations in drinking water pose an immediate health threat to infants, both human and animal, and can cause death. The bacteria commonly found in the intestinal tract of infants can convert nitrate to highly toxic nitrite (NO_2). Nitrite can replace oxygen in the bloodstream which results in oxygen starvation and causes a bluish discoloration of the infant ("blue baby" syndrome).

DID YOU KNOW?

Lakes and reservoirs usually have less than 2 mg/L of nitrate measured as nitrogen. Higher nitrate levels are found in groundwater ranging up to 20 mg/L, but much higher values are detected in shallow aquifers polluted by sewage or excessive use of fertilizers.

Phosphorus

Phosphorus (P) is an essential nutrient that contributes to the growth of algae and the eutrophication of lakes, although its presence in drinking water has little effect on health. In aquatic environments, phosphorus is found in the form of phosphate and is a limiting nutrient. If all of the phosphorus is used up, plant growth ceases, no matter the amount of nitrogen available. Many bodies of freshwater currently experience influxes of nitrogen and phosphorus from outside sources. The increasing concentration of available phosphorus allows plants to assimilate more nitrogen before the phosphorus is depleted. If sufficient phosphorus is available, high concentrations of nitrates will lead to phytoplankton (algae) and macrophyte (aquatic plant) production. Major sources of phosphorus include phosphates in detergents, fertilizer and feedlot runoff, and municipal wastewater discharges. The 1976 USEPA water quality standards recommended a phosphorus criterion of 0.10 µg/L (elemental) phosphorus for marine and estuarine waters but offered no freshwater criterion.

pH

pH refers to the acidity or alkalinity of water; when it exceeds regulatory limits it is considered to be a conventional pollutant. A low pH may mean a water body is too acidic to support life optimally. Some water bodies are naturally acidic, but others are made so by acid deposition or acid runoff from mining operations. pH is a measure of the hydrogen ion (H^+) concentration. Solutions range from very acidic (having a high concentration of H^+ ions) to very basic (having a high concentration of OH^- ions). The pH scale ranges from 0 to 14, with 7 being the neutral value (see Figure 10.6). The pH of water is important to the chemical reactions that take place within water, and pH values that are too high or low can inhibit the growth of microorganisms. High pH values are considered basic, and low pH values are considered acidic. Stated another way, low pH values indicate a high H^+ concentration, and high pH values indicate a low H^+ concentration. Because of this inverse logarithmic relationship, each pH unit represents a tenfold difference in H^+ concentration. Natural water varies in pH depending on its source. Pure water has a neutral pH, with equal H^+ and OH^-. Adding an acid to water causes additional positive ions to be released, so the H^+ ion concentration goes up and the pH value goes down:

$$HCl \leftrightarrow H^+ + Cl^-$$

DID YOU KNOW?

Seawater is slightly more basic (the pH value is higher) than most natural freshwater. Neutral water (such as distilled water) has a pH of 7, which is in the middle of being acidic and alkaline. Seawater happens to be slightly alkaline (basic), with a pH of about 8. Most natural water has a pH range of 6 to 8, although acid rain can have a pH as low as 4.

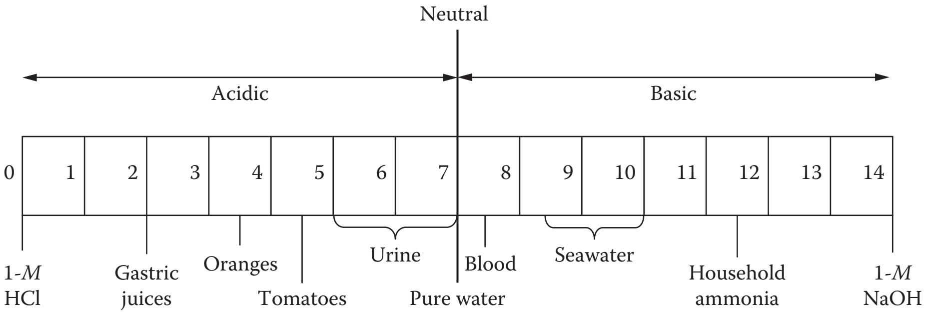

FIGURE 10.6 pH scale.

When preparing freshwater for potable water uses, waterworks operators test for the hydrogen ion concentration of the water to determine the water's pH. In coagulation tests, as more alum (acid) is added, the pH value lowers. If more lime (alkali) is added, the pH value rises. This relationship is important in water treatment—if a good floc is formed, the pH should then be determined and maintained at that pH value until the raw water changes. Pollution can change a water's pH, which in turn can harm animals and plants living in the water. For example, water coming out of an abandoned coal mine can have a pH of 2, which is very acidic and would definitely affect any fish crazy enough to try to live in it. On a logarithmic scale, this mine drainage water would be 100,000 times more acidic than neutral water—so stay out of abandoned mines.

SOLIDS

Natural water can contain a number of solid substances (what we may call impurities) or constituents. The concentrations of various solid substances in water in dissolved, colloidal, or suspended form are typically low but can vary considerably. A hardness value of up to 400 ppm of calcium carbonate, for example, is sometimes tolerated in public supplies, whereas 1 ppm of dissolved iron would be unacceptable. When a particular solids constituent can affect the good health of the water user or the environment, it is considered to be a contaminant or pollutant, and these solid contaminants or pollutants are referred to as conventional pollutants. Other than gases, all contaminants of water contribute to the solids content. Natural water carries many dissolved and undissolved solids; these are considered to be conventional pollutants. The undissolved solids are nonpolar substances and consist of relatively large particles of materials, such as silt, that will not dissolve. Classified by their size and state, their chemical characteristics, and their size distribution, solids can be dispersed in water in both suspended and dissolved forms. Solids in water can be classified as suspended, settleable, colloidal, or dissolved. Total solids are the suspended and dissolved solids that remain behind when the water is removed by evaporation. Solids are also characterized as volatile or nonvolatile. The distribution of solids is determined by computing the percentage of filterable solids by size range. Solids typically include inorganic solids such as silt and clay from riverbanks and organic matter such as plant fibers and microorganisms from natural or manmade sources.

Suspended solids are physical pollutants and may consist of inorganic or organic particles or immiscible liquids. Inorganic solids such as clay, silt, and other soil constituents are common in surface water. Organic materials—plant fibers and biological solids—are also common constituents of surface waters. These materials are often natural contaminants resulting from the erosive action of water flowing over surfaces. Fine particles from soil runoff can remain suspended in water and increase its turbidity or cloudiness. This can stunt the growth of aquatic plants by limiting the amount of sunlight reaching them. Effluents from wastewater treatment plants and industrial plants and runoff from forestry and agricultural operations are sources of suspended solids. Note that, because of the filtering capacity of the soil, suspended solids are seldom a constituent of groundwater. *Colloidal solids* are extremely fine suspended solids (particles) that are less than 1 micron (µm) in diameter; they are so small (though they still make water cloudy) that they will not settle even if allowed to sit quietly for days or weeks.

Solids in water affect how clear it is. The clarity of water, its *turbidity*, is one of the first characteristics people notice. Turbidity in water is caused by the presence of suspended matter, which results in the scattering and absorption of light rays. The greater the amount of total suspended solids (TSS) in the water, the murkier it appears and the higher the measured turbidity. Thus, in plain English, turbidity is a measure of the light-transmitting properties of water. Natural water that is very clear (low turbidity) allows us to see images at considerable depths. High-turbidity water, on the other hand, appears cloudy. Keep in mind that water of low turbidity is not necessarily without dissolved solids. Dissolved solids do not cause light to be scattered or absorbed, so the water looks clear. High turbidity causes problems for waterworks operators—components that cause high turbidity can also cause taste and odor problems and will reduce the effectiveness of disinfection.

DID YOU KNOW?

It is advisable to mix fats, oils, and grease with absorbent waste such as paper towels, kitty litter, coffee grounds, or shredded newspaper before discarding them in the trash.

Color in water can be caused by a number of solids (contaminants) such as iron, which changes in the presence of oxygen to yellow or red sediments. The color of water can be deceiving. In the first place, color is considered an aesthetic quality of water with no direct health impact. Second, many of the colors associated with water are not true colors but the result of colloidal suspension (apparent color). This apparent color can often be attributed to iron and to dissolved tannins extracted from decaying plant material. True color is the result of dissolved chemicals (most often organics) that cannot be seen. True color is distinguished from apparent color by filtering the sample.

Fats, Oil, and Grease

Fats, oil, and grease (FOG) are household wastes (conventional pollutants) that are routinely disposed of improperly down kitchen drains or flushed down toilets. Putting these greasy materials down a sink can lead to sewer clogs, and the clogs can lead to wastewater backing up into a home or business, spilling out onto the streets, and even making its way into storm drains and to the beaches.

Oil spills in or near surface water bodies can have a devastating effect on fish, other aquatic organisms, birds, and mammals. Note that spills are not the only source of oil in water; for example, oil leaking from automobiles and other vehicles or released during accidents is washed off roads with rainwater and into water bodies. Improper disposal of used oil from vehicles is another source; motor and other recreational boats release unburned fuel into water bodies.

Pathogenic Organisms

From the perspective of human use and consumption, the biggest concern associated with microorganisms is infectious disease. Microorganisms are naturally found in water (and elsewhere in the environment) and can cause infections. However, organisms that are not native to aquatic systems are of greatest concern—native or not, they can be transported by natural water systems. These organisms usually require an animal host for growth and reproduction. Nonpoint sources of these microorganisms include runoff from livestock operations and stormwater runoff. Point sources include improperly operating sewage treatment plants. When the surface water body provides drinking water to a community, the threat of infectious microorganism contamination is very real and may be life threatening. People who live in industrial nations with generally safe water supplies think of pathogenic contamination as a Third World problem. However, several problems in industrial nations (e.g., contamination of the local water supply in Sydney, Australia, in 1998) have alerted us to the very real possibility of dangerous contamination in our own water supplies.

Other pathogenic contamination problems in water and humans have manifested themselves via certain waterborne protozoans that can cause disease. Of particular interest to water pollution practitioners are *Entamoeba histolytica* (amoebic dysentery and amoebic hepatitis), *Giardia lamblia* (giardiasis), *Cryptosporidium* (cryptosporidiosis), and *Cyclospora* (cyclosporiasis). Sewage contamination transports eggs, cysts, and oocysts of parasitic protozoa and helminthes (tapeworms, hookworms, etc.) into raw water supplies, leaving water treatment (in particular, filtration) and disinfection as the means by which to diminish the danger of contaminated water for the consumer.

To prevent the occurrence of *Giardia* and *Cryptosporidium* spp. in surface water supplies and to address increasing problems with waterborne diseases, the USEPA implemented its Surface Water Treatment Rule (SWTR) in 1989. The rule requires both filtration and disinfection of all surface water supplies as a means of primarily controlling *Giardia* spp. and enteric viruses. Since implementation of its Surface Water Treatment Rule, the USEPA has also recognized that *Cryptosporidium* species are agents of waterborne disease. In its 1996 series of surface water regulations, the USEPA included *Cryptosporidium*.

To test the need for and the effectiveness of the Surface Water Treatment Rule, LeChevallier et al. (1991) conducted a study on the occurrence and distribution of *Giardia* and *Cryptosporidium* organisms in raw water supplies to 66 surface water filter plants. These plants were located in 14 states and a Canadian province. A combined immunofluorescence test indicated that cysts and oocysts were widely dispersed in the aquatic environment. *Giardia* was detected in more than 80% of the samples, and *Cryptosporidium* was found in 85% of the sample locations. Taking into account several variables, 97% of the raw water samples indicated the presence of *Giardia* or *Cryptosporidium*. After evaluating their data, the researchers concluded that the Surface Water Treatment Rule might have to be upgraded (subsequently, it has been) to require additional treatment.

Giardia

Giardia lamblia (also known as the hiker'/traveler's scourge or disease) is a microscopic parasite that can infect warm-blooded animals and humans. Although *Giardia* was discovered in the 19th century, not until 1981 did the World Health Organization (WHO) classify *Giardia* as a pathogen. An outer shell called a *cyst* allows *Giardia* to survive outside the body for long periods of time. If viable cysts are ingested, *Giardia* can cause the illness known as *giardiasis*, an intestinal illness that can cause nausea, anorexia, fever, and severe diarrhea.

In the United States, *Giardia* is the most commonly identified pathogen in waterborne disease outbreaks. Contamination of a water supply by *Giardia* can occur in two ways: (1) by the activity of animals in the watershed area of the water supply, or (2) by the introduction of sewage into the water supply. Wild and domestic animals are major contributors to the contamination of water supplies. Studies have also shown that, unlike many other pathogens, *Giardia* is not host specific. In short, *Giardia* cysts excreted by animals can infect and cause illness in humans. Additionally, in several major outbreaks of waterborne diseases, the sources of the *Giardia* cysts were sewage-contaminated water supplies.

Treating the water supply, however, can effectively control waterborne *Giardia*. Chlorine and ozone are examples of two disinfectants known to effectively kill *Giardia* cysts. Filtration of the water can also effectively trap and remove the parasite from the water supply. The combination of disinfection and filtration is the most effective water treatment process available today for prevention of *Giardia* contamination.

In drinking water, *Giardia* is regulated under the Surface Water Treatment Rule. Although the SWTR does not establish a maximum contaminant level (MCL) for *Giardia*, it does specify treatment requirements to achieve at least 99.9% (3-log) removal or inactivation of *Giardia*. This regulation requires all drinking water systems using surface water or groundwater under the direct influence of surface water to disinfect and filter the water. The Enhanced Surface Water Treatment Rule (ESWTR), which includes *Cryptosporidium* and further regulates *Giardia*, was established in 1996.

Giardiasis

Giardiasis is recognized as one of the most frequently occurring waterborne diseases in the United States. *Giardia lamblia* cysts have been discovered in places as far apart as Estes Park, Colorado (near the Continental Divide); Missoula, Montana; Wilkes-Barre, Scranton, and Hazleton, Pennsylvania; and Pittsfield and Lawrence, Massachusetts, just to name a few. Giardiasis is characterized by intestinal symptoms that usually last one week or more and may be accompanied by one or more of the following: diarrhea, abdominal cramps, bloating, flatulence, fatigue, and weight loss. Although vomiting and fever are commonly listed as relatively frequent symptoms, people involved in waterborne outbreaks in the United States have not commonly reported them. Most *Giardia* infections persist for only 1 or 2 months, but some people experience a more chronic phase that can follow the acute phase or may become manifest without an antecedent acute illness. Loose

DID YOU KNOW?

Prescription drugs available in the United States to treat giardiasis include metronidazole and furazolidone. Based on a review of drug trials in which the efficacies of these drugs were compared (Davidson, 1984), metronidazole cured 92% of patients and furazolidone cured about 84% of patients. Later studies have confirmed the efficacy of metronidazole and furazolidone, particularly the latter for pediatric patients (e.g., Gardner and Hill, 2001).

stools and increased abdominal gassiness with cramping, flatulence, and burping characterize the chronic phase. Fever is not common, but malaise, fatigue, and depression may ensue (Rubenstein and Federman, 1985). For a small number of people, the persistence of infection is associated with the development of marked malabsorption and weight loss. Similarly, lactose (milk) intolerance can be a problem for some people. This can develop coincidentally with the infection or be aggravated by it, causing an increase in intestinal symptoms after ingestion of milk products. Some people may have several of these symptoms without evidence of diarrhea or have only sporadic episodes of diarrhea every three or four days. Still others may not have any symptoms at all. The problem, then, may not be one of determining whether or not someone is infected with the parasite but how harmoniously the host and the parasite can live together. When such harmony does not exist or is lost, it then becomes a problem of how to get rid of the parasite, either spontaneously or by treatment.

Giardiasis occurs worldwide. In the United States, *Giardia* is the parasite most commonly identified in stool specimens submitted to state laboratories for parasitologic examination. During a 3-year period, approximately 4% of 1 million stool specimens submitted to state laboratories tested positive for *Giardia* (CDC, 1979). Other surveys have demonstrated *Giardia* prevalence rates ranging from 1 to 20%, depending on the location and ages of persons studied. Giardiasis ranks among the top 20 infectious diseases that cause the greatest morbidity in Africa, Asia, and Latin America; it has been estimated that about 2 million infections occur per year in these regions (Walsh and Warren, 1979). People who are at highest risk for acquiring *Giardia* infection in the United States may be placed into five major categories:

1. People in cities whose drinking water originates from streams or rivers and whose water treatment process does not include filtration, or where filtration is ineffective because of malfunctioning equipment
2. Hikers, campers, and those who enjoy the outdoors
3. International travelers
4. Children who attend daycare centers, daycare center staff, and parents and siblings of children infected in daycare centers
5. Homosexual men

People in categories 1, 2, and 3 have in common the same general source of infection; that is, they acquire *Giardia* from fecally contaminated drinking water. City residents usually become infected because the municipal water treatment process does not include the filter necessary to physically remove the parasite from the water. The number of people in the United States at risk (i.e., the number who receive municipal drinking water from unfiltered surface water) is estimated to be 20 million. International travelers may also acquire the parasite from improperly treated municipal waters in cities or villages in other parts of the world, particularly in developing countries. In Eurasia, only travelers to Leningrad appear to be at increased risk. In prospective studies, 88% of U.S. and 35% of Finnish travelers to Leningrad who had negative stool tests for *Giardia* on departure to the Soviet Union developed symptoms of giardiasis and had positive tests for *Giardia* after they returned home (Brodsky et al., 1974). With the exception of visitors to Leningrad, however, *Giardia* has not been implicated as a major cause of traveler's diarrhea, as it has been detected in fewer than 2% of travelers who develop diarrhea. However, hikers and campers risk infection every time they drink untreated raw water from a stream or river. Persons in categories 4 and 5 become exposed through more direct contact with feces or an infected person—exposure to the soiled diapers of an infected child in cases associated with daycare centers or through direct or indirect anal–oral sexual practices in the case of homosexual men.

Although community waterborne outbreaks of giardiasis have received the greatest publicity in the United States during the past decade, about half of the *Giardia* cases discussed with the staff of the Centers for Disease Control and Prevention over a 3-year period had a daycare exposure as the most likely source of infection. In the United States, the highest incidence and prevalence of infection is found among children under 5 years of age, especially for those attending daycare centers (USEPA, 1999). Numerous outbreaks of *Giardia* in daycare centers have been reported; infection rates for children in daycare center outbreaks have been found to range from 21 to 44% in the United States and from 8 to 27% in Canada (Black et al., 1981). The highest infection rates are usually observed in children who wear diapers (1 to 3 years of age).

Local health officials and managers of water utility companies need to realize that sources of *Giardia* infection other than municipal drinking water exist. Armed with this knowledge, they are less likely to make a quick (and sometimes wrong) assumption that a cluster of recently diagnosed cases in a city is related to municipal drinking water. Of course, drinking water must not be ruled out as a source of infection when a larger than expected number of cases is recognized in a community, but the possibility that the cases are associated with a daycare center outbreak, drinking untreated stream water, or international travel should also be entertained.

To understand the finer aspects of *Giardia* transmission and strategies for control, drinking water practitioners must become familiar with several aspects of the parasite's biology. Two forms of the parasite exist: a *trophozoite* and a *cyst*, both of which are much larger than bacteria (Figure 10.7). Trophozoites live in the upper small intestine, where they attach to the intestinal wall by means

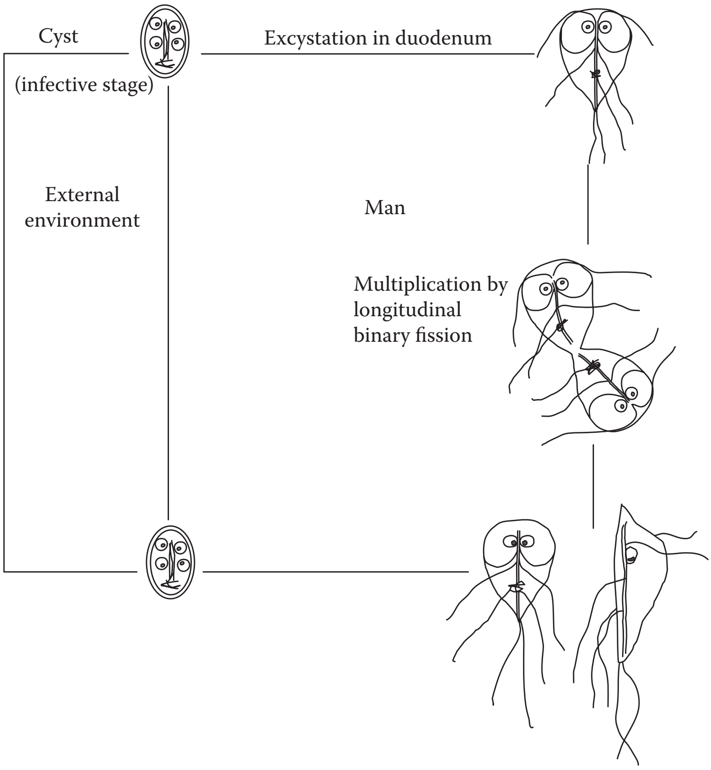

FIGURE 10.7 Life cycle of *Giardia lamblia*.

DID YOU KNOW?

Giardia has an incubation period of 1 to 8 weeks.

of a disc-shaped suction pad on their ventral surface. Trophozoites actively feed and reproduce at this location. At some time during the trophozoite's life, it releases its hold on the bowel wall and floats in the fecal stream through the intestine. As it makes this journey, it undergoes a morphologic transformation into an egg-like structure called a cyst. The cyst (about 6 to 9 nm in diameter and 8 to 12 µm in length) has a thick exterior wall that protects the parasite against the harsh elements that it will encounter outside the body. This cyst form of parasite is infectious to other people or animals. Most people become infected either directly (by hand-to-mouth transfer of cysts from the feces of an infected individual) or indirectly (by drinking feces-contaminated water). Less common modes of transmission include ingestion of fecally contaminated food and hand-to-mouth transfer of cysts after touching a fecally contaminated surface. After the cyst is swallowed, the trophozoite is liberated through the action of stomach acid and digestive enzymes and becomes established in the small intestine.

Although infection after ingestion of only one *Giardia* cyst is theoretically possible, the minimum number of cysts shown to infect a human under experimental conditions is 10 (Rendtorff, 1954). Trophozoites divide by binary fission about every 12 hours. What this means in practical terms is that if a person swallowed only a single cyst, reproduction at this rate would result in more than 1 million parasites 10 days later and 1 billion parasites by day 15.

The exact mechanism by which *Giardia* causes illness is not well understood, but it is not necessarily related to the number of organisms present. Nearly all of the symptoms, however, are related to dysfunction of the gastrointestinal tract. The parasite rarely invades other parts of the body, such as the gall bladder or pancreatic ducts. Intestinal infection does not result in permanent damage.

Data reported by the CDC indicate that *Giardia* is the most frequently identified cause of diarrheal outbreaks associated with drinking water in the United States. The remainder of this section is devoted specifically to waterborne transmissions of *Giardia*. *Giardia* cysts have been detected in 16% of potable water supplies (lakes, reservoirs, rivers, springs, groundwater) in the United States at an average concentration of 3 cysts per 100 L (Rose et al., 1991). Waterborne epidemics of giardiasis are a relatively frequent occurrence. In 1983, for example, *Giardia* was identified as the cause of diarrhea in 68% of waterborne outbreaks in which the causal agent was identified. From 1965 to 1982, more than 50 waterborne outbreaks were reported (CDC, 1984). In 1984, about 250,000 people in Pennsylvania were advised to boil their drinking water for 6 months because of *Giardia*-contaminated water.

Many of the municipal waterborne outbreaks of *Giardia* have been subjected to intense study to determine their cause. Several general conclusions can be made from data obtained in those studies. Waterborne transmission of *Giardia* in the United States usually occurs in mountainous regions where community drinking water obtained from clear running streams is chlorinated but not filtered before distribution. Although mountain streams appear to be clean, fecal contamination upstream by human residents or visitors, as well as by *Giardia*-infected animals such as beavers, has been well documented. Water obtained from deep wells is an unlikely source of *Giardia* because of the natural filtration of water as it percolates through the soil to reach underground cisterns. Wells that pose the greatest risk of fecal contamination are poorly constructed or improperly located ones. A few outbreaks have occurred in towns that include filtration in the water treatment process, but the filtration was not effective in removing *Giardia* cysts because of defects in filter construction, poor maintenance of the filter media, or inadequate pretreatment of the water before filtration. Occasional outbreaks have also occurred because of accidental cross-connections between water and sewage systems. Two major ingredients are necessary for a waterborne outbreak: (1) *Giardia* cysts must be present in untreated source water, and (2) the water purification process must fail to either kill or remove *Giardia* cysts from the water.

Although beavers are often blamed for contaminating water with *Giardia* cysts, the fact that they are responsible for introducing the parasite into new areas seems unlikely. Far more likely is that they are also victims: *Giardia* cysts may be carried in untreated human sewage discharged into the water by small-town sewage disposal plants or they may originate from cabin toilets that drain directly into streams and rivers. Backpackers, campers, and sports enthusiasts may also deposit *Giardia*-contaminated feces in the environment, which are subsequently washed into streams by rain. In support of this concept is a growing amount of data indicating a higher *Giardia* infection rate in beavers living downstream from U.S. national forest campgrounds when compared with beavers living in more remote areas that have a near zero rate of infection.

Although beavers may be unwitting victims of the *Giardia* story, they still play an important part in the contamination scheme, because they can (and probably do) serve as amplifying hosts. An *amplifying host* is one that is easy to infect, serves as a good habitat for the parasite to reproduce, and, in the case of *Giardia*, returns millions of cysts to the water for every one ingested. Beavers are especially important in this regard, because they tend to defecate in or very near the water, which ensures that most of the *Giardia* cysts excreted are returned to the water.

The microbial quality of water resources and the management of the microbially laden wastes generated by the burgeoning animal agriculture industry are critical local, regional, and national problems. Animal wastes from cattle, hogs, sheep, horses, poultry, and other livestock can contain high concentrations of microorganisms, such as *Giardia*, that are pathogenic to humans.

The contribution of other animals to waterborne outbreaks of *Giardia* is less clear. Muskrats (another semiaquatic animal) have been found in several parts of the United States to have high infection rates (30 to 40%) (Frost et al., 1980). Studies have shown that muskrats can be infected with *Giardia* cysts from humans and beavers. Occasional *Giardia* infections have been reported in coyotes, deer, elk, cattle, dogs, and cats (but not in horses and sheep) encountered in mountainous regions of the United States. Naturally occurring *Giardia* infections have not been found in most other wild animals (e.g., bear, nutria, rabbit, squirrel, badger, marmot, skunk, ferret, porcupine, mink, raccoon, river otter, bobcat, lynx, moose, bighorn sheep).

With regard to what is required to kill or remove *Giardia* cysts from a contaminated water supply, we know that cysts can survive in cold water (4°C) for at least 2 months, and they are killed instantaneously by boiling water (100°C) (Bingham et al., 1979). We do not know how long the cysts will remain viable at other water temperatures (e.g., at 0°C or in a canteen at 15 to 20°C), nor do we know how long the parasite will survive on various environment surfaces, such as under a pine tree, in the sun, on a diaper-changing table, or in carpets in a daycare center.

The effect of chemical disinfection (chlorination, for example) on the viability of *Giardia* cysts is an even more complex issue. The number of waterborne outbreaks of *Giardia* that have occurred in communities where chlorination was employed as a disinfectant process demonstrates that the amount of chlorine used routinely for municipal water treatment is not effective against *Giardia* cysts. These observations have been confirmed in the laboratory under experimental conditions (Jarroll et al., 1979). This does not mean that chlorine does not work at all. It does work under certain favorable conditions. Without getting too technical, gaining some appreciation of the problem can be achieved by taking a look at a few of the variables that influence the efficacy of chlorine as a disinfectant:

- *Water pH*—At pH values above 7.5, the disinfectant capability of chlorine is greatly reduced.
- *Water temperature*—The warmer the water, the higher the efficacy. Chlorine does not work in ice-cold water from mountain streams.
- *Organic content of the water*—Mud, decayed vegetation, or other suspended organic debris in water chemically combines with chlorine, making it unavailable as a disinfectant.
- *Chlorine contact time*—The longer that *Giardia* cysts are exposed to chlorine, the more likely it is that the chemical will kill them.

- *Chlorine concentration*—The higher the chlorine concentration, the more likely it is that chlorine will kill *Giardia* cysts. Most water treatment facilities try to add enough chlorine to give a free (unbound) chlorine residual at the customer tap of 0.5 mg per liter of water.

These five variables are so closely interrelated that improving one can often compensate for another; for example, if chlorine efficacy is expected to be low for icy stream water, the chlorine contact time or chlorine concentration, or both, could be increased. In the case of *Giardia*-contaminated water, producing safe drinking water with a chlorine concentration of 1 mg per liter and contact time as short as 10 minutes might be possible if all the other variables are optimal—a pH of 7.0, water temperature of 25°C, and total organic content of the water close to zero. On the other hand, if all of these variables are unfavorable—pH of 7.9, water temperature of 5°C, and high organic content—chlorine concentrations in excess of 8 mg/L with several hours of contact time may not be consistently effective. Because water conditions and water treatment plant operations (especially those related to water retention time and, therefore, to chlorine contact time) vary considerably in different parts of the United States, neither the USEPA nor the CDC has been able to identify a chlorine concentration that would be safe yet effective against *Giardia* cysts under all water conditions. For this reason, the use of chlorine as a preventive measure against waterborne giardiasis generally has been used under outbreak conditions when the amount of chlorine and contact time have been tailored to fit specific water conditions and the existing operational design of the water utility. In an outbreak, for example, the local health department and water utility may issue an advisory to boil water, may increase the chlorine residual at the consumer's tap from 0.5 mg/L to 1 or 2 mg/L, and, if the physical layout and operation of the water treatment facility permit, increase the chlorine contact time. These are emergency procedures intended to reduce the risk of transmission until a filtration device can be installed or repaired or until an alternative source of safe water (a well, for example) can be made operational.

The long-term solution to the problem of municipal waterborne outbreaks of giardiasis involves improvements in and more widespread use of filters in the municipal water treatment process. The sand filters most commonly used in municipal water treatment today cost millions of dollars to install, which makes them unattractive for many small communities. The pore sizes in these filters are not sufficiently small to remove *Giardia* (6 to 9 μm by 8 to 12 μm). For the sand filter to remove *Giardia* cysts from the water effectively, the water must receive some additional treatment before it reaches the filter. The flow of water through the filter bed must also be carefully regulated.

An ideal prefilter treatment for muddy water would include sedimentation (a holding pond where large suspended particles are allowed to settle out by the action of gravity) followed by flocculation or coagulation (the addition of chemicals such as alum or ammonium to cause microscopic particles to clump together). The sand filter easily removes the large particles resulting from the flocculation–coagulation process, including *Giardia* cysts bound to other microparticulates. Chlorine is then added to kill the bacteria and viruses that may escape the filtration process. If the water comes from a relatively clear source, chlorine may be added to the water before it reaches the filter.

The successful operation of a complete waterworks operation is a complex process that requires considerable training. Troubleshooting breakdowns or recognizing the potential problems in the system before they occur often requires the skills of an engineer. Unfortunately, most small water utilities with water treatment facilities that include filtration cannot afford the services of a full-time engineer. Filter operation or maintenance problems in such systems may not be detected until a *Giardia* outbreak is recognized in the community. The bottom line is that, although filtration is the best protection against waterborne giardiasis that water treatment technology has to offer for municipal water systems, it is not infallible. For municipal water filtration facilities to work properly, they must be properly constructed, operated, and maintained.

Whenever possible, persons outdoors should carry drinking water of known purity with them. When this is not practical and when water from streams, lakes, ponds, or other outdoor sources must be used, time should be taken to properly disinfect the water before drinking it.

Cryptosporidium

Ernest E. Tyzzer first described the protozoan parasite *Cryptosporidium* in 1907. Tyzzer frequently found a parasite in the gastric glands of laboratory mice. He identified the parasite as a sporozoan but of uncertain taxonomic status and named it *Cryptosporidium muris*. Later, in 1910, after more detailed study, he proposed *Cryptosporidium* as a new genus and *muris* as the type of species. Amazingly, except for developmental stages, Tyzzer's original description of the life cycle (Figure 10.8) was later confirmed by electron microscopy. In 1912, Tyzzer described another new species, *Cryptosporidium parvum* (Tyzzer, 1912).

For almost 50 years, Tyzzer's discovery of the genus *Cryptosporidium* remained (like himself) relatively obscure because it appeared to be of no medical or economic importance. Slight rumblings of the importance of the genus began to be felt in the medical community when Slavin (1955) wrote about a new species, *Cryptosporidium melagridis*, which was associated with illness and death in turkeys. Interest remained slight even when *Cryptosporidium* was found to be associated with bovine diarrhea (Panciera et al., 1971).

Not until 1982 did worldwide interest focus on the study of organisms in the genus *Cryptosporidium*. At that time, the medical community and other interested parties were beginning a full-scale, frantic effort to find out as much as possible about acquired immune deficiency syndrome (AIDS), and the CDC reported that 21 AIDS-infected males from six large cities in the United States had severe protracted diarrhea caused by *Cryptosporidium*. It was in 1993, though, that *Cryptosporidium*—the "pernicious parasite"—made itself and Milwaukee famous (Mayo Foundation, 1996).

> ***Note:*** The *Cryptosporidium* outbreak in Milwaukee caused the deaths of 100 people—the largest episode of waterborne disease in the United States in the 70 years since health officials began tracking such outbreaks.

The massive waterborne outbreak in Milwaukee (more than 400,000 persons developed acute and often prolonged diarrhea or other gastrointestinal symptoms) increased interest in *Cryptosporidium* at an exponential level. The Milwaukee incident spurred both public interest and the interest of public health agencies, agricultural and environmental agencies and groups, and suppliers of drinking

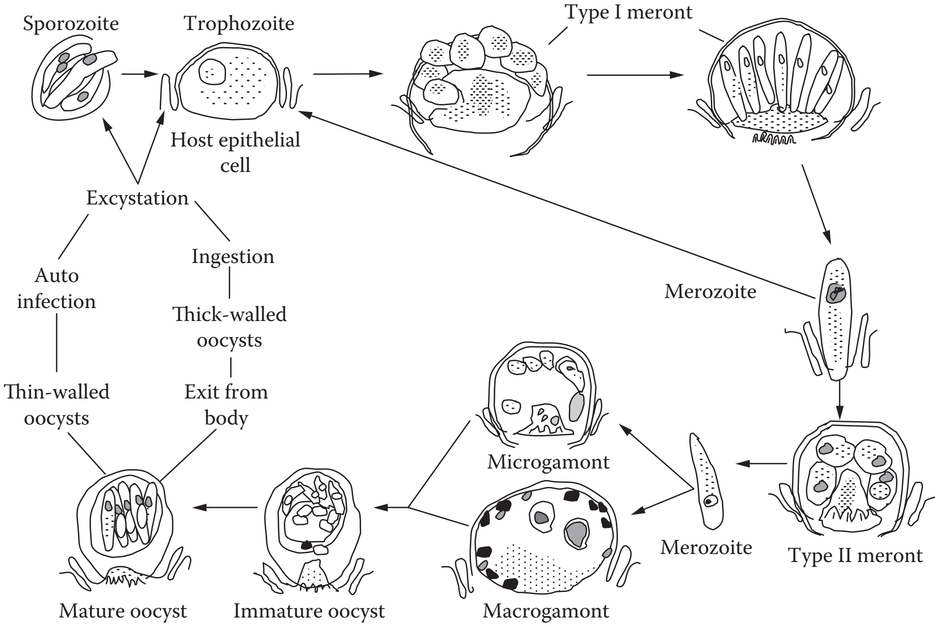

FIGURE 10.8 Life cycle of *Cryptosporidium parvum*.

TABLE 10.1
Valid Named Species of *Cryptosporidium*

Species	Host	Species	Host
C. baileyi	Chicken	*C. nasorium*	Fish
C. felis	Domestic cat	*C. parvum*	House mouse
C. meleagridis	Turkey	*C. serpentis*	Corn snake
C. murishouse	House mouse	*C. wrairi*	Guinea pig

Source: Fayer, R. et al., in *Cryptosporidium and Cryptosporidiosis*, Fayer, R., Ed., CRC Press, Boca Raton, FL, 1997, pp. 1–41.

water. This increase in interest level and concern resulted in new studies of *Cryptosporidium*, with an emphasis on developing methods for recovery, detection, prevention, and treatment (Fayer et al., 1997). The USEPA is particularly interested in this pathogen. In its reexamination of regulations on water treatment and disinfection, the USEPA issued a maximum contaminant level goal (MCLG) and contaminant candidate list (CCL) for *Cryptosporidium*. Its similarity to *Giardia lamblia* and the need for an efficient conventional water treatment capable of eliminating viruses forced the USEPA to regulate surface water supplies in particular. The Enhanced Surface Water Treatment Rule (ESWTR) includes regulations ranging from watershed protection to specialized operation of treatment plants (certification of operators and state overview) and effective chlorination. Protection against *Cryptosporidium* includes control of waterborne pathogens such as *Giardia* and viruses (De Zuane, 1997).

Cryptosporidium Basics

Cryptosporidium is one of several single-celled protozoan genera in the phylum Apircomplexa (all referred to as coccidian). *Cryptosporidium* along with other genera in the phylum Apircomplexa develop in the gastrointestinal tract of vertebrates through all of their life cycle; in short, they live in the intestines of animals and people. This microscopic pathogen causes a disease called *cryptosporidiosis*. The dormant (inactive) form of *Cryptosporidium* is called an *oocyst* and is excreted in the feces of infected humans and animals. The tough-walled oocysts survive under a wide range of environmental conditions.

Several species of *Cryptosporidium* were incorrectly named after the host in which they were found, and subsequent studies have invalidated many species. Now, eight valid species of *Cryptosporidium* (see Table 10.1) have been named. Upton (1997) reported that *C. muris* infects the gastric glands of laboratory rodents and several other mammalian species but is not known to infect humans (even though several texts state otherwise). *C. parvum*, however, infects the small intestine of an unusually wide range of mammals, including humans, and is the zoonotic species responsible for human cryptosporidiosis. In most mammals, *C. parvum* is predominately a parasite of neonate (newborn) animals. Even though exceptions occur, older animals generally develop poor infections, even when unexposed previously to the parasite (Upton, 1997). Humans are the one host that can be seriously infected at any time in their lives, and only previous exposure to the parasite results in either full or partial immunity to challenge infections.

Oocysts are present in most surface bodies of water across the United States, many of which supply public drinking water. Oocysts are more prevalent in surface waters when heavy rains increase runoff of wild and domestic animal wastes from the land or when sewage treatment plants are overloaded or break down. Only laboratories with specialized capabilities can detect the presence of *Cryptosporidium* oocysts in water. Unfortunately, current sampling and detection methods are unreliable. Recovering oocysts trapped on the material used to filter water samples is difficult. When a sample has been obtained, however, determining whether the oocyst is alive and if it is *C. parvum* and thus can infect humans can be easily accomplished by looking at the sample under a microscope.

The number of oocysts detected in raw (untreated) water varies with location, sampling time, and laboratory methods. Water treatment plants remove most, but not always all, oocysts. Low numbers of oocysts are sufficient to cause cryptosporidiosis, but the low numbers of oocysts sometimes present in drinking water are not considered cause for alarm in the public. Protecting water supplies from *Cryptosporidium* demands multiple barriers. Why? Because *Cryptosporidium* oocysts have tough walls that can withstand many environmental stresses and are resistant to chemical disinfectants such as chlorine that are traditionally used in municipal drinking water systems.

Physical removal of particles, including oocysts, from water by filtration is an important step in the water treatment process. Typically, water pumped from rivers or lakes into a treatment plant is mixed with coagulants, which help settle out particles suspended in the water. If sand filtration is used, even more particles are removed. Finally, the clarified water is disinfected and piped to customers. Filtration is the only conventional method now in use in the United States for controlling *Cryptosporidium*.

Ozone is a strong disinfectant that kills protozoa if sufficient doses and contact times are used, but ozone leaves no residual for killing microorganisms in the distribution system, as does chlorine. The high costs of new filtration or ozone treatment plants must be weighed against the benefits of additional treatment. Even well-operated water treatment plants cannot ensure that drinking water will be completely free of *Cryptosporidium* oocysts. Water treatment methods alone cannot solve the problem; watershed protection and monitoring of water quality are critical. Land use controls such as septic system regulations and best management practices to control runoff can help keep human and animal wastes out of water.

Under the Surface Water Treatment Rule of 1989, public water systems must filter surface water sources unless water quality and disinfection requirements are met and a watershed control program is maintained. This rule, however, did not address *Cryptosporidium*. The USEPA has now set standards for turbidity (cloudiness) and coliform bacteria (which indicate that pathogens are probably present) in drinking water. Frequent monitoring must occur to provide officials with early warning of potential problems to enable them to take steps to protect public health. Unfortunately, no water quality indicators can reliably predict the occurrence of cryptosporidiosis. More accurate and rapid assays of oocysts will make it possible to notify residents promptly if their water supply is contaminated with *Cryptosporidium* and thus avert outbreaks. The bottom line is that the collaborative efforts of water utilities, government agencies, healthcare providers, and individuals are needed to prevent outbreaks of cryptosporidiosis.

Cryptosporidiosis

> *Cryptosporidium parvum* is an important emerging pathogen in the U.S. and a cause of severe, life-threatening disease in patients with AIDS. No safe and effective form of specific treatment for cryptosporidiosis has been identified to date. The parasite is transmitted by ingestion of oocysts excreted in the feces of infected humans or animals. The infection can therefore be transmitted from person-to-person, through ingestion of contaminated water (drinking water and water used for recreational purposes) or food, from animal to person, or by contact with fecally contaminated environmental surfaces. Outbreaks associated with all of these modes of transmission have been documented. Patients with human immunodeficiency virus infection should be made more aware of the many ways that *Cryptosporidium* species are transmitted, and they should be given guidance on how to reduce their risk of exposure.
>
> **Juranek (1995)**

Since the Milwaukee outbreak, concern about the safety of drinking water in the United States has increased, and new attention has been focused on determining and reducing the risk of acquiring cryptosporidiosis from community and municipal water supplies. Cryptosporidiosis is spread by putting something in the mouth that has been contaminated with the stool of an infected person or animal. In this way, people swallow the *Cryptosporidium* parasite. As mentioned earlier, a person can become infected by drinking contaminated water or eating raw or undercooked food contaminated with *Cryptosporidium* oocysts, by direct contact with the droppings of infected animals or stools of infected humans, or by hand-to-mouth transfer of oocysts from surfaces that may have become contaminated with microscopic amounts of stool from an infected person or animal.

Symptoms may appear 2 to 10 days after infection by the parasite. Although some persons may not have symptoms, others have watery diarrhea, headache, abdominal cramps, nausea, vomiting, and low-grade fever. These symptoms may lead to weight loss and dehydration. In otherwise healthy persons, these symptoms usually last 1 to 2 weeks, at which time the immune system is able to defeat the infection. In persons with suppressed immune systems, such as persons who have AIDS or who recently have had an organ or bone marrow transplant, the infection may continue and become life threatening.

Currently, no safe and effective cure for cryptosporidiosis exists. People with normal immune systems improve without taking antibiotic or antiparasitic medications. The treatment recommended for this diarrheal illness is to drink plenty of fluids and to get extra rest. Physicians may prescribe medication to slow the diarrhea during recovery. The best way to prevent cryptosporidiosis is to

- Avoid water or food that may be contaminated.
- Wash hands after using the toilet and before handling food.
- Be sure, if you work in a daycare center, to wash your hands thoroughly with plenty of soap and warm water after every diaper change, even if you wear gloves when changing diapers.

During community-wide outbreaks caused by contaminated drinking water, drinking water practitioners should inform the public to boil drinking water for 1 minute to kill the *Cryptosporidium* parasite.

Cyclospora

Cyclospora organisms, which until recently were considered blue–green algae, were discovered at the turn of the 19th century. The first human cases of *Cyclospora* infection were reported in the 1970s. In the early 1980s, *Cyclospora* was recognized as a pathogen in patients with AIDS. We now know that *Cyclospora* is endemic in many parts of the world and appears to be an important cause of traveler's diarrhea. *Cyclospora* are two to three times larger than *Cryptosporidium* but otherwise have similar features. *Cyclospora* diarrheal illness in patients with healthy immune systems can be cured by a week of therapy with timethoprim–sulfamethoxazole (TMP–SMX).

So, what exactly is *Cyclospora*? In 1998, the CDC described *Cyclospora cayetanensis* as a unicellular parasite previously known as a cyanobacterium-like (blue–green algae-like) or coccidian-like body. The disease is known as *cyclosporiasis*. *Cyclospora* infects the small intestine and causes an illness characterized by diarrhea with frequent stools. Other symptoms can include loss of appetite, bloating, gas, stomach cramps, nausea, vomiting, fatigue, muscle ache, and fever. Some individuals infected with *Cyclospora* may not show symptoms. Since the first known cases of illness caused by *Cyclospora* infection were reported in the medical journals in the 1970s, cases have been reported with increasing frequency from around the world (in part because of the availability of better techniques for detecting the parasite in stool specimens).

Huang et al. (1995) detailed what they believe is the first known outbreak of diarrheal illness associated with *Cyclospora* in the United States. The outbreak, which occurred in 1990, consisted of 21 cases of illness among physicians and others working at a Chicago hospital. Contaminated tap water from a physicians' dormitory at the hospital was the probable source of the organisms. The tap water probably picked up the organism while in a storage tank at the top of the dormitory after the failure of a water pump.

The transmission of *Cyclospora* is not a straightforward process. When infected persons excrete the oocyst state of *Cyclospora* in their feces, the oocysts are not infectious and may require from days to weeks to become so (i.e., to sporulate). Thus, transmission of *Cyclospora* directly from an infected person to someone else is unlikely; however, indirect transmission can occur if an infected

DID YOU KNOW?

Cyclospora organisms have not yet been grown in tissue cultures or laboratory animal models.

person contaminates the environment and oocysts have sufficient time, under appropriate conditions, to become infectious. For example, *Cyclospora* may be transmitted by ingestion of water or food contaminated with oocysts. Outbreaks linked to contaminated water, as well as outbreaks linked to various types of fresh produce, have been reported (Herwaldt et al., 1997). The various modes of transmission and sources of infection are not yet fully understood nor is it known whether animals can be infected and serve as sources of infection for humans.

Persons of all ages are at risk for infection. Persons living or traveling in developing countries may be at increased risk, but infection can be acquired worldwide, including in the United States. In some countries of the world, infection appears to be seasonal. Based on currently available information, avoiding water or food that may be contaminated with stool is the best way to prevent infection. Reinfection can occur.

> ***Note:*** Pathogenic parasites are not easily removed or eliminated by conventional treatment and disinfection unit processes (De Zuane, 1997). This is particularly true for *Giardia lamblia*, *Cryptosporidium*, and *Cyclospora*. Filtration facilities can be adjusted with regard to depth, prechlorination, filtration rate, and backwashing to become more effective in the removal of cysts. The pretreatment of protected watershed raw water is a major factor in the elimination of pathogenic protozoa.

TOXIC POLLUTANTS

There are hundreds of potentially toxic water pollutants. Of these, the USEPA, under the Clean Water Act, regulates more than 100 pollutants of special concern. These include arsenic and the metals mercury, lead, cadmium, nickel, copper, and zinc. Organic toxic pollutants include benzene, toluene, and many pesticides, herbicides, and insecticides.

NONTOXIC POLLUTANTS

Nontoxic pollutants include chemicals such as chlorine, phenols, iron, and ammonia. Color and heat are also nontoxic pollutants regulated under the Clean Water Act. Pure water is colorless, but water in natural water systems is often colored by foreign substances; for example, many facilities discharge colored effluents into surface water systems. Colored water is not aesthetically acceptable to the general public; thus, the intensity of the color of water that can be released is regulated by law. Heat or thermal nontoxic pollution can cause problems but is not ordinarily a serious pollutant, although in localized situations it can cause problems with temperature-sensitive organism populations.

MACROSCOPIC POLLUTANTS

Macroscopic pollutants include large visible items (such as floatables, flotsam and jetsam, nurdles, marine debris, and shipwrecks) contaminating or polluting surface water bodies (lakes, rivers, streams, oceans). In an urban stormwater context, these large visible items are termed *floatables*—waterborne litter and debris, including toilet paper, condoms, tampon applicators, plastic bags, six-packs rings, food cans, jugs, cigarette butts, yard waste, polystyrene foam, metal, and glass beverage bottles (see Figures 10.9 to 10.12 and Case Study 10.3), as well as oil and grease. Floatables come from street litter that ends up in storm drains (catch basins) and sewers. Floatables can be discharged into the surrounding waters during certain storm events when water flow into treatment plants (i.e.,

FIGURE 10.9 Floatable litter in beach grass along shore of Chesapeake Bay, Norfolk, Virginia. (Photograph by F.R. Spellman.)

FIGURE 10.10 Stormwater outfalls at Ocean View Beach, Chesapeake Bay, Norfolk, Virginia. (Photograph by F.R. Spellman.)

FIGURE 10.11 Stormwater outfall pipes at Ocean View Beach, Chesapeake Bay, Norfolk, Virginia. (Photograph by F.R. Spellman.)

FIGURE 10.12 Floatable litter along Ocean View Beach, Chesapeake Bay, Norfolk, Virginia. (Photograph by F.R. Spellman.)

those without overflow storage lagoons) exceeds treatment capacity. Floatables contribute to visual pollution, they detract from the pleasure of outdoor experiences, and they pose a threat to wildlife and human health.

The terms *flotsam* and *jetsam*, as used currently, refer to any kind of marine debris. The two terms have different meanings, however. Jetsam refers to materials jettisoned voluntarily (usually to lighten the load in an emergency) into the sea by the crew of a ship. Flotsam describes goods that are floating on the water without having been thrown in deliberately, often after a shipwreck.

A *nurdle* (strongly resembling a fish egg), also known as mermaid's tears, is a preproduction plastic pellet or plastic resin pellet typically under 5 mm in diameter and is a major component of marine debris. It is estimated that at least 60 billion pounds of nurdles are manufactured annually in the United States alone (Heal the Bay, 2009). Not only are they a significant source of ocean and beach pollution, but nurdles also frequently find their way into the digestive tracts of various marine creatures.

In the past, the major source of *marine debris* was naturally occurring driftwood. In the modern era, however, the increasing use of plastic with its subsequent discharge by humans into waterways has resulted in plastic materials and products being the most prevalent form (as much 80%) of marine debris. Plastics are persistent water pollutants because they do not biodegrade as many other substances do. Not only is waterborne plastic unsightly but it also poses a serious threat to fish, seabirds, marine reptiles, and marine mammals, as well as to boats and coastal habitations (NOAA, 2009). *Shipwrecks* are large derelict ships that have been abandoned at sea. In addition to the navigational hazards that shipwrecks present, they also result in oil spillage, flotsam, and the release of lubricants, greases, paint, and heavy metals such as mercury.

DID YOU KNOW?

It has been estimated that container ships lose over 10,000 containers at sea each year, usually during a storm (Podsada, 2001). One famous spillage occurred in the Pacific Ocean in 1992, when thousands of rubber ducks and other toys went overboard during a storm. The toys have since been found all over the world; scientists have used the incident to gain a better understanding of ocean currents.

Case Study 10.3. River Cleanup

Volunteers for the biannual Conestoga River cleanup found everything from tires, washing machines, bicycles, and motor scooters to candy wrappers and car engines in the river—several truckloads of trash. Low water levels allowed volunteers to remove trash in the middle of the river, where in higher water seasons it had been unreachable. They will sell the metal for scrap, and the Lancaster County Solid Waste Authority will waive the tipping fee for disposing of the rest of the illegally dumped trash. Volunteers also planted bushes (donated by the Chesapeake Bay Foundation) on the stream banks, to serve the dual function of erosion and dumping prevention. Organizers see signs that the river cleanup program is helping in several ways. More volunteers turn out each time for the cleanup, allowing the group to expand their coverage. They also feel the message is getting through to people that the river is not the place to dump their trash. The river gives up less trash each year. State Representative Mike Sturla hopes that people are beginning to understand that "this is not the place to put it" (Rutter, 1998).

PHARMACEUTICALS AND PERSONAL CARE PRODUCTS

The acronym PPCPs (for pharmaceuticals and personal care products) was coined by Daughton and Ternes (1999). Sometimes referred to as "emerging pollutants," PPCPs are not truly emerging; rather, it is the understanding of the significance of their occurrence in the environment that is beginning to develop (USEPA, 2005). PPCPs represent a very broad, diverse collection of thousands of chemical substances, including prescription (see Figure 10.13), veterinary, and over-the-counter (OTC) therapeutic drugs; fragrances; cosmetics; sunscreen agents; diagnostic agents; nutraceuticals (vitamins); biopharmaceuticals (medical drugs produced by biotechnology); growth-enhancing chemicals used in livestock operations; and many others. This broad collection of substances refers, in general, to any product used by individuals for personal health or cosmetic reasons (e.g., anti-aging cleansers, toners, exfoliators, facial masks, serums, and lip balm). Sources of PPCPs include the following:

- Human bathing, shaving, and swimming
- Illicit drugs
- Veterinary drug use, especially antibiotics and steroids

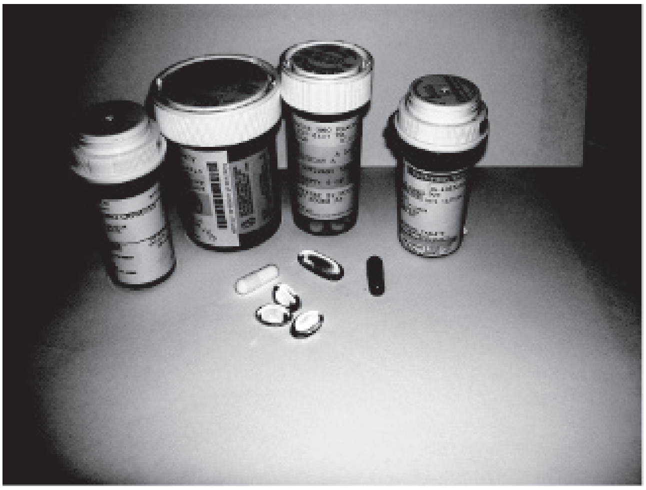

FIGURE 10.13 PPCPs: assorted nutraceuticals and prescription drugs. (Photograph by F.R. Spellman.)

DID YOU KNOW?

Although PPCPs are used in large quantities, the concentrations of PPCPs currently being found in water suppliers are very small. The laboratory tests for these compounds do not report concentrations in parts per million (ppm) or parts per billion (ppb) but instead report concentrations in parts per trillion (ppt), which is the same as nanograms per liter. One part per million is equivalent to a shot glass full of water dipped from an Olympic swimming that is 2 meters deep. One part per billion is equivalent to one drop from an eye dropper filled from the same Olympic pool. One part per trillion is equivalent to 1 drop in 20 Olympic pools that are 2 meters deep, or 1 second in 31,700 years (Spellman, 2015).

- Agribusiness
- Residues from pharmaceutical manufacturing
- Residues from hospitals

People contribute PPCPs to the environment when:

- Medication residues pass out of the body and into sewer lines.
- Externally applied drugs and personal care products they use wash down the shower drain.
- Unused or expired medications are placed in the trash.

The problem with PPCPs is that we do not know what we do not know about them—the jury is still out on their exact environmental impact. Thus far, studies have shown that pharmaceuticals are present in our nation's water bodies. Further research suggests that certain drugs may cause ecological harm. More research is needed to determine the extent of ecological harm and any role it may have in potential human health effects. To date, scientists have found no evidence of adverse human health effects from PPCPs in the environment.

EMERGING CONTAMINANTS*

We are quickly approaching a time when we will enter into the fifth generation of people exposed to toxic chemicals from before conception to adulthood. In a few cases, we have identified the hazards of certain chemicals and their compounds and have implemented restrictions. One well-known chemical compound that comes to mind with regard to its environmental harm and subsequent banning is dichlorodiphenyltrichloroethane (DDT). Let's take a look at DDT before moving on to other chemicals.

DDT

The insecticide DDT was initially produced in the 1920s and was developed as the first of the modern synthetic insecticides in the 1940s. It was extensively used between 1945 and 1965 to great effect to control and eradicate insects that were responsible for malaria, typhus, and other insect-borne human diseases among both military and civilian populations, as well as for insect control in crop and livestock production, institutions, homes, and gardens. DDT was an excellent insecticide because even at low levels it was very effective at killing a wide variety of insects. The quick success of DDT as a pesticide and its broad use in the United States and other countries led to the development of resistance by many insect pest species. Moreover, the chemical properties that made this a good pesticide also made it persist in the environment for a long time.

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* Adapted from Spellman, F.R., *Personal Care Products and Pharmaceuticals in Wastewater and the Environment*, DEStech Publishers, Lancaster, PA, 2014.

DID YOU KNOW?

Eagles, and other birds are thriving after the 1972 DDT ban (USEPA, 2012). Populations of relatively rare birds such as bald eagles, brown pelicans, ospreys, and peregrine falcons are increasing and becoming more visible in many U.S. Fish and Wildlife national refuges.

This persistence led to accumulation of the pesticide in non-target species, especially raptorial birds (e.g., falcons, eagles). Due to the properties of DDT, the concentration of DDT in birds could be much higher than concentrations in insects or soil. Birds at the top of the food chain (e.g., pelicans, falcons, eagles, grebes) had the highest concentrations of DDT. Although the amount of DDT did not kill the birds, it interfered with calcium metabolism, which led to thin eggshells. As a result, eggs would crack during development, allowing bacteria to enter, which killed the developing embryos. This had a great impact on the population levels of these birds. Peregrine falcons and brown pelicans were placed on the endangered species list in the United States, partially due to the declining reproductive success of the birds due to DDT exposure.

Rachel Carson, that unequaled environmental journalist of profound vision and insight, published *Silent Spring* in 1962, which helped to draw public attention to this problem and to the need for better pesticide controls. This was the very beginning of the environmental movement in the United States and is an excellent example of reporting by someone affiliated with the media that identified a problem and warned of many similar problems that could occur unless restrictions were put in place related to chemical pesticide use. Partially as a result of Carson's flagship book, scientists documented the link between DDT and eggshell thinning. This resulted in the U.S. Department of Agriculture, the federal agency responsible for regulating pesticides before formation of the U.S. Environmental Protection Agency in 1970, initiating regulatory actions in the later 1950s and 1960s to prohibit many uses of DDT because of mounting evidence of the pesticide's declining benefits and environmental and toxicological effects.

In 1972, the USEPA issued a cancellation order for DDT based on adverse environmental effects of its use, such as those to wildlife (the known effects on other species, such as raptors), as well as the potential human health risks posed by DDT. Since then, studies have continued, and a causal relationship between DDT exposure and reproductive effects is suspected. Today, DDT is classified as a probable human carcinogen by U.S. and international authorities. This classification is based on animal studies in which some animals developed liver tumors. Known to be very persistent in the environment, DDT will accumulate in fatty tissues and can travel long distances in the upper atmosphere. Since the use of DDT was discontinued in the United States, its concentration in the environment and animals has decreased, but because of its persistence residues of concern from historical use still remain. Moreover, DDT is still used in developing countries because it is inexpensive and highly effective. Other alternatives are too expensive for these other countries to use (USEPA, 2012).

A Brief History of the Development and Use of Chemicals

Humankind's development of chemical manufacturing and our use of chemicals can be traced back to the earliest time of recorded history, including the 4000 BCE accounts of glassmaking, brickmaking, and copper smelting practices; the use of coal in 3000 BCE for fuel and to produce asphalt for use in adhesives, waterproofing, and road building; the brewing of beer by the Sumerians in 1750 BCE; Aristotle proposing in 350 BCE the use of distillation to desalinate seawater; sulfuric acid being produced by the lead-chamber method in 1746; Charles Goodyear vulcanizing rubber in 1839; Alfred Nobel inventing dynamite in 1866; Alexander Fleming discovering penicillin in 1928; DuPont manufacturing the refrigerant gas Freon®; the drug firm Eli Lilly patenting Prozac® in 1988; and Pfizer introducing Viagra® in 1998. Chemicals continue to be developed, and the motive force driving most chemical development and use is our persistent drive to maintain or achieve the so-called "good life" that many of us desire.

Here are a few fascinating numbers and facts. There are approximately 13,500 chemical manufacturing facilities in the United States owned by more than 9000 companies. There are 84,000 chemicals in use in the United States, with approximately 700 new ones being added each year. Manufacturers generally manufacture chemicals classified into two groups: commodity chemicals and specialty chemicals. Commodity chemical manufacturers produce large quantities of basic and relatively inexpensive compounds in large plants, often built specially to make one chemical. Commodity plants often run continuously, typically shutting down only a few weeks a year for maintenance. Specialty-batch or performance chemical manufacturers produce smaller quantities of more expensive chemicals that are used less frequently on an as-needed basis. Facilities are located all over the country, with many companies located in Texas, Ohio, New Jersey, Illinois, Louisiana, Pennsylvania, and North and South Carolina.

Let's get back to the numbers. In the United States, under the Toxic Substances Control Act (TSCA), five chemicals were banned—only five. This may seem odd because, when the TSCA was passed in 1976, 60,000 chemicals were included in the inventory of existing chemicals. Since that time, the USEPA has only successfully restricted or banned five chemicals and has only required testing on another 200 existing chemicals. An additional 24,000 chemicals have entered the marketplace, so the TSCA inventory now includes more than 84,000 chemicals. The chemical industry is an essential contributor to the U.S. economy, with shipments valued at about $555 billion per year.

If we know several chemicals are dangerous or harmful to us and our environment, why have only five of them been banned? The best answer is that under TSCA it is difficult to ban a chemical that predated the Rule and thus has been grandfathered. So, which five chemicals has the TSCA banned? If you were a knowledgeable contestant on the television show *Jeopardy*, you might respond with, "What are PCBs, chlorofluorocarbons, dioxin, hexavalent chromium, and asbestos?" An easy question with a straightforward answer, right? Well, not so fast. Technically, you would be incorrect with that answer. Even though the USEPA did initially ban most asbestos-containing products in the United States, in 1991 the rule was vacated and remanded by the Fifth Circuit Court of Appeals. As a result, most of the original bans on the manufacture, importation, processing, or distribution in commerce for most asbestos-containing product categories originally covered in the 1989 final rule were overturned. Only the bans on corrugated paper, rollboard, commercial paper, specialty paper, and flooring felt and any new uses of asbestos remained banned under the 1989 rule. Most asbestos-containing products can still be legally manufactured, imported, processed, and distributed in the United States, even though more than 45,000 Americans have died from asbestos exposure in the past three decades. According to the U.S. Geological Survey, the production and use of asbestos have declined significantly (USEPA, 2014).

Endocrine Disruptors

A growing body of evidence suggests that humans and wildlife species have suffered adverse health effects after exposure to endocrine disrupting chemicals (also referred to as *environmental endocrine disruptors*). Environmental endocrine disruptors can be defined as exogenous agents that interfere with the production, release, transport, metabolism binding, action, or elimination of natural hormones in the body responsible for maintaining homeostasis and regulating developmental processes. The definition reflects a growing awareness that the issue of endocrine disruptors in the environment extends considerably beyond that of exogenous estrogens and includes antiandrogens and agents that act on other components of the endocrine system such as the thyroid and pituitary glands (Kavlock et al., 1996). Disrupting the endocrine system can occur in various ways. Some chemicals can mimic a natural hormone, fooling the body into over-responding to the stimulus (e.g., a growth hormone that results in increased muscle mass) or responding at inappropriate times (e.g., producing insulin when it is not needed). Other endocrine-disrupting chemicals can block the effects of a hormone from certain receptors. Still others can directly stimulate or inhibit the endocrine system, causing overproduction or underproduction of hormones. Certain drugs are used to intentionally cause some of these effects, such as birth control pills. In many situations involving environmental chemicals, an endocrine effect may not be desirable.

In recent years, some scientists have proposed that chemicals might inadvertently be disrupting the endocrine system of humans and wildlife. Reported adverse effects include declines in populations, increases in cancers, and reduced reproductive function. To date, these health problems have been identified primarily in domestic or wildlife species with relatively high exposures to organochlorine compounds, including DDT and its metabolites, polychlorinated biphenyls (PCBs), and dioxides, or to naturally occurring plant estrogens (phytoestrogens; see Sidebar 10.1). However, the relationship of human diseases of the endocrine system and exposure to environmental contaminants is poorly understood and scientifically controversial.

SIDEBAR 10.1. PHYTOESTROGENS

Phytoestrogens are naturally occurring polycyclic phenols found in certain plants. These are chemicals that may have weak estrogenic effects when they are ingested and metabolized. Two important groups of phytoestrogens are isoflavones and lignans. The isoflavones include formononetin, daidzein, biochanin A, genistein, *O*-desmthylangolensin, and equol. Plant sources of isoflavones include legumes, with the largest contribution coming from soy-based foods. Because soy flour and soy protein isolates may be added to processed meats, meat substitutes, breads, and protein food bars, these items can be a major source of isoflavones (Grace et al., 2004; Lampe et al., 1999). However, the isoflavone content of soy protein preparations can vary widely and is affected by production techniques (Erdman et al., 2004). Daidzein and genistein are the main soy isoflavones. Kudzu root, used in some dietary supplements, also contains appreciable amounts of daidzein. Naringenin, a precursor to genistein, is found in some citrus fruits. Formononetin and biochanin A are methylated isoflavones found in clovers, which may be used in red clover dietary supplements; these isoflavones are metabolized in the body to daidzein and genistein, respectively.

Ingested daidzein is further metabolized to *O*-desmethylangolensin and to equol by intestinal bacteria. Equol, but not *O*-desmethylangolensin, has estrogenic activity. About 30% of adults can be characterized as equol producers and demonstrate higher serum equol levels after daidzein consumption (Cassidy et al., 2006; Setchell et al., 2003a). This ability to produce equol may be related to an individual's intestinal microflora and influenced by dietary habits (Rowland et al., 2000). The relevance of equol-producer status to potential health-related effects is unclear (Vafeiadou et al., 2006).

Lignans include matairesinol and secoisolariciresinol, which are transformed by intestinal bacteria into the estrogenic compounds enterolactone and enterodiol, respectively (Cornwell et al., 2004; Rowland et al., 2003). Enterodiol may also interconvert with enterolactone. Lignans are found in flax seeds, whole-wheat flour, tea, some fruits, and other cereal grains. Other phytoestrogens of interest are resveratrol and *trans*-resveratrol, found in grape skins, wine, and peanuts.

Diet is the source of human exposure to phytoestrogens. The absorption and metabolism of phytoestrogens demonstrate large interindividual variability, which may relate to differences in both human pharmacokinetics and metabolism by intestinal bacteria. Phytoestrogens are ingested in their naturally occurring β-glycoside forms. The β-glycosidic forms are hydrolyzed to their aglycones in the intestine, absorbed, and then glucuronidated in the intestinal wall and liver (Doerge et al., 2000; Rowland et al., 2003). The glucuronidated metabolites of isoflavones predominate in blood and urine (Rozman et al., 2006; Setchell et al., 2001).

The isoflavones are excreted from the body about 24 hours after ingestion, mainly in urine and, to a lesser extent, in feces. Urinary concentrations of daidzein and genistein did not correlate well with the ingested doses, possibly due to limited absorption of these isoflavones at higher doses (Setchell et al., 2003b). In contrast, plasma and urine lignan concentrations after flax seed consumption increased in a dose-dependent manner (Nesbitt et al., 1999). Equol excretion may depend on diet, the type of intestinal bacteria present, and individual genetic factors (Rowland et al., 2000; Setchell et al., 2002; Setchell and Cassidy, 1999).

After hydrolysis to the aglycones forms, phytoestrogens can weakly bind to estrogen receptor beta (ER-β), which is expressed in arteries and smooth muscle. Individual phytoestrogens may be either estrogen agonists or antagonists. Equol has more potent estrogenic activity than it precursor, daidzein. Equol also has been shown to have antiandrogenic activity in animals (Lund et al., 2004; Magee and Rowland, 2004). Genistein binds ER-β with greater affinity than equol (Doerge and Sheehan, 2000). Although far less potent, phytoestrogens can be present in concentrations 100 to 1000 times greater than the endogenously produced estrogens. Soy-based infant formula can result in plasma concentrations of isoflavones in infants that are 13,000 to 22,000 times higher than endogenous estrogen concentrations in infants (Setchell et al., 1997). Phytoestrogens may also act through pathways other than the interaction with estrogen receptors. These actions include inhibiting the transformation of estrogen to estradiol, inhibiting enzymes important for steroid biosynthesis and cell growth, and having antioxidant and antiangiogenesis activities (Adlercreutz et al., 1995; Dixon and Ferreria, 2002; Sirtori et al., 2005). Numerous studies of either dietary soy or phytoestrogens and health outcomes have demonstrated inconsistent or inconclusive results. Consensus reviews of these studies suggest that no evidence clearly shows that dietary phytoestrogens significantly reduce cardiovascular disease risk, reduce postmenopausal vasomotor symptoms, improve bone mineral density, or reduce cancer risk (Cornwell et al., 2004; Messina et al., 2006; NAMS, 2000; Nedrow et al., 2006; Sacks et al., 2006; Sirtori et al., 2005).

Adverse effects on fertility have been observed in animals that graze red clover (i.e., "clover disease"). Results of chronic feeding studies in pregnant animals suggest that high doses of phytoestrogens alter the fetal hormonal environment (Cornwell et al., 2004). For example, in the 1940s, sheep farmers in western Australia began to experience an epidemic of still births despite three seasons of exceptionally good weather. The merino sheep looked healthy; however, the ewes failed to go into labor. The lambs died in still birth and often the mothers as well. In a matter of 5 years, the ewes failed to conceive at all, even after repeated breeding with fertile rams. Specialists found the problem. Clover. Fifteen years earlier, ranchers had imported a clover from the Mediterranean region in Europe. The first scientific paper on this phenomenon appeared in the *Australian Veterinary Journal* in 1946 and proclaimed this as "clover disease." Three years later, three chemicals were identified as suspects. Finally, formononetin—only one of chemicals—was determined to be the culprit. Formononetin mimics estrogen. In addition, studies of children who had been fed soy-based formula as infants and who were followed through adolescence (Klein, 1998) and young adulthood (Strom et al., 2001) found no adverse reproductive or endocrine effects. *In vitro* and animal studies suggest that soy isoflavones may have immunologic and thyroid effects (Doerge and Sheehan, 2000; Sirtori et al., 2005).

Although domestic and wildlife species have demonstrated adverse health consequences from exposure to elements in the environment that interact with the endocrine system, it is not known if similar effects are occurring in the general human population, but again there is evidence of adverse effects in populations with relatively high exposures. Several reports of declines in the quality and decrease in the quantity of sperm production in humans over the last five decades and the reported

DID YOU KNOW?

During the fourth century BCE, Hippocrates observed that Queen Anne's lace prevented pregnancies, and the Greeks were known to have used pomegranate as a contraceptive. Modern research confirms their strong estrogen activity. Fennel, too, was used in the ancient world to prevent pregnancy and precipitate abortions.

increase in incidences of certain cancers (breast, prostate, testicular) that may have an endocrine-related basis have led to speculation about environmental etiologies (Kavlock et al., 1996). There is increasing concern about the impact of the environment on public health, including reproductive ability, and controversy has arisen from some reviews claiming that the quality of human semen has declined (Carlson et al., 1992). However, little notice has been paid to these warnings, possibly because they have been based on data on selected groups of men recruited from infertility clinics, from among semen donors, or from candidates for vasectomy. Furthermore, the sampling of publications used for review was not systematic, thus implying a risk of bias. Because a decline in semen quality may have serious implications for human reproductive health, it is of great importance to elucidate whether the reported decrease in sperm count reflects a biological phenomenon or, rather, is due to methodological errors.

Data on semen quality collected systematically from reports published worldwide indicate clearly that sperm density declined appreciably from 1938 to 1990, although we cannot conclude whether or not this decline is continuing today. Concomitantly, the incidence of some genitourinary abnormalities including testicular cancer and possibly also maldescent (faulty descent of the testicle into the scrotum) and hypospadias (abnormally placed urinary meatus) has increased. Such remarkable changes in semen quality and the occurrence of genitourinary abnormalities over a relatively short period are more probably due to environmental rather than genetic factors. Some common prenatal influences could be responsible both for the decline in sperm density and for the increase in cancer of the testis, hypospadias, and cryptorchidism (one or both testicles fail to move to scrotum). Whether estrogens or compounds with estrogen-like activity or other environmental or endogenous factors damage testicular function remains to be determined (Carlson et al., 1992). Even though we do not know what we do not know about endocrine disruptors, it is known that the normal functions of all organ systems are regulated by endocrine factors, and small disturbances in endocrine function, especially during certain stages of the life cycle such as development, pregnancy, and lactation, can lead to profound and lasting effects. The critical issue is whether sufficiently high levels of endocrine-disrupting chemicals exist in the ambient environment to exert adverse health effects on the general population.

Current methodologies for assessing, measuring, and demonstrating human and wildlife health effects (e.g., the generation of data in accordance with testing guideline) are in their infancy. The USEPA has developed testing guidelines and the Endocrine Disruption Screening Program, which is mandated to use validated methods for screening the testing chemicals to identify potential endocrine disruptors, to determine adverse effects and dose–response, to assess risk, and ultimately to manage risk under current laws.

The best way in which to end this brief discussion is to provide a statement made by experts on endocrine disruptors and the potential impact on humans, wildlife, and the environment in general (Colborn et al., 1993, p. 378):

> Large numbers and large quantities of endocrine-disrupting chemicals have been released in the environment since World War II. Many of these chemicals can disturb development of the endocrine system and of the organs that respond to endocrine signals in organisms indirectly exposed during prenatal and/or early postnatal life; effects of exposure during development are permanent and irreversible.

GROUNDWATER POLLUTION

> *The Desert Takes a Drink*
>
> A flick of lightning to the north
> where dun clouds grumble—
> while here in the middle of the wash
> black beetles tumble
> and horned toads fumble
> over sand as dry as bone
> and hard-baked mud and glaring stone.
> …
> The flood comes, crawls thickly by, roaring
> with self-applause, a brown
> spongy smothering liquid avalanche:
> great ant-civilizations drown,
> worlds go down,
> trees go under, the mud bank breaks
> and deep down underneath the bedrock shakes.
>
> **Abbey (1968)**

Of the approximately 3 feet of water that fall each year on every square foot of Earth (on average), approximately 6 inches of that water returns to the sea. Evaporation takes another 2 feet. The last 6 inches infiltrate through the Earth's interstices, voids, hollows, and cavities, filtering into the sponge-like soil. When it travels down into and through the soil, the course that the water follows may carry it only a few inches, a few feet, or several hundred feet before it joins the subterranean water stores that comprise the Earth's groundwater supply. This water supply (one that people are often oblivious to) contains an estimated 1,700,000 cubic miles of water, hidden underground. Enough water, if you could spread it over the surface of the Earth, to blanket all of the planet's land surfaces with 1000 feet of water. U.S. groundwater sources constitute a freshwater supply greater than all the surface water in the United States—and that includes the Great Lakes.

This enormous reservoir, our groundwater supply, feeds all the natural fountains and springs of Earth. These natural exits for groundwater allow it to bubble up in cool, blue pools from springs. In more unusual circumstances, from places too deep within the Earth to imagine, groundwater heats up, forms steam, and bursts from the surface in geysers and hot springs. Although we make use of many different groundwater sources, not all groundwater supplies can be tapped for use. In some places, the water is not accessible because of pumping costs and drilling difficulties. Groundwater supplies, too, are not always pure. Contaminated groundwater supplies have become a significant pollution problem. Most of the groundwater supply, however, lies within reach of the surface, accessible by drilling a borehole or well down to the water table. Humans have obtained water this way for millennia, and as more and more people inhabit Earth more use is being made of our groundwater supplies. Currently, groundwater serves as a reliable source of potable water for millions of the planet's inhabitants, and if used with moderation groundwater should remain a viable source for years to come.

SOURCES OF GROUNDWATER CONTAMINATION

The water we use, by population, breaks down to roughly 50% groundwater sources and 50% surface water sources. Large cities rely primarily on surface water for their supplies, but 95% of small communities and rural areas use groundwater. A larger percent of the U.S. population is supplied by surface water than by groundwater, but only one-fourth of the total number of communities are supplied by surface water. As a water supply source, groundwater has several desirable characteristics: (1) natural storage, which eliminates the need for manmade impoundments; (2) availability at the

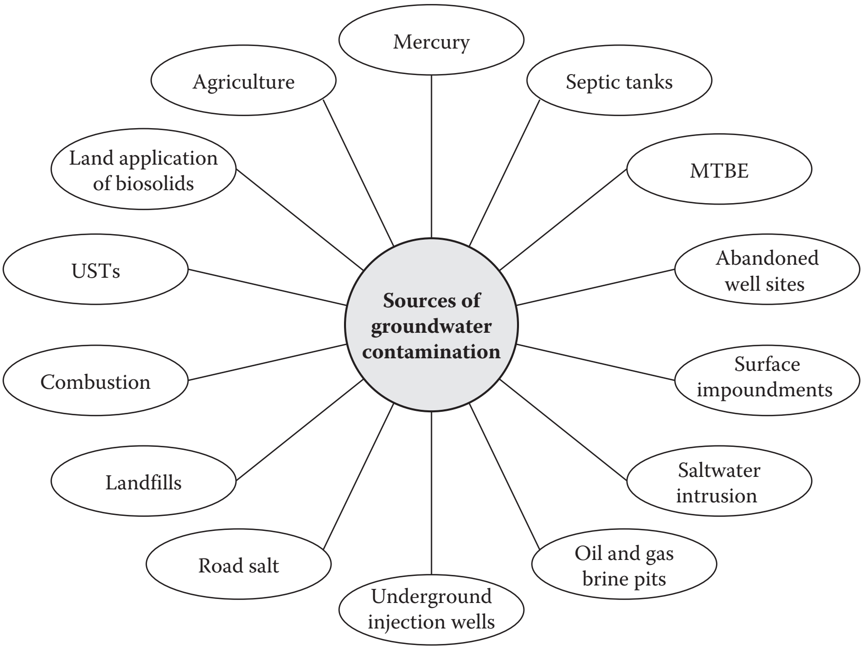

FIGURE 10.14 Sources of groundwater contamination.

point of demand, so transmission costs are reduced significantly; and (3) filtration through the natural geologic strata, which means that groundwater usually appears clearer to the eye than surface water does (McGhee, 1991). For these reasons, groundwater is generally preferred as a municipal and industrial water source.

For many years, we believed that groundwater was safe from contamination, naturally cleansed by traveling through the soil. Groundwater was considered safe to drink, and many water utilities delivered it to their customers with no further treatment. We know better now. We have discovered that groundwater is not automatically safe to use as a potable water supply. Discoveries of contaminated groundwater have led to the closure of thousands of potable water wells across the United States. The USEPA reported that in the mid-1980s more than 8000 drinking water wells in areas all over the nation were no longer usable because of contamination. Monitoring the complex groundwater situation nationwide is fraught with difficulty because of the vast number of potential and possible contamination sources, including contamination by toxic or hazardous materials leaking from waste treatment facilities, natural sources, or landfills that may not be evident to either the public or regulatory agencies, as well as from many other sources (Figure 10.14). Groundwater contamination's biggest problem is twofold: monitoring its condition is difficult and, when contaminated, restoring it is difficult (and expensive)—if possible at all.

AQUIFERS

As mentioned earlier, an aquifer performs two important functions: storage and transport. Expressed simply, the subsurface is charged with the water that then becomes groundwater when the surface water seeps down from the rain-soaked surface and sinks until it reaches an impermeable layer, where it collects and fills all the pores and cracks of the permeable portions. The top of this saturated zone is called the *water table*. In reality, the groundwater system is a bit more complicated because groundwater occurs in two different zones in unconfined aquifers (an aquifer not overlain by an impermeable layer is unconfined). These zones are distinguished by whether or not water fills all the cracks and pores between particles of soil and rock. The unsaturated zone, which lies just beneath the land surface, is characterized by crevices that contain both air and water. Although the unsaturated zone contains water (vadose water), this water is essentially unavailable for use. Water flow in a confined aquifer (a water-bearing layer sandwiched between two less permeable layers) is restricted to vertical movement only. An unconfined aquifer allows water to flow with more freedom of movement and resembles flow in an open channel.

Groundwater Flow

To have any flow at all, a hydraulic gradient must exist, whether groundwater flow occurs in an unconfined aquifer's open-channel-like flow or a confined aquifer's vertical-only (pipe-like) flow. The hydraulic gradient is the difference in hydraulic head divided by the distance along the fluid flow path. For our applications of the concept, you should know that groundwater moves through an aquifer in the direction of the hydraulic gradient, at a rate proportional to the gradient (the direction of the slope of the water table), inversely related to the aquifer's permeability. The more permeable the substrate and the steeper the slope, the more rapidly the water flows.

Groundwater, of course, contrary to popular belief, does not flow like a river. Percolating downward, groundwater moves from higher elevations to lower elevations at a variable rate that is dependent on underground conditions. Sometimes slow moving, it can also move surprisingly quickly, from less than an inch to several feet a day.

Groundwater aquifers, as we said previously, supply a large portion of the U.S. population—and almost all of the rural population. They are important sources of water. Groundwater use continues to increase, which threatens both the quantity and quality of this critically important resource. Two important points should be remembered about groundwater: (1) the groundwater supply is not inexhaustible, and (2) groundwater is not exempt from surface contamination. It is not completely purified as it percolates through the ground, even though the interconnectedness of the hydrological cycle in self-purification works to our advantage. The processes integral to the water cycle can trap toxins, complicating efforts to clean them up, which is of special concern for persistent pollutants. The natural processes that clean our water as it travels through the hydrological cycle worked well for centuries, but now, in many places, humans have overloaded the capacity of the water cycle to self purify. Although we are now cleaning up problems created by past environmental abuse and ignorance, inevitably we are creating problems that future generations will have to clean up. The solutions we try now will present future generations with problems we did not foresee, but recreating past mistakes is foolish and foolhardy. Our water system is too valuable for us to risk.

Thus, it logically follows that groundwater pollution can be a very serious problem. We already know, through experience and study, that any pollutant that contacts the ground holds the possibility for contaminating groundwater (Figure 10.15). As water enters the ground, it filters naturally through the soil; in some soils that process quite effectively, many substances are removed, including suspended solids and bacteria—and pollutants. Some chemicals are removed as they bind themselves to the surface of soil particles (phosphates). In some areas, though, industrial and municipal wastes are sprayed on the ground surface to take advantage of the natural self-purification process; the wastewater filters through the soil, becomes purified in the process, and recharges the groundwater reservoir. Natural purification of water as it passes through the soil is a beneficial process but slow, because the water has no access to air and is not readily diluted.

Drainage-basin activities that pollute surface waters also cause groundwater contamination. Problems can occur from sources as diverse as septic tanks, agriculture, industrial waste lagoons, underground injection wells, underground storage tanks, and landfills. Waste disposal sites located in unsuitable soils (or even directly over fractured dolomites and limestones) can cause major problems. Disposal sites located directly on top of such rock allow polluted water to travel into wells. At least 25% of the usable groundwater (from wells) is already contaminated in some areas (Draper, 1987).

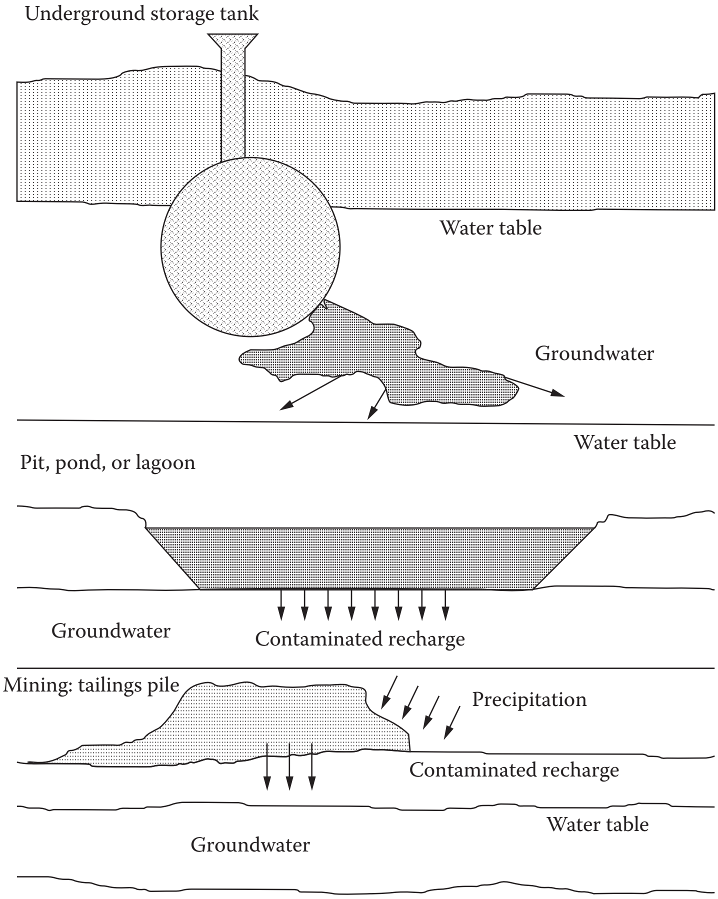

FIGURE 10.15 Common activities that can lead to groundwater contamination include leaky underground storage tanks, surface pits, ponds or lagoons, and mining tailings, which contribute to acid mine discharge.

Causes of groundwater contamination vary. Increasingly, groundwater contamination from saltwater, microbiological contaminants, and toxic organic and inorganic chemicals is being observed. The major source of groundwater contamination in the United States comes from the improper disposal of toxic industrial wastes. The levels of and problems related to contamination from these wastes are increased significantly when waste disposal sites are not protected by some type of lining, when disposal sites lie in permeable materials above usable water aquifers, and when these sites are located close to water supply wells. The Conservation Foundation (1982) reported that groundwater contamination was responsible for closing hundreds of U.S. wells. (See Case Study 10.4.)

Case Study 10.4. Nitrates and Pregnancy

Between 1991 and 1994, four women who lived in the same county in Indiana experienced an unusually high number of miscarriages. When a tasteless, odorless substance found in animal waste—nitrates—was removed from their well water, all were able to carry healthy babies to term (CDC, 1996). LaGrange, Indiana; Lancaster County, Pennsylvania; Albany, Georgia; and Pojoaque, New Mexico, are all sites where local drinking waters are often high in nitrates. Soil with large amounts of limestone and agricultural areas contaminated with animal waste are often contaminated with nitrates. Manure and chemical fertilizers can also contribute to nitrate pollution. "Blue baby syndrome," a condition of depleted oxygen levels in infants, is caused by nitrate consumption. An extensive investigation of drinking water as a factor in birth defects, adverse pregnancy outcomes, and developmental disabilities has yet to be carried out, although a comprehensive review of the problem was published by Manassaram et al. (2006). That the four Indiana women all carried healthy babies to term once the nitrate source was removed is of particular interest to toxicologists, as it indicates a strong possible link between the contaminated water and the problem pregnancies. Funding for studies, however, has proven difficult to come by. Competition for federal funding to underwrite research is stiff. Other, more well-known issues, including possible harmful effects of chlorination used for water purification and the vulnerability of our water supplies to terrorism, are competing for the same funding dollars (Crable, 1998).

WETLANDS

Wetlands are areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support and that, under normal circumstances, do support a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. Wetlands routinely replenish and purify groundwater supplies. By absorbing excess nutrients and immobilizing pesticides, heavy metals, and other toxins, wetland plants prevent them from moving up the food chain. Wetlands have been used to treat sewage in some locations; however, wetland ecosystems are relatively fragile, and their capacity to cleanse polluted water is limited. Many have been overwhelmed by pollution, although more of our natural wetland areas have been destroyed by anthropogenic activities. In the United States, for example, half of our wetlands have been lost to urban and agricultural development (Goldsmith and Hildyard, 1988).

THE BOTTOM LINE

Unless you notice water bodies best described as cesspools or experience water that smells foul and tastes worse (and ultimately might make you ill), you may think that water pollution is relative and you might find it difficult to define. Once you come up with a definition (it might have something to do with physical characteristics and negative impact), you may also consider the idea that freshwater pollution is not a new phenomenon. Only that freshwater pollution has become a major public concern is relatively new.

We have defined water pollution as the presence of unwanted substances in water beyond levels acceptable for health or aesthetics. We pointed out that water pollutants may include organic matter (living or dead), heavy metals, minerals, sediment, bacteria, viruses, toxic chemicals, and volatile organic compounds. We have also made the point that surface water pollution is a serious threat to our survival on Earth, but we also need to point out that contamination of our groundwater supplies is an even more serious threat.

Natural forms of pollutants have always been present in surface waters. Many of the pollutants we have discussed in this chapter were washed from the air, eroded from land surfaces, or leached from the soil and ultimately found their way into surface water bodies long before humans were present to walk on Earth. Floods and dead animals pollute, but their effects are local and generally temporary. In prehistoric times (and even in more recent times), natural disasters have contributed to surface water pollution. Cataclysmic events—earthquakes, volcanic eruptions, meteor impacts, transitions from ice age to interglacial to ice age—have all contributed to surface water pollution. Natural purification processes—over time—were able to self-clean surface water bodies. We can accurately say that without these self-purifying processes, the water-dependent life on Earth could not have developed as it did (Peavy et al., 1985). But, the natural problems, the ones the environment could eventually self-clean, are augmented by anthropogenic ones. Manmade problems piled on top of the natural pollutants present us with greater risks and greater challenges.

Groundwater cycles and sources are complex, and the problems that affect groundwater demand our most complicated remedial processes because of the interconnections with soil pollution. Underground storage tanks, for example, create problems as difficult in their way to control as nonpoint-source pollution's effects on surface water supplies.

DISCUSSION QUESTIONS

1. What are surface water sources? What are the common problems associated with surface water quality?
2. What regulations affect surface water pollution? How have they affected the quality of surface water supplies?
3. Describe and discuss the usual surface water pollutants and their sources.
4. Discuss watershed, nonpoint-source pollution, and the Chesapeake Bay.
5. Describe and discuss lotic surface water self-purification.
6. Discuss the problems associated with nonpoint-source pollution and how those concerns are being handled.
7. Why does USEPA consider runoff to be the most serious water pollution problem in the United States? Who will be affected by regulations controlling runoff and how?
8. Discuss the problem of solid waste disposal in water systems.
9. Where does groundwater come from? How is it used?
10. Why has groundwater been thought of as pure?
11. What percentage of the U.S. population uses groundwater as its primary water supply? Why does it break down this way?
12. How does groundwater move beneath the Earth's surface?
13. Describe and discuss hydraulic gradient.
14. Describe and discuss the problems associated with groundwater pollution. How does groundwater contamination occur?
15. Discuss the possibility of long-term and unforeseen consequences of groundwater contamination.

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11 Water Pollution Remediation

> As the world population grows, we are forced by circumstances we have created to face the realization of our resources' limitations. Most of us in the U.S. have always been fortunate enough to have had enough of whatever we needed, and whatever we wanted. When something we like breaks or wears out, we throw it away and buy a new one, and often we don't even make an attempt to fix the problem. We neglect basic maintenance until we damage our belongings beyond repair and we expect that we will always have enough. But some things are beyond our control, beyond our power or financial ability to replace or repair. Our water supply is one of these. Without concern, without attention, without preventive maintenance and reclamation, our water supply will not be able to support the needs of the future.
>
> **Spellman and Whiting (2006)**

With regard to water pollution, remediation means providing a remedy. When humans contaminate water, eventually when the contamination gets our attention, when the contamination irritates the hell out of us, when the contamination totally offends us, or when the contamination makes us ill or worse, we sometimes provide a remedy. There are, of course, various types of remedies, and many of them are discussed in this chapter, but they are not yet our concern in this brief introduction. On the contrary, at this moment it is our intent to make the point that we simply do not seem to get it when we contaminate water and then repeat our actions—over and over again. When it comes to preventing pollution, our intentions and actions seem somewhat topsy-turvy. This trend is not new to human nature or to environmental problems. Maybe we can sum up environmental remediation and learning from our mistakes by turning to the wisdom provided to us by the Mad Hatter and Alice in *Alice's Adventures in Wonderland* (Carroll, 1865):

Alice: Nobody ever tells us to study the right things we do. We're only supposed to learn from the wrong things. But we are permitted to study the right things other people do. And sometimes we're even told to copy them.
Mad Hatter: That's cheating!
Alice: You're quite right, Mr. Hatter. I do live in a topsy-turvy world. It seems like I have to do something wrong first, in order to learn from what not to do. And then, by not doing what I'm supposed to do, perhaps I'll be right. But I'd rather be right the first time, wouldn't you?

HISTORICAL PERSPECTIVE

The public, environmentalists, and legislators came to the realization in the early 1970s that our water resources were in critical condition and needed the protection offered by regulation. Specifically, our traditional freshwater supplies were and still are at risk: our lakes, streams, and rivers. While environmentalists were aware of how serious our water resource problems were several years before legislation was enacted in the 1950s and 1960s, their voiced environmental concerns were ignored or overridden by the loud, financially driven declarations of polluters, who simply played their standard trump card and declared "greenies" and other environmentalists to be weirdos and ultra, ultra bleeding-heart liberals. For many years, most people ignored the environmentalists, and their concerns were sidelined. Eventually, though, we woke up and put pressure on Congress to enact two important regulations designed to protect our water resources: the Clean Water Act of 1972 and the Safe Drinking Water Act (SDWA) of 1974.

The Safe Drinking Water Act came about when federal legislators became aware of the sad (and unhealthy) condition of many local drinking water supplies and the reluctance of local and state officials to remove pollutants from their wastewater. The Act set national drinking water standards, called *maximum contaminant levels* (MCLs), for pollutants that might adversely affect public health and welfare. The first standards went into effect 3 years later and specifically covered every public water supply in the country serving at least 15 service connections or 25 or more people. Because over 200 contaminants from hazardous wastes injected into the soil had been identified in groundwater, the SDWA also established standards to protect groundwater from such practices. Specifically, the SDWA requires the establishment of programs to protect critical groundwater sources of drinking water, to protect areas around wells that supply public drinking water systems, and to regulate the underground injection of wastes above and below drinking water sources.

Later, in 1982 and 1983, the U.S. Environmental Protection Agency (USEPA) established a priority list for setting regulations for over 70 substances. These substances were listed because they are toxic and likely to be found in drinking water. In 1986, when Congress reauthorized the SDWA, it amended the Act and directed the USEPA to monitor drinking water for unregulated contaminants and to inform public water suppliers about which substances to look for. The 1986 reauthorization also instructed the USEPA to set standards within 30 years for all 70 substances on its priority list. By the end of 2008, the priority list had been expanded, and the USEPA had set standards for more than 90 substances (USEPA, 2008).

Under the Act, local public water systems are required to monitor their drinking water periodically for contaminants with MCLs and for a broad range of other contaminants as specified by the USEPA. Enforcement of the standards, monitoring, and reporting are the responsibility of the individual states, but the 1986 amendments require the USEPA to act when the state fails to move or moves too slowly and authorizes substantial civil penalties against the worst violators.

The SDWA and its amendments also authorize the USEPA to set secondary drinking water standards regarding public welfare by providing guidelines on the taste, odor, color, and aesthetic aspects of drinking water—those that do not present a health risk. These guidelines are nonenforceable and are referred to as *suggested* levels. The USEPA recommends these levels to the states as reasonable goals, but federal law does not require water systems to comply with them, although some individual states have enforceable regulations regarding these concerns. The 1986 amendments also banned all future use of lead pipe and lead solder in public drinking water systems and required public water systems to tell their users of the potential sources of lead contamination, its health effects, and the steps they can reasonably take to mitigate lead contamination.

In 1972, Congress enacted the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act (CWA). The CWA stems originally from a much-amended 1948 law that helped communities to build sewage treatment plants. The CWA is the keystone of environmental law and is credited with significantly cutting the amount of municipal and industrial pollution fed into the nation's water bodies.

Through the 1970s and 1980s, the primary aim of the Clean Water Act was to make national waters fishable and swimmable. Specifically, it sought to eliminate discharge of untreated municipal and industrial wastewater into waterways (many of which are used as sources of drinking water) and provided billions of dollars to finance building sewage treatment plants.

The 1987 Water Quality Act, which reauthorized the original Clean Water Act, focused on updating standards that dealt with toxic chemicals, as much of the toxic pollution still fouling the nation's surface water bodies came from companies that had installed 1970s-era pollution control technologies but never updated them. For the first time, these regulations attempted to deal with water pollution stemming from nonpoint sources (city streets and croplands, for example); they required states to identify waters not meeting quality standards and develop programs to deal with the problem.

EFFECT OF REGULATIONS ON PREVENTING WATER POLLUTION

Are the laws pertaining to water supply protection passed since the early 1970s adequate to protect our water resources and ensure water quality? Assuming that they are might make us feel good, but such an assumption ignores several important concerns. Enacting regulation does not ensure compliance or enforcement, enacting legislation does not ensure program funding, and enacting legislation does not ensure complete coverage of the entire problem. Exceptions to regulation coverage can cause plenty of pollution problems on their own; for example, over 100,000 public water systems are exempt from SDWA requirements because they do not serve year-round residents, although these systems include schools, factories, seasonal resorts, summer camps, roadside restaurants, and hospitals.

Simply stated, regulations designed to protect the environment and at the same time protect public health and welfare are only the first step across the bridge between pollution and prevention. Once in place, regulations must be complied with and enforced. Then, the effort shifts from one of determining direction, objectives, and goals to one of implementation. In this implementation phase, technology comes into play—in fact, it plays the key role. Remember, a society can have all kinds of plans, objectives, goals, and regulations to stipulate what needs to be done to correct or mitigate an environmental problem, but none of these will bring about positive results unless the means (technology) are available at a reasonable cost to accomplish the requirements. With the means also comes a certain amount of common sense. Only solid, legitimate, careful scientific analysis can provide the answers and the solutions to environmental problems. Making environmental decisions through political action rather than scientific analysis gives us decisions that feel good or feel right, rather than solve the problem. We need to step back and size up the situation. This can only be accomplished by using proper, careful scientific methodology. The future of our water supply should not be left to dysfunctional bureaucracy, harebrained analysis, or the results of pseudo-analysis.

In the sections that follow, we briefly discuss traditional treatment technologies currently available and widely used for water, wastewater, thermal pollution, underground storage tanks (USTs), and groundwater pollution problems.

A SHERLOCK HOLMES AT THE PUMP[*]

He wandered the foggy, filthy, corpse-ridden streets of 1854 London, observing, taking notes, and searching for a murderous villain. When he found the miscreant, he took action. He removed the handle from a water pump. And, fortunately for untold thousands of lives, his action was a lifesaving one. He was a detective—of sorts. Not the real Sherlock Holmes, but absolutely as clever, as skillful, as knowledgeable, as intuitive, and definitely as driven. His real name was Dr. John Snow. His middle name? Common Sense. Snow's master criminal, his target was a mindless, conscienceless, brutal killer: *cholera*. Let's take a closer look at this medical super sleuth, at his quarry, the deadly killer cholera, and at Dr. Snow's actions to contain the spread of cholera. More to the point, let's look at Dr. Snow's subsequent impact on water treatment (disinfection) of raw water used for potable and other purposes.

DR. JOHN SNOW

An unassuming, and creative, London obstetrician, Dr. John Snow (1813–1858) achieved prominence in the mid-19th century for proving his theory that cholera is a contagious disease caused by a "poison" that reproduces in the human body and is found in the vomitus and stools of cholera patients (Snow, 1855). He theorized that the main (though not the only) means of transmission was

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[*] This section is adapted from Spellman, F.R., *Choosing Disinfection Alternatives for Water/Wastewater Treatment*, CRC Press, Boca Raton, FL, 1999.

DID YOU KNOW?

You don't need to be a rocket scientist to figure out just how deadly cholera was during the London cholera outbreak of 1854. Comparing the state of "medicine" at that time to ours is like comparing the speed potential of a horse and buggy to a state-of-the-art NASCAR race car. Simply stated: Cholera was the classic epidemic disease of the 19th century, as the plague had been for the 14th century. Its defeat was a reflection of both common sense and progress in medical knowledge—and of the enduring changes in European and American social thought.

water contaminated with this poison. His theory was not held in high regard at first, because a commonly held and popular counter-theory stated that diseases were transmitted by the inhalation of vapors. Many theories regarding the cause of cholera were expounded. In the beginning, Snow's argument did not cause a great stir; it was only one of many hopeful theories proposed during a time when cholera was causing great distress. Eventually, Snow was able to prove his theory. Later we describe how Snow accomplished this, but for now let's take a look at Snow's target, cholera.

CHOLERA

According to the U.S. Centers for Disease Control and Prevention (CDC), cholera is an acute, diarrheal illness caused by infection of the intestine with the bacterium *Vibrio cholera*. The infection is often mild or without symptoms, but sometimes it can be severe. Approximately 1 in 20 infected persons have severe disease symptoms characterized by profuse watery diarrhea, vomiting, and leg cramps. In these persons, rapid loss of body fluids leads to dehydration and shock. Without treatment, death can occur within hours. How does a person contract cholera? Again, we refer to the CDC for our answer. A person may contract cholera (even today) by drinking water or eating food contaminated with the cholera bacterium. In an epidemic, the source of the contamination is usually feces of an infected person. The disease can spread rapidly in areas with inadequate treatment of sewage and drinking water. Disaster areas often pose special risks; for example, the aftermath of Hurricane Katrina in New Orleans raised concerns about potential cholera problems. Cholera bacteria also live in brackish river and coastal waters. Shellfish eaten raw have been a source of cholera, and a few people in the United States have contracted cholera after eating raw shellfish from the Gulf of Mexico. The disease is not likely to spread directly from one person to another; therefore, casual contact with an infected person is not a risk for transmission of the disease.

FLASHBACK TO 1854 LONDON

Basically, for our purposes, the CDC has confirmed the fact that cholera is a waterborne disease. Today, we know quite a lot about cholera and its transmission, how to prevent infection, and how to treat it. But, what was known about cholera in the 1850s? Not much, but one thing is certain: They knew cholera was a deadly killer. That was just about all they knew—until Dr. John Snow proved his theory. Recall that Snow theorized that cholera is a contagious disease caused by a poison that reproduces in the human body and is found in the vomitus and stools of cholera victims. He also believed that the main means of transmission was water contaminated with this poison. Dr. Snow's theory was correct, of course, but how did he prove his theory correct? The answer to this question provides us with an account of one of the all-time legendary quests for answers in epidemiological research—and an interesting story.

Dr. Snow proved his theory in 1854, during yet another severe cholera epidemic in London. Though ignorant of the concept of bacteria carried in water, Snow traced an outbreak of cholera to a water pump located at an intersection of Cambridge and Broad Street in London. How did he isolate the source to this particular pump? He mapped the locations of deaths from cholera. His map indicated that the majority of the deaths occurred within 250 yards of that water pump. The water pump was used regularly by most of the area residents. Those who did not use the pump remained healthy. Suspecting that the Broad Street pump was the source of the plague, Snow had the water pump handle removed and ended the cholera epidemic.

Sounds like a rather simple solution, doesn't it? For us, it seems simple, but remember that in that era aspirin had not yet been formulated, to say nothing of other medical miracles we take for granted—antibiotics, for example. Dr. John Snow, by the methodical process of elimination and linkage (Sherlock Holmes would have been impressed, and he was) proved his point. Specifically, through painstaking documentation of cholera cases and correlation of the comparative incidence of cholera among subscribers to the city's two water companies, Snow showed that cholera occurred much more frequently among customers of the water company that drew its water from the lower Thames, where the river had become contaminated with London sewage. The other company obtained water from the upper Thames. Snow tracked and pinpointed the Broad Street pump's water source. You guessed it: the contaminated lower Thames, of course.

Dr. Snow, the obstetrician, became the first effective practitioner of scientific epidemiology. His creative use of logic, common sense, and scientific information enabled him to solve a major medical mystery—how cholera is transmitted.

FROM PUMP HANDLE REMOVAL TO WATER TREATMENT (DISINFECTION)

Dr. Snow's major contribution to the medical profession, to society, and to humanity in general can be summarized rather succinctly: He determined and proved that the deadly disease cholera is a waterborne disease. (Dr. Snow's second medical accomplishment was that he was the first person to administer anesthesia during childbirth.) What does all of this have to do with water treatment (disinfection)? Actually, Dr. Snow's discovery—his stripping of a mystery to its barest bones—has quite a lot to do with water treatment. Combating any disease is rather difficult without a determination of how the disease is transmitted, how it travels from vector or carrier to receiver. Dr. Snow established this connection, and from his work and the work of others progress was made in understanding and combating many different waterborne diseases.

Today, sanitation problems in developed countries (those with the luxury of adequate financial and technical resources) deal more with the consequences that arise from inadequate commercial food preparation and bacteria becoming resistant to disinfection techniques and antibiotics. We simply flush our toilets to rid ourselves of unwanted wastes and turn on our taps to take in high-quality drinking water supplies from which we have all but eliminated cholera and epidemic diarrheal diseases. This is generally the case in most developed countries today—but it certainly wasn't true in Dr. Snow's time.

The progress in water treatment, from that notable day in 1854 when Dr. Snow made the connection between deadly cholera and its means of transmission to the present, reads like a chronology of discovery leading to our modern water treatment practices. This makes sense, of course, because with the passage of time pivotal events and discoveries occur—events that have a profound affect on how we live today. Let's take a look at a few elements of the important chronological progression that evolved from the simple removal of a pump handle to the advanced water treatment (disinfection) methods we employ today to treat our water supplies.

After Snow's discovery that cholera is a waterborne disease emanating primarily from human waste, a number of events began to drive the water/wastewater treatment process. In 1859, 4 years after Snow's discovery, the British Parliament was suspended during the summer because the stench coming from the Thames was unbearable. According to one account, the river began to "seethe and ferment under a burning sun." As was the case in many cities at this time, storm sewers carried a combination of stormwater, sewage, street debris, and other wastes to the nearest body of water. In the 1890s, Hamburg, Germany, suffered a cholera epidemic. Detailed studies tied the outbreak to a contaminated water supply. Due to its response to the epidemic, Hamburg was among the first cities to use chlorine as part of a wastewater treatment regimen. About the same time, the town of Brewster, New York, became the first U.S. city to disinfect its treated wastewater. Chlorination of drinking water was used on a temporary basis in 1896, and its first known continuous use for water supply disinfection occurred in Lincoln, England, and in Chicago in 1905. Jersey City, New Jersey, became one of the first routine users of chlorine in 1908.

Time marched on, and with it came an increased realization of the need to treat and disinfect both water supplies and wastewater. Between 1910 and 1915, technological improvements in the gaseous and then solution feed of chlorine made the process more practical and efficient. Disinfection of water supplies and chlorination of treated wastewater for odor control increased over the next several decades. In the United States, disinfection, in one form or another, is now being used by more than 15,000 out of approximately 16,000 publicly owned treatment works (POTWs). The significance of this number becomes apparent when you consider that fewer than 25 of the over 600 POTWs in the United States in 1910 were using disinfectants.

WATER TREATMENT

Treatment of drinking water to remove contaminants is one of the oldest forms of public health protection. Municipalities normally control contaminants in drinking water supplies by following established treatment procedures. The contaminants of most concern to us are those that may cause disease: pathogenic microorganisms. Table 11.1 lists some of the most common diseases caused by microorganisms found in water supplies and their common sources. Although safeguarding health is the most important reason for treating drinking water, it is not the only reason. Consumer acceptance is also important. One thing is certain, however. The treatment needs of a water system differ depending on the quality of the source water.

Typically, before distribution to local destinations (e.g., homes, schools, businesses, hospitals), water withdrawn from its source (lake, river, or aquifer) undergoes some type of treatment. Again, initial water quality determines the necessary degree of treatment. Most water systems, large or small, include certain basic treatment steps. Figure 11.1 shows the steps typically taken to treat raw water and make it safe for human consumption.

Water treatment is a reasonably simple process. Once treated, the water is sent through a network of pipes (distribution system) to customers. To ensure its quality, water must be monitored and tested by licensed operators throughout the treatment and delivery process. Generally, surface water is

TABLE 11.1
Waterborne Diseases and Their Sources

Waterborne Disease	Causative Organism	Source of Organism
Gastroenteritis	*Salmonella*	Human feces
	Escherichia coli	Animal or human feces
Typhoid	*Salmonella typhosa*	Human feces
Dysentery	*Shigella*	Human feces
Cholera	*Vibrio comma*	Human feces
Infectious hepatitis	Hepatitis A (virus)	Human feces; shellfish grown in polluted waters
Amoebic dysentery	*Entamoeba histolytica*	Animal or human feces
Giardiasis	*Giardia lamblia*	Animal or human feces
Cryptosporidiosis	*Cryptosporidium*	Animal or human feces

Source: Adapted from AWWA, *Introduction to Water Treatment: Principles and Practices of Water Supply Operations*, American Water Works Association, Denver, CO, 1984.

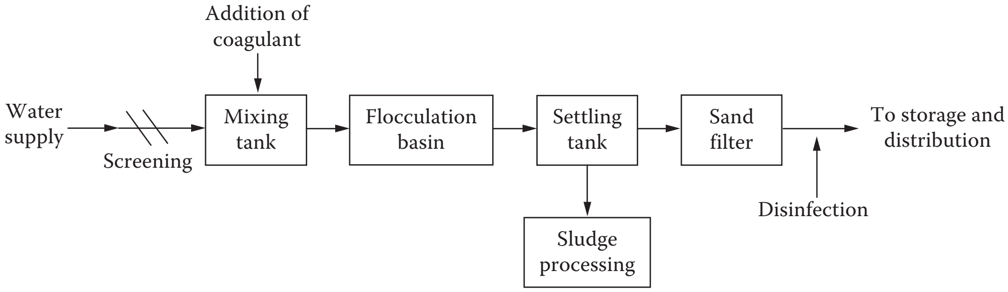

FIGURE 11.1 Conventional water treatment process.

more complicated to treat than groundwater, because contamination is more likely. Sometimes, however, groundwaters are hard because they contain calcium or magnesium, which means an additional step is added to the treatment process: using alum and lime to soften the water.

WASTEWATER TREATMENT

In the previous section, we learned some of the methodology used to clean raw water and make it suitable for human consumption. In the anthropogenic hydraulic cycle, the majority of water provided to the community by a public water supply is discharged to some form of wastewater collection and disposal system where it is purified and often then returned to surface water bodies, to again becomes part of the available water supply. Actually, there are five major sources that generate wastewater, and the wastewater of each source presents specific characteristics:

1. *Human and animal wastes* include the solid and liquid discharges of humans and animals, and millions of bacteria, viruses, and other organisms, some of which are pathogenic. This type of waste is considered by many to be the most dangerous from a human health viewpoint.
2. *Household wastes* are the wastes (other than human and animal wastes) discharged from the home—paper, household cleaners, detergents, trash, garbage, and any other substance that the average homeowner may decide to discharge into the sewer system.
3. *Industrial wastes* are all materials that are discharged from industrial processes into the collection system. They may contain chemicals, dyes, acids, alkalies, grit, detergents, and highly toxic materials. Characteristics are industry specific and cannot be determined without detailed information on the specific industry and processes used.
4. *Stormwater runoff* into a collection system designed to carry both the wastes of the community and stormwater runoff can, during and after storms, carry large amounts of sand, gravel, road salt, and other grit, as well as excessive amounts of water.
5. *Groundwater infiltration* occurs when groundwater enters a system through cracks, breaks, or unsealed joints in old or improperly sealed collection systems. This can add large amounts of water to the wastewater flows, as well as additional grit.

Wastewater can also be classified according to the sources of the flow:

1. *Domestic wastewater* (sewage) consists mainly of human and animal wastes, household wastes, small amounts of groundwater infiltration, and perhaps small amounts of industrial wastes.
2. *Sanitary wastewater* consists of domestic wastes and significant amounts of industrial wastes. In many cases, the industrial wastes can be treated without special precautions. In other cases, the industrial wastes require special precautions or a pretreatment program to ensure that the wastes do not cause compliance problems for the plant.

3. *Industrial wastewater* is produced by industries deciding that treating their wastes independent of domestic wastes is more economical than paying for municipal wastewater treatment.
4. *Combined wastewater* includes both sanitary wastewater and stormwater runoff. All of the wastewater and stormwater of the community is transported through one system and enters the treatment system.
5. *Stormwater* is carried in many communities by separate collection systems. Stormwater flow can contain grit and street debris but no domestic or sanitary wastes.

Wastewater contains many different substances that can also be used to characterize it. Depending on the source, the specific substances present will vary, as will the amounts or concentration of each. For this reason, wastewater characteristics are normally described for an average domestic wastewater. Other sources and types of wastewater can dramatically change the characteristics.

Wastewater physical characteristics include the following:

- *Color*—Typical wastewater is gray and cloudy. Wastewater color will change significantly if allowed to go septic. Typical septic wastewater will be black.
- *Odor*—Fresh domestic wastewater has a musty odor. This odor will change significantly if septic. Septic wastewater develops the rotten egg odor associated with hydrogen sulfide production.
- *Temperature*—Wastewater temperature will normally be close to that of the water supply. Significant amounts of infiltration or stormwater flow can cause major temperature changes.
- *Flow*—The volume of wastewater is normally expressed in terms of gallons per person per day. Most treatment plants are designed using an expected flow of 100 to 200 gallons per person per day. This figure may have to be revised to reflect the degree of infiltration or stormwater flow the plant receives. Flow rates will vary throughout the day. This variation, which can be as much as 50% to 200% of the average daily flow, is known as the *diurnal flow variation*.

Wastewater chemical characteristics include the following:

- *Alkalinity* is a measure of the wastewater's capability to neutralize acids. It is measured in terms of bicarbonate, carbonate, and hydroxide alkalinity. Alkalinity is essential to buffer (hold the neutral pH) wastewater during the biological treatment process.
- *Biochemical oxygen demand* (BOD) is a measure of the amount of biodegradable matter in the wastewater; it is normally measured by a 5-day test conducted at 20°C. The BOD_5 of domestic waste is normally in the range of 100 to 300 mg/L.
- *Chemical oxygen demand* (COD) is a measure of the amount of oxidizable matter present in the sample. The COD is normally in the range of 200 to 500 mg/L. The presence of industrial wastes can increase this significantly.
- *Dissolved gases* are gases dissolved in wastewater. The specific gases and normal concentrations are based on the composition of the wastewater. Typical domestic wastewater contains oxygen (relatively low concentrations), carbon dioxide, and hydrogen sulfide (if septic conditions exist).
- *Nitrogen compounds* vary in type and amount present from the raw wastewater to treated effluent. Nitrogen follows a cycle of oxidation and reduction. Most of the nitrogen in untreated wastewater will be in the forms of organic nitrogen and ammonia nitrogen, the presence and levels of which are determined by laboratory testing. The sum of these two forms of nitrogen is known as total Kjeldahl nitrogen (TKN). Wastewater will normally contain 20 to 85 mg/L of nitrogen. Organic nitrogen will usually be in the range of 8 to 35 mg/L, and ammonia nitrogen will be in the range of 12 to 50 mg/L.

- *pH* is a method for expressing the acid condition of wastewater. For proper treatment, wastewater pH should normally be in the range of 6.5 to 9.0.
- *Phosphorus* is essential to biological activity and must be present in at least minimum quantities or secondary treatment processes will not perform. Excessive amounts can cause stream damage and excessive algal growth. Phosphorus will normally be in the range of 6 to 20 mg/L. The removal of phosphate compounds from detergents has had a significant impact of the amounts of phosphorus in wastewater.
- *Solids* represent most pollutants found in wastewater. Wastewater treatment is generally designed to remove solids or to convert solids to a removable or more stable form. Solids can be classified by their chemical composition (organic or inorganic) or by their physical characteristics (settleable, floatable, or colloidal). The concentration of total solids in wastewater is normally in the range of 350 to 1200 mg/L.
- *Water* is always the major component of the wastewater. In most cases, water makes up 99.5 to 99.9% of wastewater. Even in the strongest wastewater, the total amount of contamination present is less than 0.5% of the total, and in average-strength wastes it is normally less than 0.1%.

Wastewater treatment uses natural purification processes to the maximum extent possible and in a controlled environment rather than over many miles of stream. Removing contaminants not addressed by natural processes and treating the solids generated by the treatment steps are further tasks of wastewater treatment. The specific goals of wastewater treatment plants include the following:

- Protecting public health
- Protecting public water supplies
- Protecting aquatic life
- Preserving the best uses of the waters
- Protecting adjacent lands

Wastewater treatment is accomplished by applying up to seven principle treatment steps to the incoming wastestream. Many of these steps are shown in Figure 11.2. The processes and equipment for each step are specific to the task. The major categories of treatment steps used in many treatment plants include preliminary treatment, primary treatment, secondary treatment, advanced waste treatment, disinfection, and biosolids treatment.

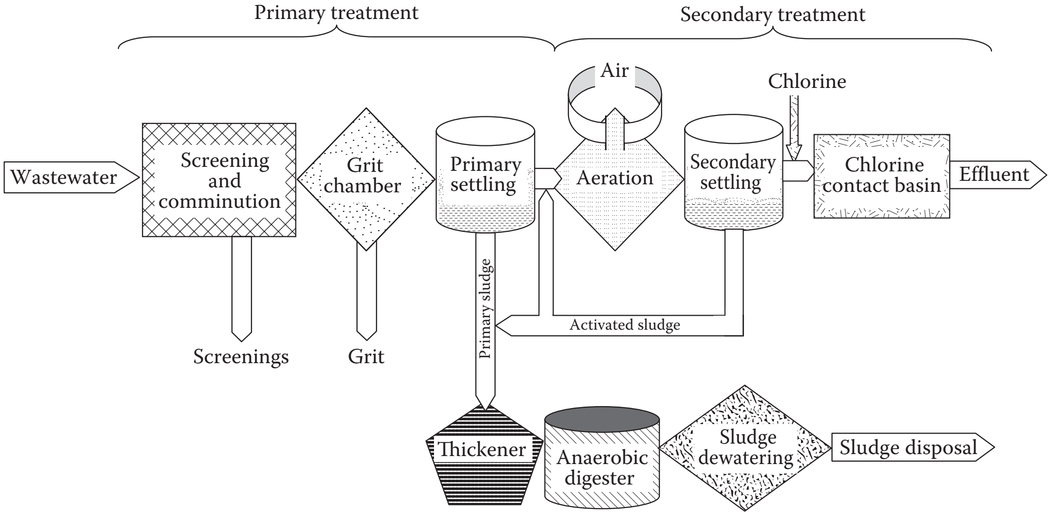

FIGURE 11.2 Typical wastewater primary, secondary, and tertiary treatment processes.

Preliminary treatment removes materials (wood, rocks, and other forms of debris) that could damage treatment plant equipment or that would occupy treatment capacity without being affected by treatment. Primary treatment removes larger particles by filtering the wastewater through screens to remove settleable and floatable solids in ponds or lagoons. Water is removed from the top of the settling lagoon and released to further treatment stages. Water that has been treated in this manner has had its sand and grit removed but still carries a heavy load of organic matter, dissolved salts, bacteria, and other microorganisms. Primary treatment removes up to about 60% of suspended solids. In heavily populated areas where several cities a few miles or less from each other take water and return it to a stream, primary wastewater treatment is not adequate.

Secondary treatment usually follows primary treatment and is designed to remove BOD_5 and dissolved and colloidal suspended organic matter by biological action. Organics are converted to stable solids, carbon dioxide, and more organisms by holding the wastewater until the organic material has been degraded by the bacteria and other microorganisms. It removes up to 90% of the oxygen-demanding wastes by using either trickling filters, where aerobic bacteria degrade sewage as it seeps through a large vat bed filled with media (rocks, plastic media, etc.) covered with bacterial growth, or an activated sludge process, in which the sewage is pumped into a large tank and mixed for several hours with bacteria-rich biosolids and air to increase bacterial degradation. To optimize this action, large quantities of highly oxygenated water are added directly by a blower system to promote bacterial growth.

Advanced wastewater treatment (tertiary sewage treatment) uses physical, chemical, and biological processes to remove additional BOD_5, solids, and nutrients. Advanced wastewater treatment is normally used in facilities that have unusually high amounts of phosphorus and nitrogen present. Disinfection is used to kill pathogenic microorganisms to eliminate the possibility of disease when the flow is discharged. Biosolids treatment works to stabilize the solids removed from the wastewater during treatment, inactivate pathogenic organisms, and reduce the volume of the biosolids by removing water (dewatering).

THERMAL POLLUTION TREATMENT

Heat is considered to be a water pollutant because of the adverse effect it has on oxygen levels and aquatic life in surface water bodies. Approximately half of the water withdrawn in the United States is used for cooling large power-producing plants. The easiest and least expensive (thus most common) cooling method is to withdraw cold water from a lake or river, pass it through heat exchangers in the facility, and then return the heated water to the same body of water. The warm water discharge raises the temperature of the receiving body, lowers the dissolved oxygen (DO) content, and causes aquatic organisms to increase their respiration rates, causing them to consume the already depleted oxygen faster. We can minimize the harmful effects of excess heat on aquatic ecosystems in a number of ways. Two of the most commonly used methods are the cooling tower and dry tower methods. In the cooling tower method, the heated water is sprayed into the air and cooled by evaporation. The obvious disadvantage of this treatment method is the loss of large amounts of water to evaporation. Production of localized fogs is another disadvantage. The dry tower method does not release water into the atmosphere; instead, the heated water is pumped through tubes and the heat is released into the air, which is similar to the action performed by an automobile's radiator. The disadvantage to using the dry tower method is the high cost of both construction and operation.

POLLUTION CONTROL TECHNOLOGY: UNDERGROUND STORAGE TANKS

No one is quite sure just how many underground storage tanks (USTs) containing hazardous substances or petroleum products are in use in the United States, but recent estimates range from 5 to 6 million. Compounding the issue, no one can even guess how many USTs have been abandoned. These abandoned tanks often still hold some portion of their contents, which may have been oozing (and sometimes pouring) out, fouling water, land, and air. Another problem is just biding its time; older USTs that are not leaking today will probably leak in the near future. One thing is certain, however; environmental contamination from leaking USTs poses a significant threat to human health and the environment.

Besides the obvious problem of fouling environmental mediums (water, soil, and air), many of these leaking USTs also pose serious fire and explosion hazards. The irony is that USTs came into common use primarily as a fire- and explosion-prevention measure in that the hazard was buried under the ground. Today, however, the hazards we worked to protect ourselves from are finding ways and means to present themselves as hazards in a different manner. The problem with leaking USTs goes beyond fouling the environment (especially groundwater, which 50% of the U.S. population relies on for drinking water) in that they pose fire and explosion hazards. Products released from these leaking tanks can damage sewer lines and buried cables and poison our crops.

What are underground storage tanks? The USEPA, under its Resource Conservation and Recovery Act (RCRA), defined USTs as tanks with 10% or more of their volume, including piping, underground. The largest portion of the USTs regulated by the USEPA are petroleum storage tanks owned by gas stations; another significant percentage includes petroleum storage tanks owned by certain industries (e.g., airports, trucking fleets, farms, manufacturing operations, golf courses) that store petroleum products for their own use.

In 1986, the U.S. Congress established a UST cleanup fund known as the Leaking Underground Storage Tank (LUST) trust fund. The USEPA, tasked with the responsibility of exploring, developing, and disseminating new cleanup technologies and the funding mechanism for the program, must still leave the primary job of cleaning up LUST sites to the various state and local governments. Owners and operators of tank facilities are liable for cleanup costs and damage caused by their tanks—not a small matter in any way. The average cost for remediating a site where petroleum has contaminated the soil and groundwater is on the order of $200,000 to $350,000, depending on the lateral and vertical extent of the contamination and the required cleanup target levels. In some cases, the cost of cleanup may exceed the value of the property.

When the USEPA and other watchdog groups initially investigated the problem of leaking USTs in 1985, they found that many of the existing USTs were more than 20 years old or of unknown age. Compounding the problem, these older tanks were usually constructed of bare steel so they were not protected against corrosion and were nearing the end of their useful lives (Holmes et al., 1993). Many of the old tanks systems had already leaked or were right on the edge of leaking. Many of these old tanks were found in abandoned gas stations (many shut down because of the oil crisis in the 1970s).

Because of the findings of the USEPA and others with regard to the scope of the problem with USTs, regulatory requirements were put into place. The regulatory requirements for USTs depend on whether the system is an existing or a new installation. An existing installation is defined as one that was installed prior to 1988. Under federal regulations (40 CFR Part 280), all existing USTs must have overfill and spill protection. Corrosion protection and leak detection systems must be installed in accordance with the schedule mandated by the federal regulations. The compliance schedule ensures that the oldest tanks (those with the greatest potential for failure) are addressed first; for example, pressured and suction piping installed prior to December 1988 had to have corrosion protection by December 1998.

When evaluating the integrity of installed USTs, it is necessary for all owners to abide by certain regulatory (minimum) requirements. Under federal law, facilities with USTs containing petroleum and hazardous substances must respond to a leak or spill within 24 hours of release or within another reasonable period of time as determined by the implementing agency. Responses to releases from USTs are site specific and depend on several different factors. Corrective action usually involves two stages. Stage one (initial response) is directed toward containment and collection of spilled material. Stage two (permanent corrective response) involves technical improvements designed to ensure that the incident does not occur again. Preventive-action technology usually includes employing containment, diversion, removal, or treatment protocols. The choice of which technology to employ in spill prevention and correction depends on its suitability, lifespan, ease of implementation, and ease of performing required maintenance checks.

Various USEPA publications provide guidance for deciding which technology to employ for cleanup of releases from petroleum USTs (e.g., USEPA, 1988, 2017). Although only a limited number of technologies are available to cleanse environmental media of the contaminants associated with gasoline, their practicality, removal efficiencies, limitations, and costs are well documented.

Two technologies are currently used to limit the migration of floating gasoline across the water table and to recover free product from the water table: the *trench method* and the *pumping well method*. The trench method uses a variety of equipment, including skimmers, filter separators, and oil/water separators. In the pumping well method, both single- and dual-pumps systems are used.

When the water table is no deeper than 10 to 15 ft below the ground surface, the trench method is most effective. The advantages of this method include the ease with which the trench can be excavated and the ability to capture the entire leading edge of the plume. The disadvantage in using the trench method is that it does not reverse groundwater flow, which means it may not be appropriate for use when a potable well supply is threatened. The cost of this system is about $150 per cubic yard of soil excavated. For deep spills (when the water table depth exceeds 20 feet below the ground surface), a pumping well system is the preferred method used to recover free product from the water table. The major advantage of using this system is that it can reverse the direction of groundwater flow. Including the cost of labor and engineering, this system ranges from about $150 to $300 per foot for 4- to 10-inch gravel-packed galvanized steel wells (USEPA, 1988).

Because gasoline spilled onto the soil may eventually find its way to groundwater, removal of gasoline from unsaturated soils is an essential component of any corrective action plan. Several removal techniques are available, but they vary in their effectiveness and cost. The most widely used corrective action is excavation and disposal. Other methods include volatilization, incineration, venting, soil washing/extraction, and microbial degradation. Excavation and disposal can be 100% effective. Unfortunately, however, usually only a small portion of the contaminated soil can be removed because of the high costs involved. Other disadvantages of this technique include the limitations of excavation equipment (backhoes normally only reach down to about 16 feet), landfills not accepting the contaminated soil, and lack of uniform guidelines for the proper disposal of contaminated soil.

Volatilization will effectively remove about 99% of volatile organic compounds (VOCs), but this little-used process does not have an extensive enough track record to make definitive statements as to its efficiency or effectiveness in the field. Incineration, like volatilization, will remove approximately 99% of gasoline constituents in soil. Having proven itself highly reliable, incineration of gasoline-contaminated soil is widely practiced. The practice does have a few limitations: (1) the soil must be brought to the surface, thus increasing the risk of exposure; (2) incineration is usually appropriate only when toxics other than volatiles are present; and (3) permitting delays (fighting the bureaucratic paper chase) may cause time delays.

The big advantage of using venting (which can be up to 99% effective) is that it allows for the removal of gasoline without excavation; however, because critical parameters have not yet been defined, venting is not widely used in the field. Venting is relatively easy to implement, but its effectiveness is uncertain because soil characteristics may impede the free movement of vapors and could even lead to an explosion hazard.

Soil washing and extraction work to leach contaminants from the soil into a leaching medium, after which the extracted contaminants are removed by conventional methods. Under ideal conditions, up to 99% of VOCs can be removed. If the contaminated soil contains high levels of clay and silt, they may impede the separation of the solid and liquid after the washing phase. The suitability of the soil for decontamination using this method should be verified before this procedure is implemented.

Microbial degradation, theoretically, can remove up to 99% of the contaminants. This method is still being researched and field testing is in progress, so its cost effectiveness and overall effectiveness have not been verified. If further testing supports its viability for use in the field, the advantage will be that *in situ* treatment is possible that will completely destroy volatiles.

POLLUTION CONTROL TECHNOLOGY: GROUNDWATER REMEDIATION

When a pollutant is released onto or into the soil, the main force on the movement of the material is gravity (Nyer, 1992). If the ground is porous, the pollutant will move downward. Some lateral spread of the movement will occur, controlled by the porosity of the soil. The speed of movement will be dependent on the viscosity of the material spilled and the porosity of the soil. Several things can happen to the contaminant as it progresses downward, before it encounters the aquifer. Initially, the contaminant may undergo any of the following: adsorption on the soils particles, volatilization, biological degradation, and, usually to a lesser degree, hydrolysis, oxidation, reduction, and dehydrohalogenation (Olsen and Davis, 1990).

For many years groundwater was the only source of potable water available in certain areas, but it has also been the source of choice even when other sources were available because of the perception of groundwater as pure. People thought that it only required disinfection before being sent to the household tap. They assumed that precipitation filtered its way through Earth's strata to the water table where it was held in a clean state and, by the nature of its confinement there, was protected from surface contamination. This view of groundwater has problems, though. In the first place, because groundwater is so widely used and because the populations using it have increased at a steady pace, many groundwater supplies have either been depleted or lowered to the point where, in coastal areas, saltwater intrusion takes place. Second, groundwater supplies may become polluted.

Both groundwater depletion and groundwater pollution may be irreversible. Depletion can cause an aquifer to consolidate, diminishing its storage capacity. Groundwaters may be contaminated by both naturally occurring and artificial materials. Just about anything water comes into contact with will eventually be dissolved in or mixed with the flow. If contaminated, the water is likely to remain that way.

Of particular concern in groundwater pollution are nonaqueous-phase liquids (NAPLs). NAPLs are classified as either light (LNAPLs) or dense (DNAPLs). LNAPLs include such products as gasoline, heating oil, and kerosene. The widespread use of underground storage tanks has made these products common in many soils. Because LNAPLs are light, they tend to float on the groundwater, penetrating the capillary fringe and depressing the water surface. Even when the source of the spill is controlled, the soil will remain contaminated, and the floating layer will serve as a long-term source of contamination (McGhee, 1991). From a health standpoint, DNAPLs are a much more serious problem. They include trichloroethane, carbon tetrachloride, creosote, and dichlorobenzene, among others. Because these compounds are toxic, with low viscosity, great density, and low solubility, they not only are health hazards but are also very mobile in groundwater and spread quickly throughout a localized aquifer.

If the aquifer must be cleaned, the treatment method or methods employed for an organic cleanup will depend upon several factors, and the following points should be considered when choosing the unit operations to be used (Nyer, 1992):

- *Description of the release*—Concentration, quantity of contaminant, total time allotted for cleanup, and final use of the water
- *Properties of the spilled material*—Solubility, density, strippability, absorbability, and biodegradability
- *Site and aquifer characteristics*—Depth to water, permeability, extent of contamination, and ongoing site activities

In contaminated groundwater mitigation and treatment, usually only localized areas of an aquifer require reclamation and restoration, because the spread of contaminants is usually confined to the plume. Experience has shown, however, that even after the original source of contamination is removed cleanup of a contaminated aquifer is costly, time consuming, and troublesome. Problems with cleanup include difficulty in identifying the type of subsurface environment, locating potential contamination sources, defining potential contaminant transport pathways, determining contaminant extent and concentration, and implementing an effective remedial process (Davis and Cornwell, 1991).

Cleanup is possible but not simple. In some cases, especially where groundwater has been pumped from the subsurface, certain methods have proven successful. These efforts have been refined from processes used to treat industrial wastes; however, attempting to treat site-contaminated groundwater using these methods is often confusing. The contaminants themselves may also dictate what methodologies should work for mitigation. When the contaminant is a single chemical, the treatment system employed may be simple, but cases involving multiple contaminants are extremely complex. To determine which treatment should be employed, only representative samples and laboratory analysis will provide the needed information. Cleanup technologies commonly used for groundwater containing organic contamination include air stripping and activated carbon. The chemical precipitation process is used for inorganics in groundwater. We briefly describe each of these treatment processes in the following.

In air stripping (a relatively simple mass-transfer process), a substance in solution in water is transferred to a solution in a gas. Air stripping uses four basic equipment configurations, including diffused aeration, countercurrent packed towers, cross-flow towers, and coke tray aerators. The countercurrent packed tower system has significant advantages over the other systems (e.g., provides the greatest liquid interfacial area, high air-to-water volume ratios) and is most often used in removing volatile organics from contaminated groundwater. Carbon adsorption occurs when an organic molecule is brought to the activated carbon surface and held there by physical or chemical forces. When activated carbon particles are placed in water containing organic chemicals and mixed to give adequate contact, adsorption of the organic chemicals occurs. Activated carbon adsorption has been successfully employed for removing organics from contaminated groundwaters.

Biological treatment, a new technology still under evaluation by pilot studies, works to remove or reduce the concentration of organic and inorganic compounds. To undergo biological treatment, contaminated groundwater must first be pretreated to remove toxins that could destroy microorganisms necessary to metabolize and remove the contaminants.

To remove inorganic contaminants, the established and most commonly used methodology is chemical precipitation. Accomplished by the addition of carbonate, hydroxide, or sulfide chemicals, chemical precipitation has successfully removed heavy metals from groundwaters.

When groundwater near a potable water system (e.g., well) is contaminated, the most common way to protect the water from an approaching plume of contaminated groundwater is to use some combination of extraction wells and injection wells. Extraction wells are used to lower the water table, creating a hydraulic gradient that draws the plume to the wells. Injection wells raise the water table and push the plume away. Working in combination, extraction and injection well pumping rates can be adjusted in such a way as to manipulate the hydraulic gradient, which helps keep the plume away from the potable water well, drawing it toward the extraction well. Once extracted, the contaminated water is treated and reinjected back into the aquifer, reused, or released into the local surface water system (Masters, 1991).

THE BOTTOM LINE

Traditional treatment methods go a long way toward handling the problems of point-source pollution problems. The issues of how to handle the less obvious problems of nonpoint-source pollution and the out-of-sight problems of USTs and groundwater are now being addressed. These problems are more subtle and demand the application of a number of remediation techniques.

DISCUSSION QUESTIONS

1. Discuss how the SDWA affected our water supplies.
2. Describe and discuss secondary drinking water standards.
3. Discuss the CWA and how it has affected our water supplies.
4. What steps are involved in water treatment?
5. What steps are involved in wastewater treatment?
6. What are the physical, chemical, and source characteristics of wastewater?
7. What are the common diseases, organisms, and sources of concern for water treatment?
8. Discuss underground storage tanks and how they can affect water supply. What are the remediation techniques used to combat UST leaks?
9. What processes are used for groundwater remediation?

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Section IV

Soil

> Our economy is such that we say we "cannot afford" to take care of things: Labor is expensive, time is expensive, money is expensive, but materials—the stuff of creation—are so cheap that we cannot afford to take care of them.
>
> **—Wendall Berry, *Home Economics* (1987)**

12 Soil Basics

> An oyster that went to bed x-million years ago,
> tucked itself into a sand-bottom, yawned (so to speak)
> and woke a mile high in the Grand Canyon of the Colorado.
>
> **Ciardi (1997)**

> We stand on soil, not on earth.
>
> **Illich et al. (1991)**

> We take the air we breathe for granted. We take the water we need for granted. As for the soil? Well, we can't breathe too easily with a mouth full of soil, and we sure can't bathe in soil when there is no water.
>
> **—Frank R. Spellman**

INTRODUCTION

We take soil for granted. It's always been there, with the implied corollary that it will always be there. But, where does soil come from? Of course, soil was formed and, in a never-ending process, is still being formed; however, soil formation is a slow process—one at work over the course of millennia as mountains are worn away to dust through bare rock succession. Any activity, human or natural, that exposes rock to air begins the process. Through the agents of physical and chemical weathering, through extremes of heat and cold, through storms and earthquakes and entropy, bare rock is gradually broken, reduced, and worn away. As its exterior structures are exposed and weakened, plant life appears to speed the process along.

Lichens cover the bare rock first, growing on the surface of the rock, etching it with mild acids and collecting a thin film of soil that is trapped against the rock and clings. This changes the conditions of growth so much that the lichens can no longer survive, and they are replaced by mosses. The mosses establish themselves in the soil trapped and enriched by the lichens and collect even more soil. They hold moisture to the surface of the rock, setting up another change in environmental conditions. Well-established mosses hold enough soil to allow herbaceous plant seeds to invade the rock. Grasses and small flowering plants move in, sending out fine root systems that hold more soil and moisture and work their way into minute fissures in the surface of the rock. More and more organisms join the increasingly complex community. Weedy shrubs are the next invaders; they have heavier root systems that find their way into every crevice.

Each stage of succession affects the decay of the surface of the rock and adds its own organic material to the mix. Over the course of time, mountains are worn away, eaten away to soil, as time, plants, weather, and extremes of weather work on them. The parent material, the rock, becomes smaller and weaker as the years, decades, centuries, and millennia go by, thus producing the rich, varied, and valuable mineral resource we call soil.

SOIL: WHAT IS IT?

Perhaps no term causes more confusion in communication among typical people, soil scientists, soil engineers, and earth scientists than the word *soil* itself. In simple terms, *soil* can be defined as the topmost layer of decomposed rock and organic matter which usually contains air, moisture, and nutrients and therefore can support life. Most people would have little difficulty in understanding and accepting this simple definition, then why the confusion over the exact meaning of the word *soil*? Quite simply, confusion reigns because soil is not simple—it is quite complex. In addition, the term has different meanings to different groups (like pollution, the exact definition of soil is a personal judgment call). Let's take a look at how some of these different groups view soil.

Typical people seldom give soil a thought, because it usually doesn't directly impact their lives. They seldom think about soil as soil, but they might think of soil in terms of dirt. First of all, soil is not dirt. Dirt is misplaced soil—soil where we don't want it, such as on our hands, clothes, automobiles, or floors. Dirt is something we try to clean up and to keep out of our living environments. Second, soil is too special to be called dirt, because soil is mysterious and, whether we realize it or not, essential to our existence. Because we think of it as common, we relegate soil to an ignoble position. As our usual course of action, we degrade it, abuse it, throw it away, contaminate it, and ignore it. We treat it like dirt; only feces hold a more lowly status. Soil deserves better. Why? Because soil is not dirt; moreover, it is not filth, or grime, or squalor. Soil is composed of clay, air, water, sand, loam, and organic detritus of former life forms. If water is Earth's blood and air is Earth's breath, then soil is its flesh and bone and marrow.

Soil scientists (or pedologists) are people interested in soils as a medium for plant growth. Their focus is on the upper meter or so beneath the land surface—the *weathering zone*, which contains the organic-rich material that supports plant growth and is directly above the unconsolidated *parent material*. Soil scientists have developed a classification system for soils based on the physical, chemical, and biological properties that can be observed and measured in the soil.

Soils engineers are typically soils specialists who look at soil as a medium that can be excavated using tools. Soils engineers are not concerned with the plant-growing potential of a particular soil but rather are concerned with the ability of a particular soil to support a load. They attempt to determine (through examination and testing) the particle size, particle-size distribution, and plasticity of the soil.

Earth scientists (or geologists) have a view that typically falls between that of pedologists and soils engineers; they are interested in soils and the weathering processes as past indicators of climatic conditions and in relation to the geologic formation of useful materials ranging from clay deposits to metallic ores.

To gain a new understanding of soil, go out to a plowed farm field, pick up a handful of soil, and look at it very closely. What are you holding in your hand? Read the two descriptions that follow to gain a better understanding of what soil actually is and why it is critically important to us all (Spellman and Whiting, 2006):

1. A handful of soil is alive, a delicate living organism that is as lively as an army of migrating caribou and as fascinating as a flock of egrets. Literally teeming with life of incomparable forms, soil deserves to be classified as an independent ecosystem or, more correctly stated, as many ecosystems.
2. When we reach down and pick up a handful of soil, it should remind us (and maybe startle some of us) that without its thin living soil layer Earth would be a planet as lifeless as our own moon.

In our attempt to define soil and differentiate soil from dirt, in our trying to make the point that soil is important, critical, and vital to all of us and that it is arguably the most valuable of all mineral resources on Earth, we would be hard pressed to do so in a more succinct but complete fashion than to quote Konigsburg (1996), who stated that, "Soil is the working layer of the Earth."

The purpose of this part of the text is to provide information on just about every aspect of soil. In so doing, we do not lose sight of the fact that we currently have a problem with soil. Consider, for example, that the United States (and almost every other country) is experiencing a continuing increase in the amount and type of materials being discarded. This places a significant burden on disposal sites. It may surprise you to know that in the past three decades a significant amount of the material being landfilled is contaminated soil. This contaminated soil is only part of the problem, however. Remember, soil is in direct contact with water and air. Because water, air, and soil exist in a complex interrelationship, this contact causes problems with water and air, as well.

In the past, soil pollution problems have been exacerbated by the physical, economic, and technical limitations associated with the technologies currently available for the remediation of contaminated soil. Progress has been made in this vital area, however. Although problems must still be solved in the areas of soil remediation, technology is not necessarily one of them.

KEY TERMS DEFINED[*]

Every branch of science, including soil science, has its own language. To work even at the edge of soil science, soil pollution, and soil pollution remediation, it is necessary to acquire a familiarity with the vocabulary used in this text.

Ablation till—A superglacial, coarse-grained sediment or till that accumulates as the subadjacent ice melts and drains away and is finally deposited on the exhumed subglacial surface.

Absorption—Movement of ions and water into the plant roots as a result of either metabolic processes by the root (active absorption) or diffusion along a gradient (passive absorption).

Acid rain—Atmospheric precipitation with pH values less than about 5.6, the acidity being due to inorganic acids such as nitric and sulfuric acids that are formed when oxides of nitrogen and sulfur are emitted into the atmosphere.

Acid soil—A soil with a pH value of <7.0 or neutral. Soils may be naturally acidic from their rocky origin or due to leaching, or they may become acidic from decaying leaves or from soil additives such as aluminum sulfate (alum). Acid soils can be neutralized by the addition of lime products.

Actinomycetes—A group of organisms intermediate between the bacteria and the true fungi that usually produce a characteristic branched mycelium; includes many (but not all) organisms belonging to the order of Actinomycetales.

Adhesion—Molecular attraction that holds the surfaces of two substances (e.g., water and sand particles) in contact.

Adsorption—The attraction of ions or compounds to the surface of a solid.

Aeration, soil—The process by which air in the soil is replaced by air from the atmosphere. In a well-aerated soil, the soil air is similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain more carbon dioxide and correspondingly less oxygen than the atmosphere above the soil.

Aerobic—Growing only in the presence of molecular oxygen, as aerobic organisms.

Aggregates, soil—Soil structural units of various shapes, composed of mineral and organic material, formed by natural processes, and having a range of stabilities.

Agronomy—A specialization of agriculture concerned with the theory and practice of field crop production and soil management; the scientific management of land.

Air capacity—Percentage of soil volume occupied by air spaces or pores.

Air porosity—The proportion of the bulk volume of soil that is filled with air at any given time or under a given condition, such as a specified moisture potential; usually the large pores.

Alkali—A substance capable of liberating hydroxide ions in water, having a pH of more than 7.0, and possessing caustic properties; it can neutralize hydrogen ions, with which it reacts to form a salt and water, and is an important agent in rock weathering.

Alluvium—A general term for unconsolidated, granular sediments deposited by rivers.

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[*] This section was compiled and adapted from several sources, including USDA, *Soil Taxonomy*, 2nd ed., U.S. Department of Agriculture, Washington, DC, 1999; SCSA, *Resource Conservation Glossary*, ED044296, Soil Conservation Society of America, Ankeny, IA, 1982; SSSA, *Soil Science Glossary*, Soil Science Society of America, Madison, WI, 2008.

Amendment, soil—Any substance other than fertilizers (such as compost, sulfur, gypsum, lime, and sawdust) used to alter the chemical or physical properties of a soil, generally to make it more productive.

Ammonification—The production of ammonia and ammonium–nitrogen through the decomposition of organic nitrogen compounds in soil organic matter.

Anaerobic—Without molecular oxygen.

Anion—An atom that has gained one or more negatively charged electrons and is thus itself negatively charged.

Aspect (of slopes)—The direction that a slope faces with respect to the sun.

Assimilation—The taking up of plant nutrients and their transformation into actual plant tissues.

Atterburg limits—Water contents of fine-grained soils at different states of consistency.

Autotrophs—Plants and microorganisms capable of synthesizing organic compounds from inorganic materials by either photosynthesis or oxidation reactions.

Available water—The portion of water in a soil that can be readily absorbed by plant roots; the amount of water released between the field capacity and the permanent wilting point.

Bedrock—The solid rock underlying soils and the regolith in depths ranging from zero (where exposed by erosion) to several hundred feet.

Biological function—The role played by a chemical compound or a system of chemical compounds in living organisms.

Biomass—The total weight of living biological organisms within a specified unit (area, community, population).

Biome—A major ecological community extending over large areas.

Blow-out—A deflation depression, eroded by wind from the face of a vegetated dune.

Breccia—A rock composed of coarse angular fragments that are cemented together.

Calcareous soil—Containing sufficient calcium carbonate (often with magnesium carbonate) to effervesce visibly when treated with hydrochloric acid.

Caliche—A layer near the surface, more or less cemented by secondary carbonates of calcium or magnesium precipitated from the soil solution. It may occur as a soft, thin soil horizon; as a hard, thick bed just beneath the solum; or as a surface layer exposed by erosion.

Capillary water—Water held within the capillary pores of soils; mostly available to plants.

Catena—The sequence of soils that occupy a slope transect, from the topographic divide to the bottom of the adjacent valley.

Cation—An atom that has lost one or more negatively charged electrons and is thus itself positively charged.

Chelate (from Greek *chele* for "claw")—A complex organic compound containing a central metallic ion surrounded by organic chemical groups.

Class, soil—A group of soils having a definite range in a particular property such as acidity, degree of slope, texture, structure, land-use capability, degree of erosion, or drainage.

Clay—A soil separate consisting of particles <0.0002 mm in equivalent diameter.

Cohesion—Holding together; a force holding a solid or liquid together due to attraction between like molecules; decreases with rise in temperature.

Colloidal—Matter of very fine particle size.

Convection—A process of heat transfer in a fluid involving the movement of substantial volumes of the fluid concerned. Convection is very important in the atmosphere and to a lesser extent in the oceans.

Denitrification—The biochemical reduction of nitrate or nitrite to gaseous nitrogen, either as molecular nitrogen or as an oxide of nitrogen.

Detritus—Debris from dead plants and animals.

Diffusion—The movement of atoms in a gaseous mixture or ions in a solution, primarily as a result of their own random motion.

Drainage—The removal of excess water, both surface and subsurface, from plants. All plants (except aquatics) will die if exposed to an excess of water.

Duff—The matted, partly decomposed organic surface layer of forest soils.

Erosion—Wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep.

Eutrophication—A process of lake aging whereby aquatic plants are abundant and waters are deficient in oxygen. The process is usually accelerated by enrichment of waters with surface runoff containing nitrogen and phosphorus.

Evapotranspiration—The combined loss of water from a given area, during a specified period of time, by evaporation from the soil surface and by transpiration from plants.

Exfoliation—Mechanical or physical weathering that involves the disintegration and removal of successive layers of rock mass.

Fertility, soil—The quality of a soil that enables it to provide essential chemical elements in quantities and proportions for the growth of specified plants.

Fixation—The transformation in soil of a plant nutrient from an available to an unavailable state.

Fluvial—Deposits of parent materials laid down by rivers or streams.

Friable—A soil consistency term pertaining to the ease of crumbling of soils.

Heaving—The partial lifting of plants, buildings, roadways, fence posts, etc., out of the ground as a result of freezing and thawing of the surface soil during the winter.

Heterotroph—An organism capable of deriving energy for life processes only from the decomposition of organic compounds and incapable of using inorganic compounds as sole sources of energy or for organic synthesis.

Horizon, soil—A layer of soil, approximately parallel to the soil surface, differing in properties and characteristics from adjacent layers below or above it.

Humus—More or less stable fraction of the soil organic matter (usually dark in color) remaining after the major portions of added plant and animal residues have decomposed.

Hydration—The incorporation of water into the chemical composition of a mineral, converting it from an anhydrous to a hydrous form; the term is also applied to a form of weathering in which hydration swelling creates tensile stress within a rock mass.

Hydraulic conductivity—The rate at which water is able to move through a soil.

Hydrolysis—The reaction between water and a compound (commonly a salt). The hydroxyl from the water combines with the anion from the compound undergoing hydrolysis to form a base; the hydrogen ion from the water combines with the cation from the compound to form an acid.

Hygroscopic coefficient—The amount of moisture in a dry soil when it is in equilibrium with some standard relative humidity near a saturated atmosphere (about 98%), expressed in terms of percentage on the basis of oven-dry soil.

Infiltration—The downward entry of water into the soil.

Ions—Atoms that have lost or gained one or more negatively charged electrons.

Land classification—The arrangement of land units into various categories based on the properties of the land and its suitability for some particular purpose.

Leaching—The removal of materials in solution from the soil by percolating waters.

Liebig's law—The growth and reproduction of an organism are determined by the nutrient substance (oxygen, carbon dioxide, calcium, etc.) that is available in minimum quantity with respect to organic needs, the limiting factor.

Loam—The textural class name for soil having moderate amounts of sand, silt, and clay.

Loess—An accumulation of wind-blown dust (silt) that may have undergone mild digenesis.

Marl—An earthy deposit consisting mainly of calcium carbonate, usually mixed with clay. Marl is used for liming acid soils. It is slower acting than most lime products used for this purpose.

Mineralization—The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

Nitrogen fixation—The biological conversion of elemental nitrogen (N_2) to organic combinations or to forms readily utilized in biological processes.

Osmosis—The movement of a liquid across a membrane from a region of high concentration to a region of low concentration. Water and nutrients move into roots independently.

Oxidation—The loss of electrons by a substance.

Parent material—The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of soils is developed by pedogenic processes.

Ped—A unit of soil structure such as an aggregate, crumb, prism, block, or granule, formed by natural processes.

Pedogenic/pedological process—Any process associated with the formation and development of soil.

pH—The degree of acidity or alkalinity of the soil. Also referred to as *soil reaction*, this measurement is based on the pH scale where 7.0 is neutral, values from 0.0 to 7.0 are acid, and values from 7.0 to 14.0 are alkaline. The pH of soil is determined by a simple chemical test where a sensitive indicator solution is added directly to a soil sample in a test tube.

Photosynthesis—The process by which green leaves of plants, in the presence of sunlight, manufacture their own needed materials from carbon dioxide in the air and water and minerals taken from the soil.

Porosity, soil—The volume percentage of the total bulk not occupied by solid particles.

Profile, soil—A vertical section of the soil through all its horizons and extending into the parent material.

Reduction—The gain of electrons and therefore the loss of positive valence charge by a substance.

Regolith—The unconsolidated mantle of weathered rock and soil material on the Earth's surface; loose earth materials above solid rock.

Rock—The material that forms the essential part of the Earth's solid crust, including loose incoherent masses such as sand and gravel, as well as solid masses of granite and limestone.

Rock cycle—The global geological cycling of lithospheric and crustal rocks from their igneous origins through all or any stages of alteration, deformation, resorption, and reformation.

Runoff—The portion of the precipitation on an area that is discharged from the area through stream channels.

Salinization—The process of accumulation of salts in soil.

Sand—A soil particle between 0.05 and 2.0 mm in diameter; a soil textural class.

Silt—A soil separate consisting of particles between 0.05 and 0.002 mm in equivalent diameter; a soil textural class.

Slope—The degree of deviation of a surface from horizontal, measured in a numerical ratio, percent, or degrees.

Soil—An assemblage of loose and normally stratified granular minerogenic and biogenic debris at the land surface; it is the supporting medium for the growth of plants.

Soil air—The soil atmosphere; the gaseous phase of the soil, which is the volume not occupied by soil or liquid.

Soil horizon—A layer of soil, approximately parallel to the soil surface, with distinct characteristics produced by soil-forming processes. These characteristics form the basis for systematic classification of soils.

Soil profile—A vertical section of the soil from the surface through all its horizons, including C horizons.

Soil structure—The combination or arrangement of primary soil particles into secondary particles, units, or peds. These secondary units may be, but usually are not, arranged in the profile in such a manner as to give a distinctive characteristic pattern. The secondary units are characterized and classified on the basis of size, shape, and degree of distinctness into classes, types, and grades, respectively.

Soil texture—The relative proportions of the various soil separates in a soil.

Soluble—Dissolves easily in water.

Solum (pl. *sola*)—The upper and most weathered part of the soil profile; the A, E, and B horizons.

Subsoil—That part of the soil below the plow layer.

Till—Unstratified glacial drift deposited directly by the ice and consisting of clay, sand, gravel, and boulders intermingled in any proportion.

Tilth—The physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its impedance to seedling emergence and root penetration.

Topsoil—The layer of soil moved in cultivation.

Weathering—All physical and chemical changes produced in rocks at or near the Earth's surface by atmospheric agents.

ALL ABOUT SOIL

> Weekend gardeners tend to think of soil as the first few inches below the Earth's surface—the thin layer that needs to be weeded and that provides a firm foundation for plants. But the soil actually extends from the surface down to the Earth's hard rocky crust. It is a zone of transition, and, as in many of nature's transition zones, the soil is the site of important chemical and physical processes. In addition, because plants need soil to grow, it is arguably the most valuable of all the mineral resources on Earth.
>
> **Beazley (1992)**

Before we begin a journey that takes us through the territory that is soil and examine soil from micro to macro levels, we need to stop for a moment and discuss why, beyond the obvious reason, soil is so important to us, to our environment, to our very survival.

FUNCTIONS OF SOIL

We normally relate soil to our backyards, to farms, to forests, or to a regional watershed. We think of soil as the substance upon which plants grow. Soils play other roles, though. There are six main functions of soil that are important to us (see Figure 12.1): (1) soils serve as a medium for plant growth, (2) soils regulate our water supplies, (3) soils are recyclers of raw materials, (4) soils provide a habitat for organisms, (5) soils are used as an engineering medium, and (6) soils provide materials. Let's take a closer look at each of these functions of soils.

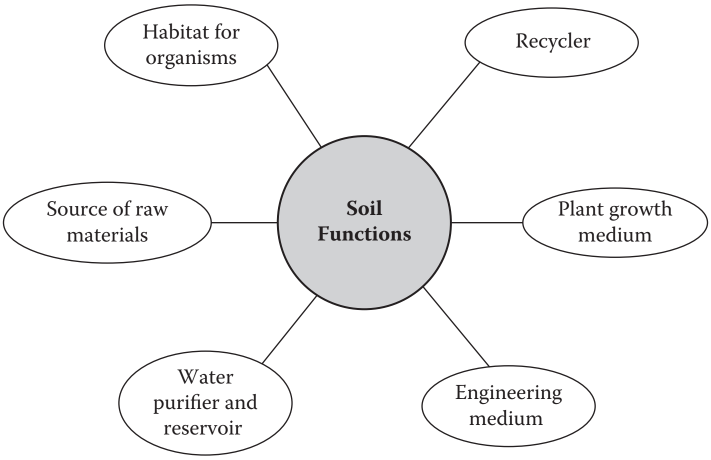

FIGURE 12.1 Functions of soil.

Soil as a Plant Growth Medium

We are all aware of the primary function of soil—to serve as a plant growth medium, a function that becomes more important with each passing day as Earth's population continues to grow. Although soil is a medium for plant growth, soil itself is actually alive as well. We depend on soil for life, and at the same time soil depends on life. Its very origin, its maintenance, and its true nature are intimately tied to living plants and animals. What does this mean? Let's take a look at how the elegant prose of renowned environmental writer Rachel Carson (1962) explained this paradox:

> The soil community … consists of a web of interwoven lives, each in some way related to the others—the living creatures depending on the soil, but the soil in turn is a vital element of the earth only so long as this community within it flourishes.

The soil might say to us if it could, "Don't kill off the life within me and I will do the best I can to provide life that will help to sustain your life." What we have here is a tradeoff—one vitally important to both soil and ourselves. Remember that most of Earth's people are tillers of the soil; the soil is their source of livelihood, and those soil tillers provide food for us all.

As a plant growth medium, soil provides vital resources and performs essential functions for the plant. To grow in soil, plants must have water and nutrients. Soil provides both of these. To grow and to sustain its growth, a plant must have a root system. Soil provides pore spaces for roots. To grow and maintain growth, a plant's roots must have oxygen for respiration and carbon dioxide exchange and ultimate diffusion out of the soil. Soil provides the air and pore spaces (the ventilation system) for this. To continue to grow, a plant must have support. Soil provides this support.

If a plant seed is planted in a soil and is exposed to the proper amount of sunlight for growth to occur, the soil still must provide nutrients through a root system that has space to grow, a continuous stream of water (about 500 g of water are required to produce 1 g of dry plant material) for root nutrient transport and plant cooling, and a pathway for both oxygen and carbon dioxide transfer. Just as important, soil water provides the plant with the normal fullness or tension (turgor) it needs to stand—the structural support it needs to face the sun for photosynthesis to occur.

In addition to the functions stated above, soil is also an important moderator of temperature fluctuations. If you have ever dug in a garden on a hot summer day, you probably noticed that the soil was warmer (even hot) on the surface but much cooler just a few inches below the surface.

Soil as a Regulator of Water Supplies

When we walk on land, few of us probably realize that we are actually walking across a bridge. This bridge (in many areas) transports us across a veritable ocean of water below us, deep—or not so deep—under the surface of the Earth. Consider what happens to rain. Where does the rain water go? Some, falling directly over water bodies, becomes part of the water body again, but an enormous amount falls on land. Some of the water, obviously, runs off—always following the path of least resistance. In modern communities, stormwater runoff is a hot topic. Cities have taken giant steps to try to control runoff, to send it where it can be properly handled to prevent flooding. Let's take a closer look at precipitation and the sinks it pours into, then relate this usually natural operation to soil water. We begin with surface water, then move on to that ocean of water below the soil's surface: groundwater.

Surface water (water on the Earth's surface as opposed to subsurface water, or groundwater) is mostly a product of precipitation: rain, snow, sleet, or hail. Surface water is exposed or open to the atmosphere and results from overland flow, the movement of water on and just under the Earth's surface. This overland flow is the same thing as surface runoff, which is the amount of rainfall that passes over the Earth's surface. Specific sources of surface water include rivers, streams, lakes, impoundments, shallow wells, rain catchments, tundra ponds, or meskegs (peat bogs).

Most surface water is the result of surface runoff. The amount and flow rate of surface runoff are highly variable. This variability stems from two main factors: (1) human interference (influences), and (2) natural conditions. In some cases, surface water runs quickly off land. Generally, this is undesirable from a water resources standpoint because the water does not have enough time to infiltrate into the ground and recharge groundwater aquifers. Other problems associated with quick surface water runoff are erosion and flooding. Probably the only good thing that can be said about surface water that quickly runs off land is that it does not have enough time (normally) to become contaminated with high mineral content. Surface water running slowly off land can be expected to have all the opposite effects.

Surface water travels over the land to what amounts to a predetermined destination. What factors influence how surface water moves? Surface water's journey over the face of the Earth typically begins at its drainage basin, sometimes referred to as its *drainage area*, *catchment*, or *watershed*. For a groundwater source, this is known as the *recharge area*, the area from which precipitation flows into an underground water source.

The area of a surface water drainage basin is usually measured in square miles, acres, or sections. If a city takes water from a surface water source, essential information for the assessment of water quality includes how large the drainage basin is and what lies within it.

We know that water does not run uphill; instead, surface water runoff (like the flow of electricity) follows along the path of least resistance. Generally speaking, water within a drainage basin will naturally be shunted by the geological formation of the area toward one primary watercourse (a river, stream, creek, brook) unless some manmade distribution system diverts the flow. Various factors directly influence the flow of surface water over land:

- *Rainfall duration*—Length of the rainstorm affects the amount of runoff. Even a light, gentle rain will eventually saturate the soil if it lasts long enough. When the saturated soil can absorb no more water, rainfall builds up on the surface and begins to flow as runoff.
- *Rainfall intensity*—The harder and faster it rains, the more quickly soil becomes saturated. With hard rains, the surface inches of soil quickly become inundated; with short, hard storms, most of the rainfall may end up as surface runoff because the moisture is carried away before significant amounts of water are absorbed into the ground.
- *Soil moisture*—Obviously, if the soil is already laden with water from previous rains, the saturation point will be reached sooner than if the soil were dry. Frozen soil also inhibits water absorption; up to 100% of snow melt or rainfall on frozen soil will end up as runoff because frozen ground is impervious.
- *Soil composition*—Runoff amount is directly affected by soil composition. Hard rock surfaces will shed all rainfall, obviously, but so will soils with heavy clay composition. Clay soils possess small void spaces that swell when wet. When the void spaces close, they form a barrier that does not allow additional absorption or infiltration. On the opposite end of the spectrum, coarse sand allows easy water flowthrough, even in a torrential downpour.
- *Vegetation cover*—Runoff is limited by groundcover. Roots of vegetation, pine needles and cones, leaves, and branches create a porous layer (of decaying natural organic substances) above the soil. This porous organic sheet (groundcover) readily allows water into the soil. Vegetation and organic waste also act as a cover to protect the soil from hard, driving rains. Hard rains can compact bare soils, close off void spaces, and increase runoff. Vegetation and groundcover work to maintain the infiltration and water-holding capacity of the soil. Note that vegetation and groundcover also reduce evaporation of soil moisture as well.
- *Ground slope*—Flat-land water flow is usually so slow that large amounts of rainfall can infiltrate the ground. Gravity works against infiltration on steeply sloping ground, where up to 80% of rainfall may become surface runoff.
- *Human influences*—Various human activities have a definite impact on surface water runoff. Most human activities tend to increase the rate of water flow. For example, canals and ditches are usually constructed to provide steady flow, and agricultural activities generally remove groundcover that would work to retard the runoff rate. At the opposite extreme, manmade dams are generally built to retard the flow of runoff.

Human habitations, with their paved streets, tarmac, paved parking lots, and buildings create surface runoff potential, because so many surfaces are impervious to infiltration. All of these surfaces hasten the flow of water, and they also increase the possibility of flooding, often with devastating results. Because of urban increases in runoff, a whole new industry has developed: stormwater management.

Paving over natural surface acreage has another serious side effect. Without enough area available for water to infiltrate the ground and percolate through the soil to eventually reach and replenish (recharge) groundwater sources, those sources may eventually fail, with devastating impact on the local water supply.

Now let's shift gears and take a look at groundwater. Water falling to the ground as precipitation normally follows three courses. Some runs off directly to rivers and streams, some infiltrates to ground reservoirs, and the rest evaporates or transpires through vegetation. The water in the ground is invisible and may be thought of as a temporary natural reservoir (ASTM, 1969; Spellman, 2008). Almost all groundwater is in constant motion toward rivers or other surface water bodies.

Groundwater is defined as water below the Earth's crust but above a depth of 2500 feet. Water located between the Earth's crust and the 2500-foot level is considered usable (potable) freshwater. In the United States, it is estimated that at least 50% of total available freshwater storage is in underground aquifers (Kemmer, 1979).

In this text, we are concerned with that amount of water retained in the soil to ensure plant life and growth. Recall that earlier we stated that 500 g of water are required to produce 1 g of dry plant material. Note that about 5 g of this water become an integral part of the plant. Unless rainfall is frequent, you don't have to be a rocket scientist to figure out that the ability of soil to hold water against the force of gravity is very important. Thus, one of the vital functions of soil is to regulate the water supply to plants.

Soil as a Recycler of Raw Materials

Imagine what it would be like to step out into the open air and be hit by a stench that not only would offend your olfactory sense but could almost reach out and grab you (like the situation we had in the cave earlier, but worse). Imagine looking out upon the cluttered fields in front of your domicile and seeing nothing but stack upon stack upon stack of the sources of the horrible, putrefied, foul, decaying, gagging, choking, retching stench. We are talking about plant and animal remains and waste, mountains of it, reaching toward the sky and surrounded by colonies of flies of all varieties. "Ugh," you say. Well, if it were not for the power of the soil to recycle waste products, then this scene or something very much like it would be possible. Of course, this scenario is impossible because under these conditions there would be no more life to die and stack up.

Soil is a recycler—probably the premier recycler on Earth. The simple fact is that if it were not for the incredible recycling ability of soil, plants and animals would have run out of nourishment long ago. Soil recycles in other ways; for example, consider the geochemical cycles (i.e., the chemical interactions between soil, water, air, and life on Earth) in which soil plays a major role.

Soil possesses the incomparable ability and capacity to assimilate great quantities of organic wastes, turn them into beneficial organic matter (humus), and then convert the nutrients in the wastes to forms that can be utilized by plants and animals. In turn, the soil returns carbon to the atmosphere as carbon dioxide, where it again will eventually become part of living organisms through photosynthesis. Soil performs several different recycling functions—most of them good, some of them not so good.

Consider one recycling function of soil that may not be so good. Soils have the capacity to accumulate large amounts of carbon as soil organic matter, which can have a major impact on global changes such as the greenhouse effect. Moreover, it is important that wastes be applied in appropriate amounts and not contain toxic and environmentally harmful elements or compounds that could poison soils, wastes, and plants.

TABLE 12.1
A Representative Sample of Soil Organisms

Microorganisms (Protists)
Bacteria
Fungi
Actinomycetes
Algae
Protozoa

Nonarthropod Animals
Nematodes
Earthworms and potworms

Vertebrates
Mice, moles, voles
Rabbits, gophers, squirrels

Arthropod Animals
Springtails
Mites
Millipedes and centipedes
Harvestman
Ants
Diplopoda
Diptera
Crustacea

Soil as a Habitat for Organisms

> Life not only formed the soil, but other living things of incredible abundance and diversity now exist within it; if this were not so the soil would be a dead and sterile thing.
>
> **Carson (1962)**

One thing is certain, most soils are not dead and sterile things. The fact is, a handful of soil is an ecosystem. It may contain up to billions of organisms belonging to thousands of species. Table 12.1 lists a few (very few) of these organisms. Obviously, communities of living organisms inhabit the soil. What is not so obvious is that they are as complex and intrinsically valuable as are those organisms that roam the land surfaces and waters of Earth.

Soil as an Engineering Medium

We usually think of soil as being firm and solid (solid ground, *terra firma*). As solid ground, soil is usually a good substrate upon which to build highways and structures; however, not all soils are firm and solid. Some are not as stable as others. Whereas construction of buildings and highways may be suitable in one location on one type of soil, it may be unsuitable in another location with different soil. To construct structurally sound and stable highways and buildings, construction on soils and with soil materials requires knowledge of the diversity of soil properties. Note that working with manufactured building materials that have been engineered to withstand certain stresses and forces is much different than working with natural soil materials, even though engineers have the same concerns about soils as they do with manmade building materials (concrete and steel). It is much more difficult to evaluate the ability of a soil to resist compression or to remain in place and to determine its bearing strength, shear strength, and stability than it is to make these same determinations for manufactured building materials.

Soil as a Source of Materials

In addition to providing valuable minerals for various purposes, soil is commonly used to provide materials for road building and dam construction.

CONCURRENT SOIL FUNCTIONS

Soils perform specific critical functions no matter where they are located (USDA, 2009), and they perform more that one function at the same time as described below and shown in Figure 12.2:

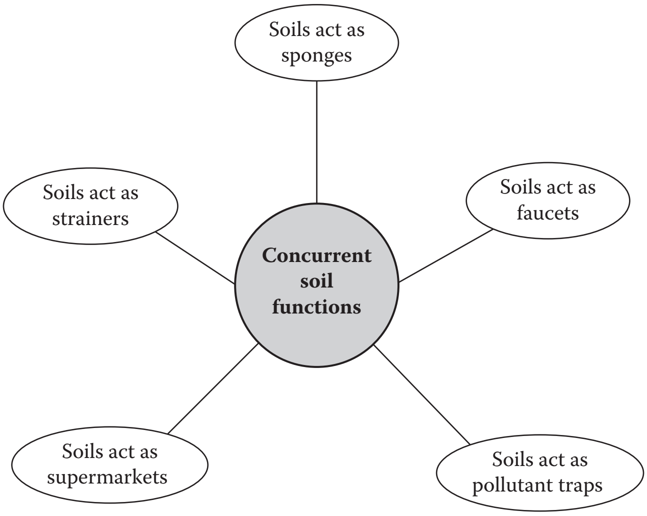

FIGURE 12.2 Concurrent soil functions.

- Soils act like sponges, soaking up rainwater and limiting runoff. Soils also impact groundwater recharge and flood-control potentials in urban areas.
- Soils act like faucets, storing and releasing water and air for plants and animals to use.
- Soils act like supermarkets, providing valuable nutrients and air and water to plants and animals. Soils also store carbon and prevent its loss into the atmosphere.
- Soils act like strainers or filters, filtering and purifying water and air that flow through them.
- Soils buffer, degrade, immobilize, detoxify, and trap pollutants, such as oil, pesticides, herbicides, and heavy metals, and keep them from entering groundwater supplies. Soils also store nutrients for future use by plants and animals above ground and by microbes within soils.

SOIL PROPERTIES

Any fundamental discussion about soil should begin with a definition of what soil is. The word *soil* is derived through Old French from the Latin *solum*, which means floor or ground. John Steinbeck referenced the scars, crusts, and crusting of soil. The Swiss writer Charles-Ferdinand Ramuz referred to soil as that soft stuff under the feet. A student of Hippocrates talked about soil as an immense quantity of forces. A more current and concise definition is made difficult by the great diversity of soils throughout the globe; however, here is a generalized definition from the Soil Science Society of America (SSSA, 2008):

> Soil is unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors of: parent material, climate, macro- and microorganisms, and topography, all acting over a period of time and producing a product—soil—that differs from the material from which it is derived in many physical, chemical, and biological properties, and characteristics.

Engineers might define soil by saying that soil occupies the unconsolidated mantle of weathered rock making up the loose materials on the Earth's surface, commonly known as the *regolith* (see Figure 12.3). Soil can be described as a three-phase system, composed of a solid, liquid, and gaseous phase (see Figure 12.4A). This phase relationship is important in dealing with soil pollution, because each of the three phases of soil is in equilibrium with the atmosphere and with rivers, lakes, and the oceans. Thus, the fate and transport of pollutants are influenced by each of these components.

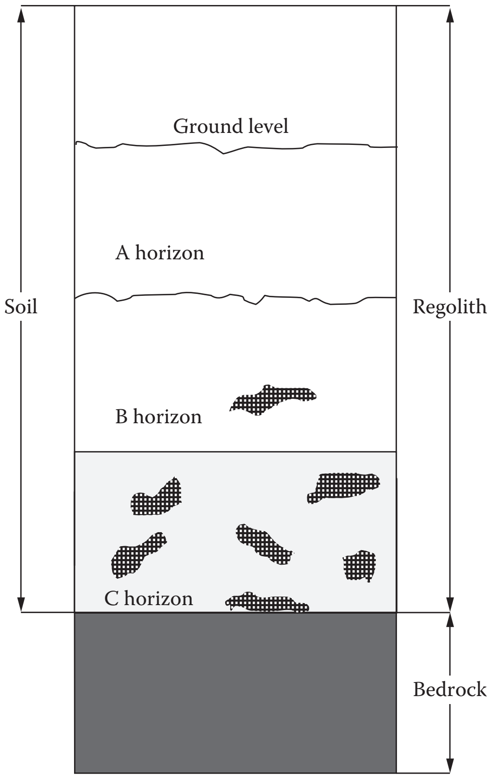

FIGURE 12.3 Relative positions of the regolith, its soil, and the underlying bedrock.

Soil is also commonly described as a mixture of air, water, mineral matter, and organic matter (see Figure 12.4B); the relative proportions of these four components greatly influence the productivity of soils. The interface of these soil components, where the regolith meets the atmosphere, is what concerns us here.

Keep in mind that the four major ingredients that make up soil are not mixed or blended like cake batter. Instead, a major and critically important constituent of soil is the pore spaces, which are vital to air and water circulation, as they provide space for roots to grow and microscopic organisms to live. Without sufficient pore space, soil would be too compacted to be productive. Ideally,

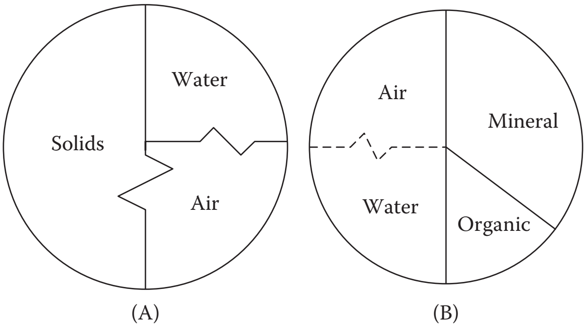

FIGURE 12.4 (A) Three phases of soil: solids, water, and air. Broken lines indicate that these phases are not constant but change with conditions. (B) Another view of soil (a loam surface soil) as being comprised of air, water, and mineral and organic solids.

the pore space will be divided roughly equally between water and air, with about one-quarter of the soil volume consisting of air and one-quarter consisting of water. The relative proportions of air and water in a soil typically fluctuate significantly as water is added and lost. Compared to surface soils, subsoils tend to contain less total pore space, less organic matter, and a larger proportion of micropores, which tend to be filled with water.

Let's take a closer look at the four major components that make up soil. Soil air circulates through soil pores in the same way air circulates through a ventilation system. Only when the pores (the ventilation ducts) become blocked by water or other substances does the air fail to circulate. Although soil pores normally connect to interface with the atmosphere, soil air is not the same as atmospheric air. It differs in composition from place to place. Soil air also normally has a higher moisture content than the atmosphere. The content of carbon dioxide (CO_2) is usually higher and that of oxygen (O_2) lower than the accumulations of these gases in the atmosphere.

Earlier we stated that only when soil pores are occupied by water or other substances does air fail to circulate in the soil. For proper plant growth, this is of particular importance, because in soil pore spaces that are water dominated, air oxygen content is low and carbon dioxide levels are high, which restricts plant growth.

The presence of water in soil (often reflective of climatic factors) is essential for the survival and growth of plant and other soil organisms. Soil moisture is a major determinant of the productivity of terrestrial ecosystems and agricultural systems. Water moving through soil materials is a major force behind soil formation. Along with air, water, and dissolved nutrients, soil moisture is critical to the quality and quantity of local and regional water resources.

Mineral matter varies in size and is a major constituent of nonorganic soils. Mineral matter consists of large particles (rock fragments), including stones, gravel, and coarse sand. Many of the smaller mineral matter components are made of a single mineral. Minerals in the soil (for plant life) are the primary source of most of the chemical elements essential for plant growth.

Soil organic matter consists primarily of living organisms and the remains of plants, animals, and microorganisms that are continuously broken down (biodegraded) in the soil into new substances that are synthesized by other microorganisms. These other microorganisms continually use this organic matter and reduce it to carbon dioxide via respiration until it is depleted, making repeated additions of new plant and animal residues necessary to maintain soil organic matter (Brady and Weil, 2007).

Now that we have defined soil, let's take a closer look at a few of the basics pertaining to soil and some of the common terms used in any discussion related to soil basics. Soil is the layer of bonded particles of sand, silt, and clay that covers the land surface of the Earth. Most soils develop in multiple layers. The topmost layer, topsoil, is the layer of soil moved in cultivation and in which plants grow. This topmost layer is actually an ecosystem composed of both biotic and abiotic components—inorganic chemicals, air, water, and decaying organic material that provides vital nutrients for plant photosynthesis, as well as living organisms. Below the topmost layer is the subsoil, the part of the soil below the plow level, usually no more than a meter in thickness. Subsoil is much less productive, partly because it contains much less organic matter.

Below that is the parent material, the unconsolidated (and more or less chemically weathered) bedrock or other geologic material from which the soil is ultimately formed. The general rule of thumb is that it takes about 30 years to form 1 inch of topsoil from subsoil; it takes much longer than that for subsoil to be formed from parent material, with the length of time depending on the nature of the underlying matter (Franck and Brownstone, 1992).

PHYSICAL PROPERTIES OF SOIL

From the soil pollution technologist's point of view (regarding land conservation and methodologies for contaminated soil remediation through reuse and recycling), five major physical properties of soil are of interest: soil texture, slope, structure, organic matter, and color. Soil texture, or the relative proportions of the various soil separates in a soil (see Figure 12.5), is a given and cannot be

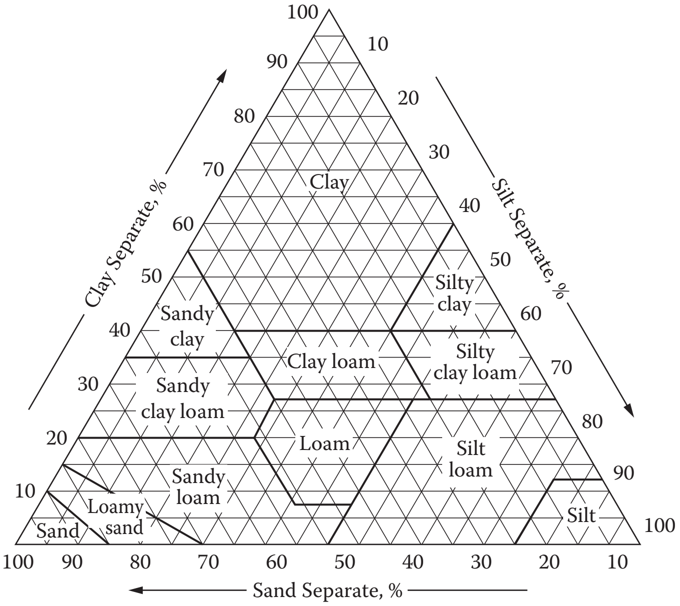

FIGURE 12.5 Textural triangle. (Adapted from USDA, *Urban Soil Primer*, U.S. Department of Agriculture, Washington, DC, 2009.)

easily or practically changed significantly. It is determined by the size of the rock particles (sand, silt, and clay particles) or the soil separates within the soil. The largest soil particles are gravel, which consist of fragments larger than 2.0 mm in diameter.

Particles between 0.05 and 2.0 mm are classified as sand. Silt particles range from 0.002 to 0.05 mm in diameter, and the smallest particles (clay particles) are less than 0.002 mm in diameter. Clays are composed of the smallest particles, but these particles have stronger bonds than silt or sand; once broken apart, though, they erode more readily. Particle size has a direct impact on erosion. Rarely does a soil consist of only one single size of particle; most are a mixture of various sizes.

The slope (or steepness of the soil layer) is another given, important because the erosive power of runoff increases with the steepness of the slope. Slope also allows runoff to exert increased force on soil particles, which breaks them apart more readily and carries them farther away.

Soil structure (tilth) should not be confused with soil texture—they are different. In fact, in the field, the properties determined by soil texture may be considerably modified by soil structure. Soil structure refers to the combination or arrangement of primary soil particles into secondary particles (units or peds). Simply stated, soil structure refers to the way various soil particles clump together. Clusters of soil particles, called *aggregates*, can vary in size, shape, and arrangement; they combine naturally to form larger clumps called *peds*. Sand particles do not clump because sandy soils lack structure. Clay soils tend to stick together in large clumps. Good soil develops small friable (easily crumbled) clumps. Soil develops a unique, fairly stable structure in undisturbed landscapes, but agricultural practices break down the aggregates and peds, lessening erosion resistance.

The presence of decomposed or decomposing remains of plants and animals (organic matter) in soil helps not only fertility but also soil structure—especially the ability of water to store water. Live organisms such as protozoa, nematodes, earthworms, insects, fungi, and bacteria are typical inhabitants of soil. These organisms work to either control the population of organisms in the soil or to aid in the recycling of dead organic matter. All soil organisms, in one way or another, work to release nutrients from the organic matter, changing complex organic materials into products that can be used by plants.

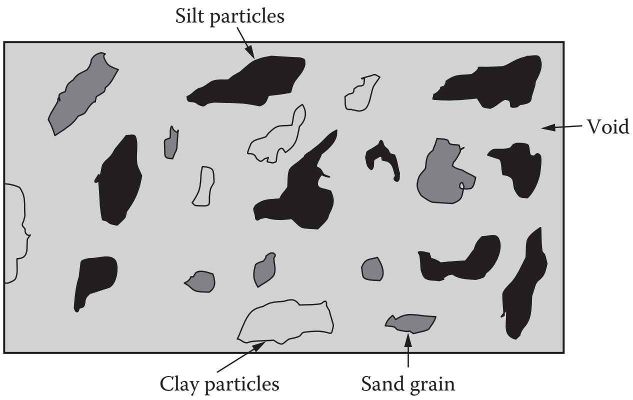

FIGURE 12.6 Enlarged view: cross-section of sandy soil.

Just about anyone who has looked at soil has probably noticed that soil color is often different from one location to another. Soil colors range from very bright to dull grays, to a wide range of reds, browns, blacks, whites, yellows, and even greens. Soil color is dependent primarily on the quantity of humus and the chemical form of iron oxides present.

Soil scientists use a set of standardized color charts (the *Munsell Color System*) to describe soil colors. They consider three properties of color—hue, value, and chroma—in combination to come up with a large number of color chips to which soil scientists can compare the color of the soil being investigated.

SOIL SEPARATES

As pointed out in the previous section, soil particles have been divided into groups (*soil separates*) based on their size (sand, silt, and clay; see Figure 12.6) by the International Soil Science Society System, the U.S. Public Roads Administration, and the U.S. Department of Agriculture (USDA). In this text, we use the classification established by the USDA. The size ranges in these separates reflect major changes in how the particles behave and in the physical properties they impart to soils. Table 12.2 lists the separates, their diameters, and the number of particles in 1 g of soil (according to the USDA).

Sand ranges in diameter from 0.05 to 2 mm and is divided into five classes (see Table 12.2). Sand grains are more or less spherical (rounded) in shape, with variable angularity, depending on the extent to which they have been worn down by abrasive processes such as rolling around by flowing water during soil formation.

TABLE 12.2
Characteristics of Soil Separates (USDA)

Soil Separate	Diameter (mm)	Number of Particles per Gram
Very coarse sand	2.00–1.00	90
Coarse sand	1.00–0.50	720
Medium sand	0.50–0.25	5700
Fine sand	0.25–0.10	46,000
Very fine sand	0.10–0.05	722,000
Silt	0.05–0.002	5,776,000
Clay	Below 0.002	90,260,853,000

Sand forms the framework of soil and gives it stability when in a mixture of finer particles. Sand particles are relatively large, which allows voids that form between each grain to also be relatively large. This promotes free drainage of water and the entry of air into the soil. Sand is usually composed of a high percentage of quartz; because quartz is most resistant to weathering, its breakdown is extremely slow. Many other minerals are found in sand, depending on the rocks from which the sand was derived. In the short term (on an annual basis), sand contributes little to plant nutrition in the soil; however, in the long term (thousands of years of soil formation), soils with a lot of weatherable minerals in their sand fraction develop a higher state of fertility.

Silt (essentially microsand), though spherically and mineralogically similar to sand, is smaller, too small to be seen with the naked eye (see Figure 12.6). It weathers faster and releases soluble nutrients for plant growth faster than sand. Too fine to be gritty, silt imparts a smooth feel (like flour) without stickiness. The pores between silt particles are much smaller than those in sand (sand and silt are just progressively finer and finer pieces of the original crystals in the parent rocks). In flowing water, silt is suspended until it drops out when flow is reduced. On the land surface, silt, if disturbed by strong winds, can be carried great distances and is deposited as loess.

The clay soil separate is (for the most part) much different from sand and silt (see Figure 12.6). Clay is composed of secondary minerals that were formed by the drastic alteration of the original forms or by the recrystallization of the products of their weathering. Because clay crystals are plate like (sheeted) in shape they have a tremendous surface area-to-volume ratio, giving clay a great capacity to adsorb water and other substances on its surfaces. Clay actually acts as a storage reservoir for both water and nutrients. There are many kinds of clay, each with different internal arrangements of chemical elements which give them individual characteristics.

SOIL FORMATION

Everywhere on Earth's land surface is either rock formation or exposed soil. When rocks formed deep in the Earth are thrust upward and exposed to the Earth's atmosphere, the rocks adjust to the new environment, and soil formation begins. Soil is formed as a result of physical, chemical, and biological interactions in specific locations. Just as vegetation varies among biomes, so do the soil types that support that vegetation. The vegetation of the tundra and rain forest differ vastly from each other and from vegetation of the prairie and coniferous forest; soils differ in similar ways.

In the soil-forming process, two related, but fundamentally different, processes are occurring simultaneously. The first is the formation of soil parent materials by *weathering* of rocks, rock fragments, and sediments. This set of processes is carried out in the zone of weathering. The end point is producing parent material for the soil to develop in and is referred to as C horizon material (see Figure 12.7). It applies in the same way for glacial deposits as for rocks. The second set of processes is the formation of the soil profile by *soil-forming processes*, which gradually change the C horizon material into A, E, and B horizons. Figure 12.7 illustrates two soil profiles, one on hard granite and one on a glacial deposit.

WEATHERING

Soil development takes time and is the result of two major processes: weathering and morphogenesis, which can be described as bare rock succession. Weathering, the breaking down of bedrock and other sediments that have been deposited on the bedrock by wind, water, volcanic eruptions, or melting glaciers, happens physically, chemically, or by a combination of both. Weathering is the first step in the erosion process; again, it causes the breakdown of rocks, either to form new minerals that are stable on the surface of Earth or to break the rocks down to smaller particles. Simply, weathering (which projects itself on all surface material above the water table) is the general term used for all the ways in which a rock may be broken down. The factors that influence weathering include the following:

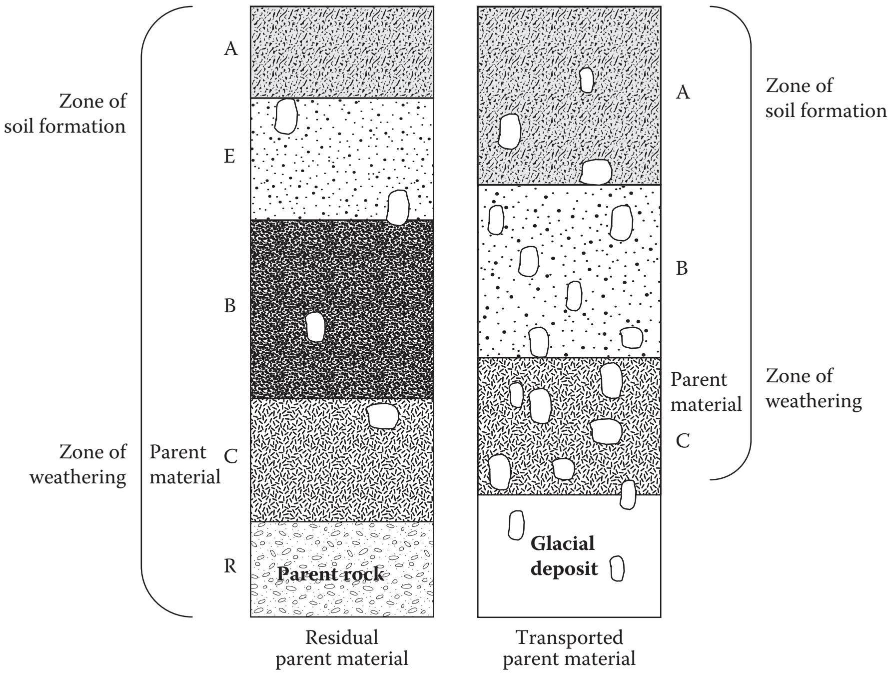

FIGURE 12.7 Soil profiles on residual and transported parent materials.

- *Rock type and structure*—Each mineral contained in rocks has a different susceptibility to weathering. A rock with bedding planes, joints, and fractures provides pathways for the entry of water, leading to more rapid weathering. Differential weathering (rocks erode at differing rates) can occur when rock combinations consist of some rocks that weather faster than more resistant rocks.
- *Slope*—On steep slopes, weathering products may be quickly washed away by rains. Wherever the force of gravity is greater than the force of friction holding particles upon a slope, these tend to slide downhill.
- *Climate*—Higher temperatures and high amounts of water generally cause chemical reactions to run faster. Rates of weathering are higher in warmer than in colder dry climates.
- *Animals*—Rodents, earthworms, and ants that burrow into soil bring material to the surface where it can be exposed to the agents of weathering.
- *Time*—Length of time depends on slope, animals, and climate.

Although weathering processes are separated, it is important to recognize that these processes work in tandem to break down rocks and minerals to smaller fragments. Geologists recognize two categories of weathering processes:

- *Physical (or mechanical) weathering*—Disintegration of rocks and minerals by a physical or mechanical process.
- *Chemical weathering*—Decomposition of rock by chemical changes or solution.

Physical Weathering

Physical weathering involves the disintegration of a rock by physical processes. These include freezing and thawing of water in rock crevices, disruption by plant roots or burrowing animals, and the changes in volume that result from chemical weathering with the rock. These and other physical weathering processes are discussed below:

- *Development of joints*—Joints are another way that rocks yield to stress. Joints are fractures or cracks in which the rocks on either side of the fracture have not undergone relative movement. Joints form as a result of expansion due to cooling or relief of pressure as overlying rocks are removed by erosion. They form free space in rock by which other agents of chemical or physical weathering can enter (unlike faults that show offset across the fracture). They play an important part in rock weathering as zones of weakness and water movement.
- *Crystal growth*—As water percolates through fractures and pore spaces it may contain ions that precipitate to form crystals. When crystals grow they can cause the necessary stresses needed for mechanical rupturing of rocks and minerals.
- *Heat*—It was once thought that the daily heating and cooling of rocks was a major contributor to the weathering process. This view is no longer shared by most practicing geologists; however, it should be pointed out that sudden heating of rocks from forest fires may cause expansion and eventual breakage of rock.
- *Biological activities*—Plant and animal activities are important contributors to rock weathering. Plants contribute to the weathering process by extending their root systems into fractures and growing, causing expansion of the fracture. The effects of plant growth are evident in many places, such as when they are planted near cement work (streets, brickwork, and sidewalks). Animal burrowing in rock cracks can break rock.
- *Frost wedging*—Frost wedging is often produced by the alternating freezing and thawing of water in rock pores and fissures. Expansion of water during freezing causes the rock to fracture. Frost wedging is more prevalent at high altitudes where there may be many freeze–thaw cycles. One classic and striking example of weathering of Earth's surface rocks by frost wedging is illustrated by the formation of hoodoos in Bryce Canyon National Park, Utah. Bryce Canyon receives a meager 18 inches of precipitation annually, but it is amazing what this little bit of water can do under the right circumstances (NPS, 2008). Approximately 200 freeze–thaw cycles occur annually in Bryce. During these periods, snow and ice melt in the afternoon and water seeps into the joints of the Bryce or Claron Formation. When the sun sets, temperatures plummet and the water refreezes, expanding up to 9% as it becomes ice. This frost wedging process exerts tremendous pressure or force on the adjacent rock and shatters the weak rock. The assault from frost wedging is a powerful force, but, at the same time, rainwater (the universal solvent), which is naturally acidic, slowly dissolves away the limestone, rounding off the edges of fractured rocks and washing away the debris. Small rivulets of water run down Bryce's rim, forming gullies. As gullies are cut deeper, narrow walls of rock known as fins being to emerge. Fins eventually develop holes known as windows. Windows grow larger until their roofs collapse, creating hoodoos. As old hoodoos age and collapse, new ones are born.

DID YOU KNOW?

Bryce Canyon National Park lies along the high eastern escarpment of the Paunsaugunt Plateau in the Colorado Plateau region of southern Utah. Its extraordinary geological character is expressed by thousands of rock chimneys (hoodoos) that occupy amphitheater-like alcoves in the Pink Cliffs, whose bedrock host is the Eocene-age Claron Formation (Davis and Pollock, 2003).

DID YOU KNOW?

Hoodoo (n.), pronounced "hü-dü," is perhaps derived from voodoo (*vodou*). A hoodoo is a natural column of rock in western North America, often in fantastic form (http://www.merriam-webster.com/dictionary/hoodoo).

Chemical Weathering

Chemical weathering involves the decomposition of rock by chemical changes or solution. Rocks that are formed under conditions found deep within the Earth are exposed to quite different conditions when uplifted onto the surface; for example, temperatures and pressures are lower on the surface, and copious amounts of free water and oxygen are available. The chief chemical weathering processes are oxidation, carbonation, hydration, and solution in water.

Persistent Hand of Water

Because of its unprecedented impact on shaping and reshaping Earth, at this point in the text it is important to point out that, given time, nothing, absolutely nothing, on Earth is safe from the heavy hand of water. The effects of water sculpting by virtue of movement and accompanying friction will be covered later in the text. For now, with regard to water exposure and chemical weathering, the main agent responsible for chemical weathering reactions is not water movement but water and weak acids formed in water. The acids formed in water are solutions that have abundant free H^+ ions. The most common weak acid that occurs in surface waters is carbonic acid (H_2CO_3). Carbonic acid is produced when atmospheric carbon dioxide dissolves in water; it exists only in solution. Hydrogen ions are quite small and can easily enter crystal structures, releasing other ions into the water:

$$H_2O + CO_2 \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3$$

$$\text{Water} + \text{Carbon dioxide} \rightarrow \text{Carbonic acid} \rightarrow \text{Hydrogen ion} + \text{Bicarbonate ion}$$

Types of Chemical Weathering Reactions

As mentioned, chemical weathering breaks rocks down by adding or removing chemical elements and changing them into other materials. Again, as stated, chemical weathering consists of chemical reactions, most of which involve water. Types of chemical weathering include the following:

- Hydrolysis, which is a water–rock reaction that occurs when an ion in the mineral is replaced by H^+ or OH^-
- Leaching, which occurs when ions are removed by dissolution into water
- Oxidation, which is a result of oxygen being plentiful near the Earth's surface and reacting with minerals to change the oxidation state of an ion
- Dehydration, which occurs when water or a hydroxide ion is removed from a mineral
- Complete dissolution

Bare Rock Succession

Physical weathering and chemical weathering do not always (if ever) occur independently of each other. Instead, both types of weathering normally work in combination. A classic example of the effect—the power of their simultaneous actions—can be seen in an ecological process known as bare rock succession, described in the chapter opening.

DID YOU KNOW?

Plants such as mosses and lichens penetrate rock and loosen particles. Bare rocks are also subjected to chemical weathering due to chemical attack and dissolution of rock. Accomplished primarily through oxidation via exposure to oxygen gas in the atmosphere, acidic precipitation (after having dissolved small amounts of carbon dioxide gas from the atmosphere), and acidic secretions of microorganisms (bacteria, fungi, and lichens), chemical weathering speeds up in warm climates and slows down in cold ones.

FINAL STAGES OF SOIL FORMATION

The final stages of soil formation consist of the processes of morphogenesis, or the production of a distinctive soil profile with its constituent layers or horizons. The soil profile (the vertical section of the soil from the surface through all its horizons, including C horizons) gives the environmental scientist critical information. When properly interpreted, soil horizons can provide warnings regarding potential problems in using the land and can tell much about the environment and history of a region. Soil profiles allow us to describe, sample, and map soils.

Soil horizons are distinct layers, roughly parallel to the surface, which differ in color, texture, structure, and content of organic matter. The clarity with which horizons can be recognized depends on the relative balance of the migration, stratification, aggregation, and mixing processes that take place in the soil during morphogenesis. In podzol-type soils (formed mainly in cool, humid climates), striking horizonation is quite apparent; in vertisol-type soils (soils high in swelling clays), the horizons are less distinct. When horizons are studied, they are given a letter symbol to reflect the genesis of the horizon.

Certain processes work to create or destroy clear soil horizons. Processes that tend to create clear horizons by vertical redistribution of soil materials include the leaching of ions in soil solutions, movement of clay-sized particles, upward movement of water by capillary action, and surface deposition of dust and aerosols. Clear soil horizons are destroyed by mixing processes that occur because of organisms, cultivation practices, creep processes on slopes, frost heave, and swelling and shrinkage of clays—all part of the natural soil formation process.

SOIL CHARACTERIZATION

> Classification schemes of natural objects seek to organize knowledge so that the properties and relationships of the objects may be most easily remembered and understood for some specific purpose. The ultimate purpose of soil classification is maximum satisfaction of human wants that depend on use of the soil. This requires grouping soils with similar properties so that lands can be efficiently managed for crop production. Furthermore, soils that are suitable or unsuitable for pipelines, roads, recreation, forestry, agriculture, wildlife, building sites, and so forth can be identified.
>
> **Foth (1978)**

When people become ill, they may go to a doctor to seek a diagnosis of what is causing the illness and perhaps a prognosis regarding how their illness will progress. What do diagnosis and prognosis have to do with soil? Actually, quite a lot. The diagnostic techniques used by a physician to identify the causative factors leading to a particular illness are analogous to the soil practitioner using diagnostic techniques to identify a particular soil. Sound farfetched? It shouldn't, because it isn't. Soil scientists must be able to determine the types of soil they study or work with.

Determining the type of soil makes sense, but what does prognosis have to do with all this? Soil practitioners must be able to identify or classify a soil type, because this information allows them to correctly predict how a particular pollutant will react or respond when spilled in that type of soil. The fate of the pollutant is important in determining the possible damage inflicted on the environment—soil, groundwater, and air—because ultimately a spill could easily affect all three. Thus, the soil practitioner not only must use diagnostic tools in determining soil type but also must be familiar with the soil type to determine how a particular pollutant or contaminant will respond when spilled in that soil type.

Let's take a closer look at the genesis of soil classification. From the time humans first advanced from hunter–gatherer status to cultivators of crops, they noticed differences in productive soils and unproductive soils. The ancient Chinese, Egyptians, Romans, and Greeks all recognized and acknowledged the differences in soils as media for plant growth. These early soil classification practices were based primarily on texture, color, and wetness.

Soil classification as a scientific practice did not gain a foothold until the later 18th and early 19th centuries, when the science of geology was born. This is when such terms (with an obvious geological connotation) as *limestone soils* and *lake-laid soils*, as well as *clayey* and *sandy soils*, came into being. The Russian scientist V.V. Dokuchaev was the first to suggest, in the late 1800s, that soils were natural bodies, and he developed a generic classification of soils that was later expanded. The system was based on the theory that each soil has a definite form and structure (morphology) related to a particular combination of soil-forming factors. This system was used until 1960, when the USDA published its original *Soil Classification: A Comprehensive System*. This classification system places major emphasis on soil morphology and gives less emphasis to genesis or the soil forming factors as compared to previous systems. In 1975, this text was replaced by *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*, now in its second edition (USDA, 1999). *Soil Taxonomy* classifies objects according to their natural relationships, and soils are classified based on measurable properties of soil profiles.

Note that no clear delineation or line of demarcation can be drawn between the properties of one soil and those of another. Instead, a gradation (sometimes quite subtle, like comparing one shade of white to another) occurs in soil properties as one moves from one soil to another. Brady and Weil (2007, p. 58) noted that, "The gradation in soil properties can be compared to the gradation in the wavelengths of light as you move from one color to another. The changing is gradual, and yet we identify a boundary that differentiates what we call 'green' from what we call 'blue.'"

To properly characterize the primary characteristics of a soil, a soil must be identified down to the smallest three-dimensional characteristic sample possible; however, to accurately perform a particular soil sample characterization, a sampling unit must be large enough so the nature of its horizons can be studied and the range of its properties identified. The *pedon* (rhymes with head-on) is this unit. The pedon is roughly polygonal in shape and designates the smallest characteristic unit that can still be called a soil. Because pedons occupy a very small space (from approximately 1 to 10 m^2), they cannot, obviously, be used as the basic unit for a workable field soil classification system. To solve this problem, a group of pedons, termed a *polypedon*, is of sufficient size to serve as a basic classification unit (or, as it is commonly referred to, a *soil individual*). In the United States, these groupings have been called a *soil series*.

There is a difference between *a* soil and *the* soil. This difference is important in the soil classification scheme. A soil is characterized by a sampling unit (pedon), which as a group (polypedons) form a soil individual. The soil, on the other hand, is a collection of all of these natural ingredients and is distinguishable from other bodies such as water, air, solid rock, and other parts of the Earth's crust. By incorporating the difference between a soil and the soil, a classification system has been developed that is effective and widely used.

DIAGNOSTIC HORIZONS AND TEMPERATURE AND MOISTURE REGIMES

Soil taxonomy uses a strict definition of soil horizons called *diagnostic horizons*, which are used to define most of the orders. Two kinds of diagnostic horizons are recognized: surface and subsurface. The surface diagnostic horizons are *epipedons* (Greek *epi*, "over"; *pedon*, "soil"). The epipedons include the dark (organic rich) upper part of the soil and the upper eluvial horizons, and sometimes both. Soils beneath the epipedon horizons are *subsurface diagnostic horizons*. Each of these layers is used to characterize different soils in soil taxonomy.

In addition to using diagnostic horizons to strictly define soil horizons, soil moisture regime classes can also be used. A soil moisture regime refers to the presence of plant-available water or groundwater at a sufficiently high level. The control section of the soil (ranging from 10 to 30 cm for clay and from 30 to 90 cm for sandy soils) designates that section of the soil where water is present or absent during given periods in a year. The control section is divided into upper and lower sections. The upper portion is defined as the depth to which 2.5 m^3 of water will penetrate within 24 hours. The lower portion is the depth that 7.5 m^3 of water will penetrate.

TABLE 12.3
Soil Moisture Regimes

Moisture Regime	Percent of Global Area Occupied
Aridic	35.9
Xeric	3.5
Ustic	18.0
Udic	33.1
Perudic	1.0
Aquic	8.3

Source: Adapted from Eswaran, H., *Pedologie*, 43, 19–39, 1993.

Six soil moisture regimes have been identified:

Aridic—Characteristic of soils in arid regions
Xeric—Characteristic of having long periods of drought in the summer
Ustic—Soil moisture generally high enough to meet plant needs during growing season
Udic—Common soil in humid climatic regions
Perudic—An extremely wet moisture regime annually
Aquic—Soil saturated with water and free of gaseous oxygen

Table 12.3 lists the moisture regime classes and the percentage distribution of areas with different soil moisture regimes.

In soil taxonomy, addressed in the next section, several soil temperature regimes are also used to define classes of soils. These soil temperature regimes, shown in Table 12.4, are based on mean annual soil temperature, mean summer temperature, and the difference between mean summer and winter temperatures. The diagnostic horizons and moisture/temperature regimes just discussed are the main criteria used to define the various categories in soil taxonomy.

TABLE 12.4
Soil Temperature Regimes

Soil Temperature Regimes (Mean Annual Temperature)	Percent of Global Area Occupied
Pergelic (0°C)	10.9
Cryic (0–8°C)	13.5
Frigid (0–8°C)	1.2
Mesic (8–15°C)	12.5
Thermic (15–22°C)	11.4
Hyperthermic (>22°C)	18.5
Isofrigid (0–8°C)	0.1
Isomesic (8–15°C)	0.3
Isothermic (15–22°C)	2.4
Isohyperthermic (>22°C)	26.0
Water (NA)	1.2
Ice (NA)	1.4

Source: Adapted from Eswaran, H., *Pedologie*, 43, 19–39, 1993.

TABLE 12.5
Subdivision of Soil Taxonomy Classification System (in Hierarchical Order)

Category	Number of Taxa
Order	12
Suborder	64
Great group	~300
Subgroup	~1200
Family	~7500
Series	~18,500 (in United States)

SOIL TAXONOMY

The U.S. Soil Conservation Service's soil taxonomy (which is based on measurable properties of soil profiles) places soils in six categories (see Table 12.5):

Order—Soils not too dissimilar in their genesis. There are 12 soil orders in soil taxonomy. The names and major characteristics of each soil order are shown in Table 12.6.
Suborder—The 64 subdivisions of orders emphasize properties that suggest some common features of soil genesis.
Great group—Diagnostic horizons are the major bases for differentiating approximately 300 great groups.
Subgroup—Approximately 1200 subdivisions of the great groups.
Family—Approximately 7500 soils with subgroups having similar physical and chemical properties.
Series—A subdivision of the family, and the most specific unit of the classification system. More than 18,000 soil series are recognized in the United States.

TABLE 12.6
Soil Orders

Order	Description
Alfisol	Mild forest soil with gray to brown surface horizon, medium to high base supply (amount of interchangeable cations that remain in soil), and a subsurface horizon of clay accumulation
Andisol	Formed on volcanic ash and cinders and lightly weathered
Aridsol	Dry soil with pedogenic (soil forming) horizon, low in organic matter
Entisol	Recent soil without pedogenic horizons
Gelisol	Soils of very cold climates; defined as containing permafrost
Histosol	Organic (peat or bog) soil
Inceptisol	Soil at the beginning of the weathering process with weakly differentiated horizons
Mollisol	Soft soil with a nearly black, organic-rich surface horizon and high base supply
Oxisol	Oxide-rich soil principally a mixture of kaolin, hydrated oxides, and quartz
Spodosol	Soil that has an accumulation of amorphous materials in the subsurface horizons
Ultisol	Soil with a horizon of silicate clay accumulation and low base supply
Vertisol	Soil with high-activity clays (cracking clay soil)

Source: Adapted from Soil Survey Staff, *Soil Classification: A Comprehensive System*, 7th approximation, U.S. Department of Agriculture, Washington, DC, 1960; Soil Survey Staff, *Keys to Soil Taxonomy*, 4th ed., Virginia Polytechnic Institute and State University, Blacksburg, VA, 1990.

Soil Orders

As stated earlier, 12 soil orders are recognized; they constitute the first category of the classification (see Table 12.6).

Soil Suborders

Soil orders are further divided into 64 suborders, based primarily on the chemical and physical properties that reflect either the presence or absence of water logging or genetic differences caused by climate and vegetation. Aqualfs (from *aqua*, for "wet") are formed under wet conditions, and alfisols become saturated with water sometime during the year. The suborder names all have two syllables, with the first syllable indicating the order, such as *alf* for Alfisol and *oll* for Mollisol.

Soil Great Groups and Subgroups

Suborders are divided into great groups that are defined largely by the presence or absence of diagnostic horizons and the arrangements of those horizons. Great group names are coined by prefixing one or more additional formative elements to the appropriate suborder name. More than 300 great groups have been identified. Subgroups are subdivisions of great groups. Subgroup names indicate to what extent the central concept of the great group is expressed. Typic Fragiaqualf is a soil that is typical for the Fragiaqualf great group.

Soil Families and Series

The family category of classification is based on features that are important to plant growth such as texture, particle size, mineralogical class, and depth. Terms such as *clayey*, *sandy*, *loamy*, and others are used to identify textural classes. Terms used to describe mineralogical classes include *mixed, oxidic, carbonatic*, and others. For temperature classes, terms such as *hypothermic*, *frigid*, *cryic*, and others are used. The soil series (subdivided from soil family) gets down to the individual soil, and the name is that of a natural feature or place near where the soil was first recognized. Familiar series names include Amarillo (Texas), Carlsbad (New Mexico), and Fresno (California). In the United States, there are more than 18,000 soil series.

SOIL MECHANICS AND PHYSICS

Why does the Leaning Tower of Pisa lean? The tower leans because it was built on a nonuniform consolidation of a clay layer beneath the structure. This process is ongoing (by about 1/25 of inch per year) and may eventually lead to failure of the tower. The factors that caused the Leaning Tower of Pisa to lean (and are relevant to using soil as a foundational and building material) are what this section is all about. The mechanics and physics of soil are important factors in making the determination as to whether a particular building site is viable for building. Simply put, these two factors can help to answer the question of whether or not the soils present will support buildings. This concerns us because wherever humans build the opportunity for anthropogenic pollutants follows, and to clean up those pollutants we have to excavate below the surface of the soil again.

SOIL MECHANICS

The *mechanics* of soil are physical factors important to engineers because their focus is on the suitability of soil as a construction material. Simply put, the engineer must determine the response of a particular volume of soil to internal and external mechanical forces. Obviously, this is important in determining the suitability of the soil to withstand the load applied by structures of various types. By studying soil survey maps and reports and checking with soil scientists and other engineers familiar with the region and the soil types in that region, an engineer can determine the suitability of a particular soil for whatever purpose. Conducting field sampling to ensure that the soil product possesses the soil characteristics for its intended purpose is also essential. The soil characteristics important for engineering purposes include soil texture, kinds of clay present, depth to bedrock, soil density, erodibility, corrosivity, surface geology, plasticity, content of organic matter, salinity, and depth to seasonal water table. Engineers will also want to know the space and volume (weight–volume) relationship of the soil, stress–strain, slope stability, and compaction. Because these concepts are also of paramount importance to determining the fate of materials that are carried through soil, this section presents a discussion of them.

Weight–Volume Relationships and Void Ratio

All natural soil consists of at least three primary components (or phases): solids, water, and air (within void spaces between the solid particles). Examining the physical relationships (for soils in particular) between these phases is essential (see Figure 12.8). For convenience and clarity, in Figure 12.8, the mass of soil is represented as a block diagram. Each phase shown in the diagram is a separate block, and each major component has been reduced to a concentrated commodity within a unit volume. Note that the proportions of the components shown in Figure 12.8 will vary (sometimes widely) between and within various soil types. Remember that all water that is not chemically attached acts as a void filler. The relationship between free water and void spaces depends on available water (moisture). The volume of the soil mass is the sum of the volumes of the three components, or

$$V_T = V_a + V_w + V_s \tag{12.1}$$

The volume of the voids is the sum of V_a and V_w; however, the weight of the voids is only W_w, the weight of the water. Because weighing air in soil voids must be done within the Earth's atmosphere, the weight of air in the soil is factored in at zero. The total weight is expressed as the sum of the weights of the soil solids and water:

$$W_T = W_s + W_w \tag{12.2}$$

The relationship between weight and volume can be expressed as

$$W_m = V_m G_m Y_w \tag{12.3}$$

where

W_m = Weight of the material (solid, liquid, or gas).
V_m = Volume of the material.
G_m = Specific gravity of the material (dimensionless).
Y_w = Unit weight of water.

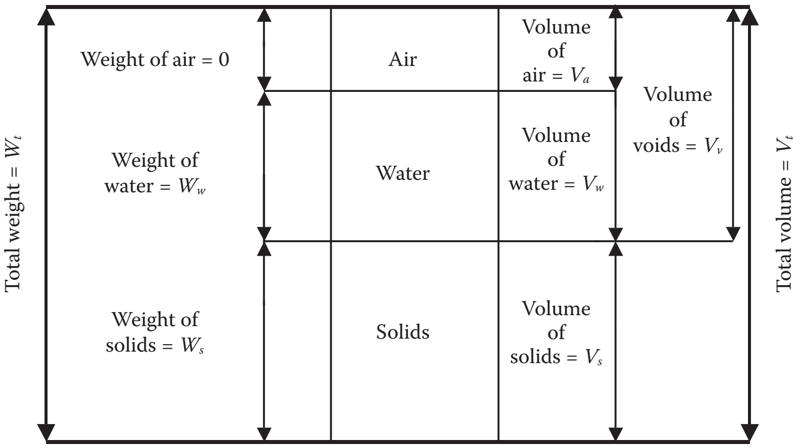

FIGURE 12.8 Weight–volume relationship of soil.

We can solve a few useful problems with the relationships described above. More importantly, this information about a particular location's soil allows engineers to mechanically adjust the proportions of the three major components by reorienting the mineral grains through compaction or tilling. In remediation, a decision to blend soil types to alter the proportions (such as increasing or decreasing the percentage of void space) may be part of a site cleanup process.

Relationships between volumes of soil and voids are described by the *void ratio* (e) and *porosity* (η). We must first determine the void ratio, which is the ratio of the void volume (V_v) to the volume of solids (V_s):

$$e = V_v/V_s \tag{12.4}$$

The first step is to determine the ratio of the volume of void spaces to the total volume. We do this by determining the porosity (η) of the soil, which is the ratio of void volume to total volume. Porosity is usually expressed as a percentage:

$$\eta = V_v/V_t \times 100\% \tag{12.5}$$

Two additional relationships can be developed from the block diagram in Figure 12.8. The terms *moisture content* (w) and *degree of saturation* (S) relate the water content of the soil and the volume of the water in the void space to the total void volume:

$$w = W_w/W_s \times 100\% \tag{12.6}$$

and

$$S = V_w/V_v \times 100\% \tag{12.7}$$

Soil Particle Characteristics

The size and shape of particles in the soil, along with density and other characteristics, give the engineer information on shear strength, compressibility, and other aspects of soil behavior. These index properties are used to create engineering classifications of soil. Simple classification tests are used to measure index properties (see Table 12.7) in the lab or the field.

TABLE 12.7
Index Properties of Soils

Soil Type	Index Property
Cohesive (fine-grained)	Water content Sensitivity Type and amount of clay Consistency Atterburg limits
Incohesive (coarse-grained)	Relative density In-place density Particle-size distribution Clay content Shape of particles

Source: Adapted from Kehew, A.E., *Geology for Engineers and Environmental Scientists*, 2nd ed., Prentice Hall, Englewood Cliffs, NJ, 1995.

From the engineering point of view, the separation of *cohesive* (fine-grained) from *incohesive* (coarse-grained) soils is an important distinction. Let's take a closer look at these two terms. The level of cohesion of a soil describes the tendency of the soil particles to stick together. Cohesive soils contain silt and clay, which, along with water content, make these soils hold together through the attractive forces between individual clay and water particles. Because the clay particles so strongly influence cohesion, the index properties of cohesive soils are more complicated than the index properties of cohesionless soils. The *consistency* of the soil—the arrangement of clay particles—describes the resistance of soil at various moisture contents to mechanical stresses or manipulations and is the most important characteristic of cohesive soils.

Sensitivity (the ratio of unconfined compressive strength in the undisturbed state to strength in the remolded state; see Equation 12.8) is another important index property of cohesive soils. Soils with high sensitivity are highly unstable.

$$S_t = (\text{Strength in undisturbed condition})/(\text{Strength in remolded condition}) \tag{12.8}$$

As we described earlier, soil water content also influences soil behavior. Water content values of soil—the *Atterburg limits*, a collective designation of the so-called limits of consistency of fine-grained soils determined with simple laboratory tests—are usually presented as the *liquid limit* (LL), *plasticity limit* (PL), and the *plasticity index* (PI). Plasticity is exhibited over a range of moisture contents referred to as plasticity limits. The lower plasticity limit is the water level at which soil begins to be malleable in the semisolid state but the molded pieces still crumble easily with a little applied pressure. When the volume of the soil becomes nearly constant with further decreases in water content, the soil reaches the shrinkage state. The upper plasticity limit (or liquid limit) is reached when the water content in a soil–water mixture changes from a liquid to a semifluid or plastic state and tends to flow when jolted. Obviously, a soil that tends to flow when wet presents special problems for both engineering purposes and remediation of contamination. The range of water content over which the soil is plastic, called the plasticity index, provides the difference between the liquid limit and the plastic limit. Soils with the highest plasticity indices are unstable in bearing loads—a key point to remember.

The best known and probably the most useful system of the several systems designed for classifying the stability of soil materials, is called the *Unified System of Classification*. This system gives each soil type (14 classes) a two-letter designation based on particle-size distribution, liquid limit, and plasticity index.

Cohensionless coarse-grained soils are classified by index properties including the size and distribution of particles in the soil. Other index properties (including particle shape, in-place density, and relative density) are important in describing cohesionless soils because they relate how closely particles can be packed together.

Soil Stress

Just as water pressure increases as you go deeper into water, the pressure within soil increases as the depth increases. A soil with a unit weight of 75 pounds per cubic feet (lb/ft^3) exerts a pressure of 75 psi at a depth of 1 foot and 225 psi at 3 feet. Of course, as the pressure on a soil unit increases, soil particles reorient themselves to support the cumulative load. This is critically important information to remember, because a soil sample retrieved from beneath the load may not be truly representative once delivered to the surface. Representative samples are essential. The response of a soil to pressure (*stress*), such as when a load is applied to a solid object, is transmitted throughout the material (see Figure 12.9). The load puts the material under pressure, which equals the amount of load divided by the surface area of the external face of the object over which it is applied. The response to this pressure or stress is called *displacement* or *strain*. Stress (like pressure) at any point within the object can be defined as force per unit area.

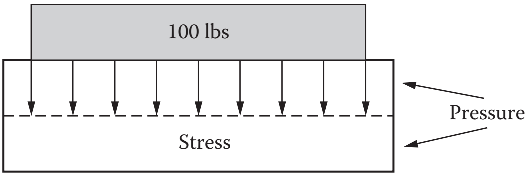

FIGURE 12.9 A 100-pound weight resting on a block causes pressure on the external surface of the block and stress on the internal planes in the body.

Soil Compressibility

Compressibility, the tendency of soil to decrease in volume under load, is most significant in clay soils because of inherently high porosity. The actual evaluation process for these properties relies on the *consolidation test*. This test subjects a soil sample to an increasing load. The change in thickness is measured after the application of each load increment.

Soil Compaction

Compaction reduces void ratio and increases the soil density, which affects how materials (including pollutants) travel through soil. Compaction is accomplished by working the soil to reorient the soil grains into a more compact state. Water content sufficient to lubricate particle movement is critical to obtaining efficient compaction.

Soil Failure

Soil structure affects natural processes such as frost heave (which could damage septic systems, disturb improperly set footings, or shift soils under an improperly seated underground storage tank and its piping) as well as changes applied to soils during remediation efforts (e.g., when excavating to mitigate a hazardous materials spill). When soil cannot support a load, *soil failure* occurs, which can include events as diverse as foundation overload, collapse of the sides of an excavation, or slope failure on the sides of a dike or hill. Because of the safety factors involved, the structural stability of a soil is critically important.

Classifying the type of soil before excavating involves determining the soil type. Finding a combination of soil types at an excavation site is common. Soil types include the following:

- *Stable rock* is generally stable but may lose stability when excavated; it is natural solid mineral material that can be excavated with vertical sides and will remain intact while exposed.
- *Type A soil* is the most stable soil; it includes clay, silty clay, sandy clay, clay loam, and sometimes silty clay loam and sandy clay loam.
- *Type B soil* is moderately stable soil that includes silt, silt loam, sandy loam, and sometimes silty clay loam and sandy clay loam.
- *Type C soil* is the least stable soil; it includes granular soils such as gravel, sand, loamy sand, and submerged soil, as well as soil from which water is freely seeping, and unstable submerged rock.

Both visual and manual tests are used to classify soil for excavation. Visual soil testing concerns soil particle size and type. In a mixture of soils, if the soil clumps when dug, it could be clay or silt. The presence of cracks in walls and spalling (breaking up into chips or fragments) may indicate Type B or C soil. Standing water or water seeping through trench walls automatically classifies the soil as Type C.

Manual soil testing includes the sedimentation test, wet shaking test, thread test, and ribbon test. A sample taken from soil should be tested, onsite or offsite, as soon as possible to preserve its natural moisture. A *sedimentation test* determines how much silt and clay are in sandy soil. Saturated sandy soil is placed in a straight-sided jar with about 5 inches of water. After the sample is thoroughly mixed (by shaking it) and allowed to settle, the percentage of sand is visible. A sample containing 80% sand, for example, will be classified as Type C. The *wet shaking test* is another way to determine the amount of sand vs. clay and silt in a soil sample. A saturated sample is shaken by hand to gauge soil permeability based on the following facts: (1) shaken clay resists water movement through it, and (2) water flows freely through sand and less freely through silt. The *thread test* is used to determine cohesion (remember, cohesion relates to stability, or how well the grains hold together). A representative soil sample is rolled between the palms of the hands to about 1/8-inch diameter and several inches in length. The rolled piece is placed on a flat surface, then picked up. If the sample holds together for 2 inches, it is considered cohesive. The *ribbon test* is used as a backup for the thread test. It also determines cohesion. A representative soil sample is rolled out (using the palms of your hands) to 3/4 inch in diameter and several inches in length. The sample is then squeezed between the thumb and forefinger into a flat unbroken ribbon 1/8 to 1/4 inch thick, which is allowed to fall freely over the fingers. If the ribbon does not break off before several inches are squeezed out, the soil is considered cohesive.

When soil has been properly classified, the necessary measures for safe excavation can be chosen, based on both soil classification and site restrictions. The two standard protective systems include sloping or benching and shoring or shielding.

Soil Physics

As a dynamic, heterogeneous body, soil is not isotropic—it does not have the same properties in all directions. Because soil properties vary directionally, various physical processes are always active in soil, as Winegardner (1996, p. 63) made clear: “All of the factors acting on a particular soil, in an established environment, at a specified time, are working from some state of imbalance to achieve a balance.” Soil practitioners must understand the factors involved in the physical processes that are active in soil. These include physical interactions related to soil water, soil grains, organic matter, soil gases, and soil temperature.

Soil and Water

Not only is water a vital component of every living being, but it is also essential to plant growth and to the microorganisms that live in the soil, in addition to being important in the weathering process, which involves the breakdown of rocks and minerals to form soil and release plant nutrients. In this section, we focus on soil water and its importance in soil, but first we need to take a closer look at water—what it is and its physical properties. Water exists as a liquid between 0° and 100°C (32° to 212°F), as a solid at or below 0°C (32°F), and as a gas at or above 100°C (212°F). One gallon of water weighs 8.33 pounds (3.778 kilograms) and is equal to 3.785 liters. One cubic foot of water equals 7.5 gallons (28.35 liters). One ton of water equals 240 gallons. One acre-foot of water equals 43,560 cubic feet (325,900 gallons). Earth’s rate of rainfall equals 340 cubic miles per day (16 million tons per second). Finally, water is dynamic (constantly in motion). It evaporates from seas, lakes, and the soil; is transported through the atmosphere; falls to Earth; runs across the land; and filters downward into and through the soil to flow along rock strata.

Water: What Is It?[*]

Water is often assumed to be one of the simplest compounds known on Earth, but water is not simple. Nowhere in nature is absolutely simple (pure) water to be found. Here on Earth, with a geologic origin dating back over 3 to 5 billion years, water found in even its purest form is composed of

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[*] Much of the following information is adapted from Spellman, F.R., *The Science of Water*, 3rd ed., CRC Press, Boca Raton, FL, 2015.

many constituents. Along with H_2O molecules, hydrogen (H^+), hydroxyl (OH^-), sodium, potassium, and magnesium, other ions and elements are present. Water contains additional dissolved compounds, including various carbonates, sulfates, silicates, and chlorides. Rainwater (often assumed to be the equivalent of distilled water) is not immune to contamination, which it collects as it descends through the atmosphere. The movement of water across the face of land contributes to its contamination, as it takes up dissolved gases such as carbon dioxide and oxygen and a multitude of organic substances and minerals leached from the soil.

Water Physical Properties

In soil physics, the physical properties of water (which are also a function of the chemical structure of water) that concern us are density, viscosity, surface tension, and capillary action. Let's take a closer look at each of these physical properties. *Density* is a measure of the mass per unit volume. The number of water molecules occupying the space of a unit volume determines the magnitude of the density. As temperature (which measures internal energy) increases or decreases, the molecules vibrate more or less strongly and frequently (which changes the distance between them), expanding or diminishing the volume occupied by the molecules. As discussed previously, liquid water reaches its maximum density at 4°C and its minimum at 100°C. In soil science work, the density may be considered to be a unit weight (62.4 lb/ft^3 or 1 g/cm^3).

Viscosity is the measure of the internal flow resistance of a liquid or gas. Stated differently, viscosity is the ease of flow of a liquid, or the capacity of a fluid to convert energy of motion (kinetic energy) into heat energy. Viscosity is the result of the cohesion between fluid particles and the interchange of molecules between layers of different viscosities. High-viscosity fluids flow slowly, while low viscosity fluids flow freely. Viscosity decreases as temperature rises for liquids.

Have you ever wondered why a needle can float on water? Or why some insects can stand on water? The reason is *surface tension*. Surface tension (or cohesion) is the property that causes the surface of a liquid to behave as if it were covered with a weak elastic skin. It is caused by the tendency of the exposed surface to contract to the smallest possible area because of unequal cohesive forces between molecules at the surface. What does surface tension have to do with soil? The surface tension property of water markedly influences the behavior of water in soils. Consider an example you may be familiar with, one that will help you understand surface tension and the other important physical properties of the water–soil interface. Water commonly rises in clays, fine silts, and other soils, and surface tension plays a major role. The rise of water through clays, silts, and other soils is its *capillarity* or *capillary action* (the property of the interaction of the water with a solid), and the two primary factors of capillary rise are surface tension (cohesion) and adhesion (the attraction of water for the solid walls of channels through which it moves).

Why does the water rise? Because the water molecules are attracted to the sides of the tube (or soil pores) and start moving up the tube in response to this attraction. The cohesive force between individual water molecules ensures that water not directly in contact with the side walls is also pulled up the tube (or soil pores). This action continues until the weight of water in the tube counterbalances the cohesive and adhesive forces. Keep in mind that for water in soil the rate of movement and the rise in height of soil water are less than one might expect on the basis of soil pore size, because soil pores are not straight like glass tubes nor are the openings uniform. Also, many soil pores are filled with air, which may prevent or slow down the movement of water by capillarity. A final word on capillarity—keep in mind that capillarity means movement in any direction, not just upward. Because the attractions between soil pores and water are as effective with horizontal pores as with vertical ones, water movement in any direction occurs.

Water Cycle (Hydrological Cycle)

The importance of the water cycle cannot be overstated; thus, we discuss the cycle again here to emphasize this point. Water is never stationary; it is constantly in motion. Again, this phenomenon occurs because of the water or hydrological cycle. In simple terms, the water cycle can be explained as follows: The sun helps transfer water from lakes and oceans to the land. As the sun shines on the Earth, the surface water is heated and evaporates, forming an invisible gas that mixes with the air. This gas is water vapor; it is pure water without any minerals or bacteria in it. Water vapor rises in the air, then cools and condenses into tiny drops of water that form clouds. Further cooling may form drops large enough to fall as rain. In this way, water is brought from the oceans to the land, where it reappears in springs and wells, soaks into the ground, or runs off again through streams and rivers back to the ocean. Of course, the actual movement of water on Earth is much more complex. Three different methods of transport are involved in this water movement: evaporation, precipitation, and runoff.

Evaporation of water is a major factor in hydrological systems. Evaporation is a function of temperature, wind velocity, and relative humidity. Evaporation (or vaporization) is, as the name implies, the formation of vapor. Dissolved constituents (such as salts) remain behind when water evaporates. Evaporation of the surface water of oceans provides most water vapor, although water can also vaporize through plants, especially from leaf surfaces in a process known as evapotranspiration. Ice can also vaporize without melting first; however, this sublimation process is slower than the vaporization of liquid water.

Precipitation includes all forms in which atmospheric moisture descends to Earth—rain, snow, sleet, and hail. Before precipitation can occur, the water that enters the atmosphere by vaporization must first condense into a liquid (clouds and rain) or solid (snow, sleet, and hail) before it can fall. This vaporization process absorbs energy, which is released in the form of heat when the water vapor condenses. You can best understand this phenomenon when you compare it to what occurs when water evaporates from your skin; this absorbs heat, making you feel cold. Note that the annual evaporation from ocean and land areas is the same as the annual precipitation.

Runoff is the flow back to the oceans of the precipitation that falls on land. This journey to the oceans is not always unobstructed—flow back may be intercepted by vegetation (from which it later evaporates), a portion of the precipitation is held in depressions, and some infiltrates into the ground. A part of the infiltrated water is taken up by plant life and returned to the atmosphere through evapotranspiration, while the remainder either moves through the ground or is held by capillary action. Eventually, water drips, seeps, and flows its way back into ponds, lakes, streams, rivers, and the oceans.

Soil Water

Have you ever wondered what happens to water after it enters the soil? Maybe not, but if you are to work in the soil science field the answer to this question is one that you definitely must know and must also have a full and complete understanding of. Water that enters the soil has (in simple terms) four ways it may go:

1. It may move on through the soil and percolate out of the root zone, eventually reaching the water table.
2. It may be drawn back to the surface and evaporate.
3. It may be taken up (transpired, or used) by plants.
4. It may be held in storage in the water profile.

What determines how much water ends up in each of these categories? It depends. Climate and the properties of the particular soil and the requirements of the plants growing in that soil all have an impact on how much water ends up in each of the categories. But, don’t forget the influence of anthropogenic actions (what we like to call the heavy hand of man). People alter the movement of water, not only by irrigation and stream diversion practices and by building but also in their choice of which crops to plant and the types of tillage practices employed.

SOIL CHEMISTRY

Almost every environmental and pollution problem we face today (and probably tomorrow) has a chemical basis. In short, in environmental science, studying such problems as greenhouse effect, ozone depletion, groundwater contamination, toxic wastes, air pollution, stream pollution, and acid rain would be difficult (if not impossible) without some fundamental understanding of basic chemical concepts. Of course, an environmental practitioner who must solve environmental problems and understand environmental remediation cleanup processes (such as emission control systems or waste treatment facilities) must be well grounded in chemical principles and the techniques of chemistry in general, because many of them are being used to solve these problems. Because the topic is beyond the intended scope of this text, soil chemistry is not discussed in this text. For an in-depth treatment of soil chemistry, see Sposito (2008).

SOLID WASTE

Humans have always been known for their garbage (Spellman and Whiting, 2006). Ancient garbage dumps (called *middens*) provide us with a wealth of information on our human ancestors and their lives. From the historical perspective, this human garbage trail has allowed archaeologists to study humans from their earliest days, discovering many fascinating facts about us. From the garbage record, for example, we've determined that at every stage humans have always lived with enormous amounts of garbage, underfoot and all around them. Still true in the poorest parts of developing countries, this all-too-human habit poses a significant hazard to human health and to the environment, today and always. Ah! But don't panic. Modern humans can solve any problem. Right? Well, let's look at the record—the record we will leave behind us. Maybe it will provide us with some insight or answers.

By the 20th century, most industrialized countries (with their modern approaches to sanitation) removed garbage and other human waste from many living and working environments. But how about the other environment? The one we abuse or rarely think about (the one that sustains our lives)? The one in which we live with its air, soil, and water, all critical to our very existence? The natural world?

We stated earlier that people can put up with just about anything, until it displeases them. Then, of course, the source of displeasure must be removed—the old "out of sight, out of mind" syndrome. So what did we do? We transferred or diverted our garbage from our immediate living and working area into waterways, we heaped and often burned it in garbage dumps (today called *surface impoundments*), or we dumped it into areas called *landfills* (often former wetlands were filled in for anticipated future use).

The effect has been so massive as to overwhelm and sometimes directly kill life in local environments. Each year, in the United States alone, about 10 billion metric tons of non-agricultural solid waste is generated. Municipal solid waste alone accounts for more than 150 metric tons each year. An average U.S. citizen discards about 4 pounds of waste each day—that's nearly 1500 pounds per person, each year.

But what is new and threatening about modern garbage is not entirely the amount (great as it is) but its toxicity and persistence. Most waste in earlier times was *biodegradable*—that is, it could and did break down in the environment as part of natural processes (via biogeochemical cycles). However, today humans routinely use products made from or that produce toxic chemicals, as well as many other hazardous substances. Many of these are poisonous to start with; others become poisonous under certain situations—for example, when they are burned or when they come into contact with certain other chemicals to form a chemical brew of unknown toxicity. This chemical brew also enters the food chain and is passed along in concentration in the bodies of larger organisms. Many of these waste products, pesticides and plastics especially, persist in the environment for years, decades, and beyond.

Decades ago, *The Wall Street Journal*, *The Washington Post*, and the *Christian Science Monitor* all called the garbage disposal situation in America a "crisis" (Peterson, 1987; Richards, 1988; Tonge, 1987). Have we weathered the crisis? Can it be solved or will we continue to expand the historical garbage trail, leaving future archaeologists a record to study that will paint our generation as one of folly, of total disregard, of deliberate misuse—capable only of poor judgment and for whom conscience is for the other guy, for other generations?

In this section, we discuss a growing and significant problem facing not only all practitioners of pollution science but also of all humanity: *anthropogenically produced wastes*. Specifically, what are we going to do with all the wastes we generate? What are the alternatives? What are the technologies available to us at present to mitigate the waste problem, a problem that grows with each passing day?

Before beginning our discussion, we should focus on an important question: When we throw waste away, is it really gone? Remember, although we are faced today and in the immediate future with growing mountains of wastes (and are running out of places on Earth to dispose of them), we are faced with an even more pressing twofold problem, one related to the waste's toxicity and persistence.

We discuss waste and the toxicity problem later, but for now think about the persistence of the wastes that we dispose of. When we excavate a deep trench and place within it several 55-gallon drums of liquid waste, then bury the entire sordid mess, are we really disposing of the waste in an Earth-friendly way? Are we disposing of it permanently at all? What happens a few years later when the 55-gallon drums corrode and leak? Where does the waste go? What are the consequences of such practices? Are they insignificant to us today because they are tomorrow's problems? We need to ask ourselves these questions and determine the answers now. If we are uncomfortable with the answers we come up with now, shouldn't we feel the same about the answers someone else (our grandchildren) will have to come up with later?

Waste is not easily disposed of. We can hide or mask it. We can move it from place to place. We can take it to the remotest corners of the Earth. But, because of its persistence, waste is not always gone when we think it is. It has a way of coming back, a way of reminding us of its presence, a way of persisting.

How persistent is waste? Very, very persistent, as thousands of documented cases make clear. In this section, we define and discuss solid wastes. In particular, we focus on a significant portion of solid wastes referred to as municipal solid waste (MSW), because people living in urban areas where many of the problems associated with solid waste occur generate these wastes.

Solid Waste Regulatory History in the United States

For most of the nation's history, municipal ordinances (rather than federal regulatory control) were the only solid waste regulations in effect. These local urban governments controlled solid waste almost from the beginning of each settlement because of the inherent severe health consequences derived from street disposal. Along with prohibiting dumping of waste in the streets, municipal regulations usually stipulated requirements for proper disposal in designated waste dump sites and mandated owners to remove their waste piles from public property.

The federal government did not begin regulating solid waste dumping until the nation's harbors and rivers were either overwhelmed with raw wastes or headed in that direction. The federal government used its constitutional powers under the Interstate Commerce Clause of the Constitution to enact the Rivers and Harbors Act in 1899. The U.S. Army Corps of Engineers was empowered to regulate and in some cases prohibit private and municipal dumping practices.

Not until 1965 did Congress finally enter the picture (as a result of strong public opinion) by adopting the Solid Waste Disposal Act of 1965, which became the responsibility of the U.S. Public Health Service to enforce. The intent of this act was to (Tchobanoglous et al., 1993):

1. Promote the demonstration, construction, and application of solid waste management and resource recovery systems that preserve and enhance the quality of air, water, and land resources.
2. Provide technical and financial assistance to state and local governments and interstate agencies in the planning and development of resource recovery and solid waste disposal programs.
3. Promote a national research and development program for improved management techniques; more effective organizational arrangements; new and improved methods of collection, separation, recovery, and recycling of solid wastes; and the environmentally safe disposal of nonrecoverable residues.
4. Provide for the promulgation of guidelines for solid waste collection, transport, separation, recovery, and disposal systems.
5. Provide for training grants in occupations involving the design, operation, and maintenance of solid waste disposal systems.

After Earth Day 1970, Congress became more sensitive to waste issues. In 1976, Congress passed solid waste controls as part of the Resource Conservation and Recovery Act (RCRA). “Solid waste” was defined as any garbage; refuse; sludge from a waste treatment plant, water supply treatment plant, or air-pollution control facility; and other discarded material.

In 1980, Public Law 96-510, 42 USC Article 9601, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), was enacted to provide a means of directly responding to and funding the activities of response to problems at uncontrolled hazardous waste disposal sites. Uncontrolled municipal solid waste landfills are facilities that have not operated or are not operating under RCRA (USEPA, 1989). Many other laws that apply to the control of solid waste management problems are now in effect. Federal legislation and associated regulations have encouraged solid waste management programs to be implemented at the state level of government. Apparently, legislation will continue to be an important part of future solid waste management.

SOLID WASTE CHARACTERISTICS

Solid waste, also called *refuse*, *litter*, *rubbish*, *waste*, *trash*, and (incorrectly) *garbage*, refers to any of a variety of materials that are rejected or discarded as being spent, useless, worthless, or in excess. Table 12.8 provides a useful waste classification system. Solid waste is probably more correctly defined as any material thing that is no longer wanted. Defining solid waste is tricky, because solid waste is a series of paradoxes (O’Reilly, 1994):

TABLE 12.8
Classification of Solid Waste

Type	Principal Components
Trash	Highly combustible waste, paper, wood, cardboard cartons (including up to 10% treated papers, plastic, or rubber scraps); commercial and industrial sources
Rubbish	Combustible waste, paper, cartons, rags, wood scraps, combustible floor sweepings; domestic, commercial, and industrial sources
Refuse	Rubbish and garbage; residential sources
Garbage	Animal and vegetable wastes; restaurants, hotels, markets, institutional, commercial, and club sources

Source: Adapted from Davis, M.L. and Cornwell, D.A., *Introduction to Environmental Engineering*, McGraw-Hill, New York, 1991, p. 585.

- It is personal in the kitchen trash can but impersonal in a landfill.
- What one individual may deem worthless (an outgrown or out-of-style coat, for example) and fit only for the trash can another individual may find valuable.
- It is of little cost concern to many Americans yet is very costly to our society in the long term.
- It is an issue of serious federal concern yet a very localized problem from municipality to municipality.

The popular adage is accurate—everyone wants waste to be picked up, but no one wants it to be put down. It goes almost without saying that the other adage, “not in my backyard” (NIMBY) is also accurate. The important point, though, is that whenever a material object is thrown away, regardless of its actual or potential value, it becomes a solid waste.

Garbage (with its tendency to decompose rapidly, create offensive odors, and even endanger animals; see Figure 12.10) is often used as a synonym for solid waste, but garbage actually refers strictly to animal or vegetable wastes resulting from the handling, storage, preparation, or consumption of food. The collective and continual production of all refuse (the sum of all solid wastes from all sources) is referred to as the *solid waste stream*. An estimated 6 billion metric tons of solid waste are produced in the United States each year (Figure 12.11A). The two largest sources of solid wastes are agriculture (animal manure, crop residues, and other agricultural byproducts) and mining (dirt, waste rock, sand, and slag, the material separated from metals during the smelting process). About 10% of the total waste stream is generated by industrial activities (plastics, paper, fly ash, slag, scrap metal, and sludge or biosolids from treatment plants). From Figure 12.11A, we see that the other 3%

Wild animals or pets can get caught in plastic garbage bags.

Trash can accumulate on the street.

FIGURE 12.10 Garbage thrown here, there, and everywhere—the thrown-away plastics often become traps for animals. (Illustration by F.R. Spellman and Kathern Welsh.)

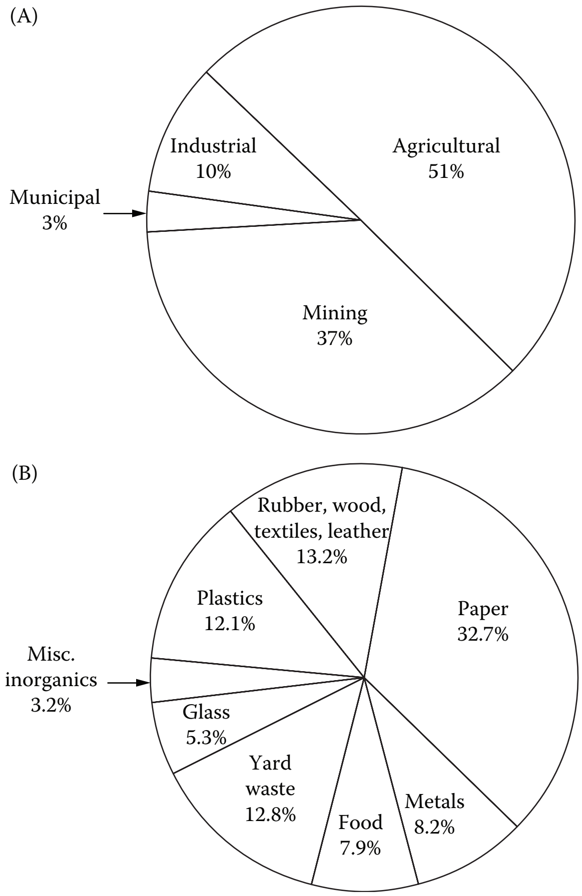

FIGURE 12.11 (A) Sources of solid waste in the United States; (B) composition of solid waste discarded in a typical day by each American. (Adapted from USEPA, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2007*, U.S. Environmental Protection Agency, Washington, DC, 2007.)

of the solid waste stream is made up of MSW, which consists of refuse generated by households, businesses, and institutions. From Figure 12.11B, we see that paper and paperboard account for the largest percentage (about 33%) of refuse materials by volume of MSW. Yard wastes are the next most abundant material, accounting for almost 13%. Glass and metals make up almost 18% of MSW, food wastes just under 13%, and plastics about 12.1%.

SOURCES OF MUNICIPAL SOLID WASTE

Sources of municipal solid waste in a community are generally related to land use and zoning. MSW sources include residential, commercial, institutional, construction and demolition, municipal services, and treatment plants.

DID YOU KNOW?

Approximately 254 million tons of municipal solid wastes were generated in the United States in 2007, equivalent to a bit more than 0.8 pounds per person per day (USEPA, 2007).

Residential Sources of MSW

Residential sources of MSW are generated by single and multifamily detached dwellings and apartment buildings. The types of solid wastes generated include food wastes, textiles, paper, cardboard, glass, wood, ashes, tin cans, aluminum, street leaves, and special bulky items, including yard wastes collected separately, white goods (refrigerators, washers, dryers, etc.), batteries, oil, tires, and household hazardous wastes.

Commercial Sources of MSW

Commercial sources of MSW include restaurants, hotels, stores, motels, service stations, repair shops, markets, office buildings, and print shops. The types of solid wastes generated include paper, cardboard, wood, plastics, glass, special wastes such as white goods and other bulky items, and hazardous wastes.

Institutional Sources of MSW

Institutional sources of MSW are generated in hospitals, schools, jails and prisons, and government centers. The types of solid wastes generated by institutional sources are the same as those generated by commercial sources.

Construction and Demolition Sources of MSW

Construction and demolition sources of MSW include new construction sites, the razing of old buildings, road repair or renovation sites, and broken pavement. The solid wastes generated by construction and demolition sources are made up of standard construction materials such as wood, steel, plaster, concrete, and soil.

Municipal Services Sources of MSW

Municipal services (excluding treatment plants) generate MSW during street cleaning; landscaping; and park, beach, recreational area, and catch basin maintenance and cleaning activities. The types of solid wastes generated by municipal services include rubbish; street sweepings; general wastes from parks, beaches, and recreational areas; and catch basin debris.

Treatment Plant Site Sources of MSW

Treatment plant sites generate MSW during water, wastewater, and other industrial treatment processes (e.g., incineration). The principal types of solid wastes generated by treatment plant sites are sludges or biosolids, fly ash, and general plant wastes.

THE BOTTOM LINE

The slow, inexorable progress of rock changing into soil gives us an ongoing demonstration of Nature's unrelenting power. While we move around on the surface of the Earth and push and shove soil into various stages and conditions, we forget one vital fact: We can do little to either slow or speed the natural process of soil creation.

Nature is a powerful and omnipresent force in our environments that we must both depend on and contend with. Human beings are another powerful force, and when you put their achievements into the equation (including the heavy hand of man and what we do to our environment), the repercussions of both the destruction that Nature can dish out and the impact on the environment by humans can become overwhelming to comprehend. Fortunately, for our peace of mind, we don't often think along this line of reasoning. Is this a good thing? Is it good to ignore Nature and what she can do? Is it important to think about the impact of humans on their surroundings?

Many people simply don't care. They think, "We all know that we impact our environment, but, what the heck, the environment will take care of itself. And, besides, why should we be concerned with what we do today to the environment—soon it will all be forgotten?" No matter what we do, we leave our mark on the land. We do impact the environment we use and inhabit, more than we are sometimes aware. Have you ever walked through an old cemetery, one with crumbling and unreadable headstones? This can be a sobering reminder to all of us of our fragility—not only of human life but also of the shortness of memory. Our point is that we must not forget; we must not only increase our awareness of our impact on our environment but also increase our memory spans—our sense of history. For long-range planning, we need long-range vision—and the ability to remember what has gone on before.

With regard to solid waste, as we examine the problems associated with solid waste disposal, whether municipal, industrial, or hazardous, the answer to a question posed in this chapter becomes more and more apparent: When we throw away waste, it is not gone. Dealing with the waste permanently has only been postponed. Sometimes this postponement means that when we go back the wastes are rendered helpful and harmless (as with some biodegradable wastes), but more often it means that the problems we must face will be worse due to chemistry and entropy. That 55-gallon drum was easier to handle before it rusted out.

Amid the cries of "not in my backyard" and "pick up the trash but don't put it down," we need to hear a more realistic and environmentally kinder truth: *There's no such thing as a free lunch*. We pay, somehow, for what we get or use, whether we see the charges or not. The price for our solid waste habits will soon be charged to us. In some places (big cities, for example), an awareness of the size of the bill is sinking in. Environmentally, what does that mean? In short, if we, as a society, are going to consume as we do, build as we do, grow as we do, then we have to pay the price for our increase. And that, sometimes, is going to mean that our waste is going to be in our backyard. We will have to increase the amount of solid waste we reuse and recycle, we will have to spend tax dollars to solve the problems with landfills and trash incineration, and we will have to seriously look at how we live, how the goods we buy are packaged, how our industries deal with their wastes—because if we don't, the bill will be more than we can afford to pay.

DISCUSSION QUESTIONS

1. Discuss and describe the stages of bare rock succession.
2. Provide a definition of soil that includes the elements important for soil scientists, soil engineers, and earth scientists, as well as the elements important for soil functionality.
3. Describe and discuss the five chief functions of soil.
4. Describe and discuss how the physical properties of soil might affect soil remediation.
5. How are soils classified? Why is soil classification important?
6. What elements comprise soil? How do these elements affect the behavior of soil?
7. What physical properties of the interaction between water and soil affect the success or failure of soil remediation?
8. What routes can water take through soil? Discuss how their eventual destinations affect remediation.
9. Distinguish between garbage, rubbish, refuse, and trash based on their composition and source.
10. Distinguish between persistent and nonpersistent solid wastes.
11. Why are biodegradable materials easier to dispose of than those that are not biodegradable?
12. What is municipal solid waste?
13. List the sources of municipal solid waste.
14. What is the difference between garbage and trash?
15. What is the difference between refuse and rubbish?

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13 Soil Pollution

It's not rocket science; soil pollution is the result of human misuse of soil.

—Frank R. Spellman

The way I see it, the difference between farmers and suburbanites is the difference in the way we feel about dirt. To *them*, the earth is something to be respected and preserved, but dirt gets no respect. A farmer likes dirt. Suburbanites like to get rid of it. Dirt is the working layer of the earth, and dealing with dirt is as much a part of farm life as dealing with manure: Neither is user-friendly but both are necessary.

Konigsburg (1996)

With the disappearance of the forest, all is changed. … The face of the earth is no longer a sponge but a dust heap, and the floods which the waters of the sky pour over it hurry swiftly along the slopes, carrying in suspension vast quantities of earthly particles which increase the abrading power and mechanical force of the current, and augmented by the sand and gravel of falling banks, fill the beds of the streams, divert them into new channels and obstruct their outlets. … From these causes, there is constant degradation of the uplands, and a consequent elevation of the beds of water-courses and of lakes by the deposition of the mineral and vegetable matter carried down by the waters. … The washing of solid from the mountains leaves bare ridges of sterile rock, and the rich organic mould which covered them, now swept down into the dank low grounds, promotes a luxuriance of aquatic vegetation that breeds fever and more insidious forms of mortal disease, by its decay and thus the earth is rendered no longer fit for the habitation of man.

Marsh (1865)

CLEAN SOIL

Logan (1995) observed that, "Soil is the darkest and coldest of all living things. The most widespread. And the most receptive. Warmed, it blooms. … Work, motion, life. All rise from the dirt and stand upon it as on a launching pad." Soil is dirt. Logic tells us that since soil is dirt, it must be dirty. Why would anyone worry about polluting soil, especially since soil is dirt—that is dirty to begin with? Why worry?

Well, we should worry about keeping soil clean for several reasons. Think about this analogy. Some people define a weed as a plant that is growing where you don't want it to grow. A tree could be classified as a weed if you want to cut it down, and if you decide to grow dandelions in your garden (some people do, for salad greens and dandelion wine) then they aren't weeds. Dirt can be defined, then, as misplaced soil; good soil might make you dirty, but it isn't dirty itself.

Soil should be kept clean because the complex web of animal and plant life on Earth depends on a thin layer of clean soil. Clean soil provides chemical nutrients to plant life on land and in the sea. Clean soil acts as an absorbent (a sponge) for the water that is absolutely necessary for life. Finally, clean soil provides a dynamic environment for many important groups of living organisms, especially the fungi and bacteria we call *decomposers*. Many people laugh at the idea of soil being clean, which is understandable because actually being able to see soil pollution is difficult, and the extent of soil pollution (and the extent to which it can affect us) is not common knowledge. We are more familiar with pollution we can see, smell, or taste, that makes us ill or otherwise affects us adversely. We readily recognize floating garbage, smog, soap scum, and dead fish for what they are: pollution or the results of pollution. Soil, on the other hand, does not reveal the manifestations of pollution so readily. Soil is complex, so complex that it is difficult to know what should be there and what should not be there. To understand the idea of soil pollution, we need to look at soil from the standpoint of its function. What should soil do? How should soil perform?

In Chapter 12, it was pointed out that soil (1) holds and supplies water, (2) supplies nutrients, (3) holds and supplies air, and (4) provides a physical support or environment. Chapter 12 also pointed out that soil is made up of both inorganic and organic materials. Formed slowly through the actions of erosion and weathering and from the activities of plants and animals, soil must have the right proportions of materials and be devoid of pollutants to properly serve its place in the biosphere. Soil pollution—the waste components present in soil that interfere with this function—is what this chapter is all about.

SOIL POLLUTANTS: TRANSPORT MECHANISMS AFFECTING FLOW REGIME

When a spill or leak occurs or when pollutants are intentionally discharged or accidentally released in soil, what happens to the pollutants? The answer is rather complex and is based on the interactions among and between the chemicals, rock, soil water, and the soil. The following text identifies and explains the properties of the pollutants that are important to the migration, retardation, transformation, and ultimate disposition or fate of pollutants in soil. But, first, a few definitions:

- *Vapor pressure and volatility*—Vapor pressure is the property that determines how easily a pollutant evaporates; the lower the vapor pressure, the more easily a pollutant will evaporate. Volatility is the tendency of a solid or liquid pollutant to pass into the vapor state, or how quickly and easily a liquid or solid pollutant evaporates at ordinary temperatures when exposed to the air.
- *Miscibility with soil water and groundwater*—Miscibility is a measure of how well a liquid pollutant can be mixed with, and will remain mixed with, water present under normal circumstances.
- *Solubility in soil water and groundwater*—Solubility is the ability of a pollutant to mix with water present under normal circumstances.
- *Density and specific gravity*—Density is the ratio of the weight of a mass to the unit of volume. Specific gravity is the ratio of the weight of the volume of liquid or solid pollutant to the weight of an equal volume of water. The specific gravity of water is 1.0; pollutants with a specific gravity below 1.0 will float on water, and those with a specific gravity over 1.0 will sink in water.
- *Dynamic viscosity*—Dynamic viscosity is the internal resistance of a liquid or gaseous pollutant while it is moving.
- *Reactivity*—Reactivity is a measure of the ability of a pollutant to undergo a chemical combination with another substance.
- *Susceptibility to biodegradation*—Susceptibility to biodegradation is a measure of the ease by which a pollutant breaks down into basic elements.

Along with the various pollutant properties that affect the fate of pollutants when they somehow enter soil, properties of the soil environment into which the pollutant is discharged are also important and must be determined, especially when remediation activities are involved. These important properties, with respect to the fate of pollutants in the soil, include the soil's

- Infiltration capacity
- Natural organic content
- Saturated and unsaturated hydraulic conductivities
- Effective porosity
- Relative permeability for immiscible pollutants and soil water

- Mineralogy
- Oxygen content
- Bacterial community

Practitioners whose job it is to protect soils or to remediate soil pollution must know the several processes that work to control the rate and extent of migration of pollution in soils. These natural processes trap the pollutant, or delay the pollutant from spreading, and cause the pollutant to degrade or change in chemistry to a less hazardous state.

The processes that work to retard pollutant movement in soils include adsorption, ion exchange, chemical precipitation, and biodegradation. Let's take a look at each one of these pollutant retardants:

- *Adsorption* is the process by which one substance is attracted to and adheres to the surface of another substance, without actually penetrating its internal structure. In soil, adsorption works to bond a pollutant to the surface of a soil particle or mineral in such a way that the substance is only available or disperses slowly. Clay and highly organic materials, for example, tend to adsorb pesticides rather than absorb them. Pollutant adsorption takes place on mineral surfaces where defects in their crystalline structure result in imbalances of electrical charges on the mineral surface. Dissolved pollutant molecules and ions with charge imbalances are attracted to mineral surfaces that have an opposite charge imbalance.
- *Ion exchange* is part of the adsorption process. A dissolved pollutant substitutes itself for another chemical already adsorbed on the mineral surface.
- *Pollutant precipitation* occurs when dissolved pollutants are removed (transported) from soil water and groundwater by various precipitation reactions. Another pollution remediation technique is *chemical precipitation*, where the pollutant is precipitated out of the contaminating stream.
- *Biodegradation* is the breakdown of organic and pollutant compounds through microbial activity that affects the distribution, movement (transport), and concentration of pollutants in soil.

The fate of certain pollutants applied to the soil surface or introduced into the soil profile depends on an extremely complex combination of interactive processes. The effectiveness of these interactive processes depends on several variable conditions: the nature of the pollutant, the manner of its application, the fundamental nature of the soil, and its transient state at the time and place of interest.

In addition to the various properties of pollutants and of the soil environment that affect pollutant migration, retardation, and transformation of mobile pollutants in soil, certain properties and conditions of the soil also affect the flow regime (Kostecki and Calabrese, 1989):

- *Soil texture*—The migration of pollutants in coarse (sandy and gravelly soils) soil is generally faster than in fine (clay or silty) soils, which are more likely to retain pollutants and prevent their migration.
- *Layered soils* (or the vertical uniformity or nonuniformity of soils)—Layered soils are more likely to retard migration in the soil profile than are uniform profiles.
- *Configuration of the soil layers*—Whether soil layers are horizontal, slanted, or sloped has an effect on pollutant flow; for example, if horizontal layers with concave troughs are present, pollutant flow is more likely to be retarded. On the other hand, in slanted or sloped layers the flow of pollutants may not only be easier but also directed, for example, toward a well or groundwater.
- *Depth of the water table*—Obviously, if the depth to the water table is extreme, it is more difficult, depending on the retardivity of the soil, for a pollutant to travel the entire distance of the soil to the water table.

- *Structure of the soil*—Natural fissures, cracks, or channels in the soil are important considerations in establishing soil pathways (enabling rapid migration of pollutants in the soils).
- *Unstable flow*—Pollutant flow not only migrates quickly through cracks and fissures but also has the tendency to concentrate in tongue-like streams (fingers), which generally begin at the transition from fine-textured to coarse-textured layers, bypassing or short-circuiting the greater volume of soil material and allowing direct transmission of pollutants to the water table.
- *Soil moisture*—Moisture has an obvious effect on the pattern and migration of organic pollutants in the soil.

MOVEMENT OF ORGANICS IN SOIL

When a mixed organic pollutant enters soil, a chain of sequential and simultaneous processes occurs. As an example, the following lists the steps involved when an organic pollutant is spilled on the soil surface:

Step 1. Volatilization of lighter components to atmosphere
Step 2. Surface runoff
Step 3. Adherence of the heavier components to soil surface
Step 4. Infiltration into the soil proper
Step 5. Downward and lateral flow with the unsaturated zone of the soil profile
Step 6. Detention above layer interfaces within the profile layer
Step 7. Retention in soil pores and attachment to soil grains
Step 8. Volatilization and vapor diffusion within the soil and out of the surface
Step 9. Selective immigration of lighter and less viscous components
Step 10. Partial dissolution of soluble emulsifiable components with the water phase of soil
Step 11. Pollutant degradation from both nonbiological and biological processes
Step 12. Internal drainage or leaking from the soil
Step 13. Mounding over the water table and creeping into it
Step 14. Penetration into the aquifer
Step 15. Dispersion and further migration within the aquifer and eventual appearance in water supplies

THE BASICS OF SOIL POLLUTION

> The Global Assessment of Soil Degradation study conducted for the United Nations Environment Programme found that in recent decades nearly 11 percent of the Earth's fertile soil has been so eroded, chemically altered, or physically compacted as to damage its original biotic function (its ability to process nutrients into a form usable by plants); about 3 percent of soil has been degraded virtually to the point where it can no longer perform that function.
>
> **World Resources Institute (1992)**

Agricultural practices have exacerbated problems with soil fertility. This problem warrants and receives major concern. The most damaging processes (erosion, salination, and waterlogging) are well known, well studied, and well documented. Fortunately, remediation practices are already in place in many locations throughout the world. Soil fertility's problems and the solutions to the problems have received considerable attention throughout the world, driven by a hungry, ever-increasing world population and by economic issues. One critically important issue in the battle to maintain and increase soil fertility (correctly stated by the World Resource Institute as "its ability to process nutrients into a form usable by plants") has only recently come to light—soil pollution.

A problem long unnoticed, soil pollution generated by industrial contamination, management of Superfund sites, exploration and production, mining, and nuclear industrial practices (among others) has affected soil quality at levels we have only recently begun to understand. The extent of soil damage in many areas is difficult to determine, because assessment itself is problematic; however, according to the evidence, staggeringly large amounts of polluted soils have been generated (Testa, 1997). In Oklahoma, for example, contaminated soil accounts for about 90% of the waste generated as a one-time occurrence.

SURFACE ORIGINS OF SOIL POLLUTANTS

All human societies, to some extent, pollute both soil and groundwater. Throughout history, people have had to develop ways of recognizing surface water contamination or face disease and death from contaminated water. These pollutants are often readily apparent and cause immediate, significant problems; however, contamination of the soil and the underground environment has remained virtually unnoticed until the last few decades, because of its unseen locations and seemingly minimal impact. Industrialization and the wide range of hazardous materials and other chemicals that have been introduced to the environment in developed countries, either by design or accident, mean, of course, that industrialized nations are most seriously affected by persistent soil pollutants. We quite simply did not comprehend how effectively the mechanisms that carry contaminants through the soil could work or the damage pollutants could do to the soil medium and the groundwater under soil's apparently protective surface. Again, because we did not know what we did not know meant that this "out of sight, out of mind" problem has been building for years, and the difficulty of tracing and remediating soil pollution is only now something we are beginning to grasp.

The number of human activities that cause underground contamination is much larger than most environmental scientists would have guessed even a few years ago. Soil quality problems originating on the surface include natural atmospheric deposition of gaseous and airborne particulate pollutants; infiltration of contaminated surface water; land disposal of solid and liquid waste materials; stockpiles, tailings, and spoils; dumps; salt spreading on roads; animal feedlots; fertilizers and pesticides; accidental spills; and composting of leaves and other yard wastes. Other sources of soil contamination are related to petroleum products, including direct disposal of used oils on the ground by individuals or industries; seepage from landfills, illegal dumps, unlined pits, ponds, and lagoons; and spills from transport accidents or even auto accidents, all of which contribute to the soil burden (Tucker, 1989). Industrial practices not permitted in the United States are sometimes utilized openly by U.S.-owned companies in developing nations, creating significant levels of pollution in countries lacking knowledge about the dangers, the economic ability, or the political structure to protect their environment.

The following discussion focuses on contamination originating on the land surface; however, be aware that soil and subsurface contamination may also originate below ground (but above the water table) due to septic tanks, landfills, sump and dry wells, graveyards, underground storage tanks, underground pipelines, and other sources. In addition, soil, the subsurface, and groundwater contamination may also originate below the water table due to mines, test holes, agricultural drainage wells, and canals.

GASEOUS AND AIRBORNE PARTICULATE POLLUTANTS

Soil figures prominently in the function of the carbon, nitrogen, and sulfur cycles—the biogeochemical cycles. While prominent in the normal operation of these cycles, soil interfaces in powerful and essential ways with the atmosphere. Consider the nitrogen cycle, where nitrates and ammonium ions in rainwater are absorbed by plant roots and soil microorganisms and converted to amino acids or to gaseous N_2 and N_2O, which diffuse back to the atmosphere. The N_2 uptake and conversion to amino acids (nitrogen fixation) by symbiotic and free-living soil microorganisms balances this loss of gaseous nitrogen. NO, NO_2, and NH_3 (other nitrogen gases) are also emitted and absorbed by soils. Soil reactions are major determinants of trace gas concentrations in the atmosphere. Air pollutants—sulfur dioxide, hydrogen sulfide, hydrocarbons, carbon monoxide, ozone, and atmospheric nitrogen gases—are absorbed by soil. Because soil reactions are subtle, they are often ignored in tracing the effects of air pollution; however, two classic examples of airborne particulate soil contamination are the accumulation of heavy metals around smelters and soils in urban areas contaminated by exhaust fumes associated with vehicle emissions. Although these two soil polluters can be serious in localized areas, long-range effects of such contamination are considered minor.

Infiltration of Contaminated Surface Water

When wells are installed near streams and rivers, the well induces recharge from the water body, providing high yield with low drawdowns; however, if the water body that the well draws from is polluted, soil-water well field contamination can result. This most commonly occurs from a shallow water supply well drawing water from the alluvial aquifer adjacent to the stream. The cone of depression imposed by pumping the well or well field creates a gradient on the water table directed toward the well. This pulls the polluted water through the soil and contaminates both the well field and well.

Land Disposal of Solid and Liquid Waste Materials

Common practices for dealing with certain recyclable wastes, such as liquid and sludge (biosolids) wastes from sewage treatment plants, food processing companies, and other sources, include land disposal, stockpiling, or land applying wastes or materials. These practices serve as a means of disposal and provide beneficial use and reuse of such materials. These waste products often work successfully to fertilize agricultural lands, golf courses, city parks, and other areas, but the land selected for use must be carefully chosen and tested. Contamination problems arise if water-soluble, mobile wastes are carried deep into the subsurface. If water tables are near the surface, groundwater contamination problems can occur.

Stockpiles, Tailings, and Spoil

The practice of stockpiling chemical products, if not properly managed, contributes to soil and subsurface pollution. Road-salt stockpiles are maintained by many local highway departments and some large industries for snow and ice removal in winter, but the salt can leach into the soil. Tailings produced in mining activities commonly contain materials (e.g., asbestos, arsenic, lead, radioactive substances) that are a health threat to humans and other living organisms. Tailings may also contain contaminants, including sulfide, which forms sulfuric acid upon contact with precipitation. The precipitation runs off or is leached from tailing piles, infiltrating the surface layer and contaminating soil. It may ultimately reach groundwater. Spoil (a common result of excavations where huge amounts of surface cover are removed, piled, and then moved somewhere else) causes problems similar to tailing problems, in that precipitation removes materials in solution in percolating waters (leaching). Pollutants migrate from the spoil, finding their way into the soil and into shallow aquifers.

Dumps

Illegal dumping is less common today than in the past, fortunately. In fact, uncontrolled dumping is prohibited in most industrialized countries. The persistent remains of dumping are still with us, however. Dumping sites can contain just about anything. Such sites present localized threats of subsurface contamination.

SALT SPREADING ON ROADS

The practice of spreading deicing salts on highways is widespread, especially in urban areas in the north. Not only does this practice contribute to the deterioration of automobiles, bridges, and the roadway itself, but it also adversely affects plants growing alongside a treated highway or sidewalk. More seriously, salt contamination quickly leaches below the land surface. The productivity of the land decreases, because most plants cannot grow in salty soils. Contamination of wells used for drinking water can occur in areas with long-term continued use.

ANIMAL FEEDLOTS AND CONCENTRATED ANIMAL FEEDING OPERATIONS*

> Don't let the folks down there know that you are looking for sites for hog facilities or they will prevaricate and try to take us to the cleaners, they will carry on to various editors, every kind of meanness and so forth, as they have been brainwashed by the Sierra Club to think that hog facilities are bad, even the folks who love baby back ribs, even the ones hunting jobs. … The panhandle region is perfect for hog operations—plenty of room, low population, nice long dry seasons, good water. There is no reason why the Texas panhandle can't produce seventy-five percent of the world's pork.
>
> **Proulx (2002)**

A current debate in agriculture is gaining steam over animal feedlots and concentrated animal feeding operations (CAFOs). An animal feedlot is a type of CAFO whereby animals are confined and finished (fed and fattened) for production. Some of the largest contributors to nonpoint-source water pollution are animal feedlots. Animal waste in feedlots literally piles up. These stationary heaps, sometimes left for extended periods, create problems with runoff containing contaminants. Not only could these contaminants enter the nearest surface water body but they could also contaminate soil by waste seepage.

The debate over the serious impacts of CAFOs on the environment and social fabric of rural living is ongoing. CAFOs produce large quantities of animal waste that are stored in leak-prone lagoons, putting America's water at risk. Livestock factories also pose a threat to local soil and air quality, and fish and wildlife suffer from manure spills. The huge corporations that run the livestock factories are edging out family farmers, who often use more environmentally friendly techniques. Owning a home might be the American dream, but a hog operation in the backyard is a nightmare for property values.

There is also an urban–rural interface to consider—for example, the various aspects of urban–wildlife interfaces, urban sprawl, and its impact on forestry. Other issues include air pollution, antibiotics, hormones, and other chemical contaminants deposited into the environment via the manure environmental medium interface. The fact is the mythology behind the popular image of traditional, idyllic, self-contained farm operations stands in stark contrast to the modern reality of factory farming based on concentrated animal feeding operations. Siting of CAFOs is a divisive issue, pitting neighbors against neighbors in rural communities amid angry debates about odors, environmental degradation, increasing concentration among producers, and a sense of injustice among those who feel unheard and disenfranchised (Barrette, 1996; Keller and Miller, 1997).

Concentrated animal feeding operations are farming operations where large numbers of livestock or poultry (often in the thousands) are housed inside buildings or in confined feedlots. The U.S. Environmental Protection Agency (USEPA) defines a CAFO as a concentrated animal feeding operation where animals are confined for more than 45 days per year. To classify as a CAFO, such an operation must also have over 1000 animal units, a standardized number based on the amount of waste each species produces, or basically 1000 pounds of animal weight (USDA, 2017). Thus, dairy cattle count as 1.4 animal units each. A CAFO could house more than 750 mature

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* This section is adapted from Spellman, F.R. and Whiting, N.E., *Concentrated Animal Feeding Operations*, CRC Press, Boca Raton, FL, 2006.

dairy cattle (milking and or dry cows) or 500 horses and discharge into navigable water through a manmade ditch or a similarly manmade device. Following are the numbers of various species per 1000 animal units:

- 2500 hogs
- 700 dairy cattle
- 1000 beef cattle
- 125,000 broiler chickens
- 82,000 layer hens

Unless you have actually seen such an operation, grasping the scope of the problem can be difficult. In an attempt to quantify the issue, consider how the amounts of CAFO-generated animal manure compare to human waste production. Here is a small-scale example: One hog per day excretes 2.5 times more waste than an adult human—nearly 3 gallons (Cantrell et al., 2004). Here is a medium-scale example: One 10,000-hog operation produces as much waste in a single day as a town of 25,000 people (Sierra Club, 2004), but at least the town has a treatment plant. Here is a bigger picture: In 2003, humans generated about 150 million tons (wet weight) of sanitary waste annually in the United States, based on a population of 285 million and an average waste generation of about 0.518 tons per person per year (USEPA, 2003a); however, the approximately 15,000 CAFOs in the United States produce an estimated 500 million tons of manure annually (USEPA, 2003b).

Here's the bottom line: By these estimates, all confined animals generate well over *3 times* more raw waste than is generated by humans in the United States. Much of this waste undergoes no or very little waste treatment. Waste handling for any CAFO is a major business concern and expense. Unless regulation and legislation support sound environmental practices for these operations, CAFO owners have little incentive to improve their waste handling practices.

Corporate livestock factories tout themselves as saviors to the rural communities they target. Everyone is promised something: job creation for local inhabitants, increased tax revenues for local coffers, expanded markets for family farmers, and increased purchasing power for hometown businesses, and high-tech production for consumers. Simply put, "Get big or get out." However, the facts paint a different picture. Corporate livestock factories actually disable community development with self-serving contracts and tax breaks, market-monopolizing strategies, and few local purchases (Cantrell et al., 1999a). Do bigger farms really benefit the overall economy of the community? Consider the effects of hog mega-barns on communities, the environment, and independent hog producers in Canada (National Farmers Union, 2000):

- Large corporate hog producers and attendant vertical integration threaten family farm hog production by pushing down prices, closing markets for family farmers, and obscuring price signals. In effect, the domination of the hog production and packing sectors by a handful of large, vertically integrated corporations destroys the open market in hogs.
- Vertical integration and the transfer of hog production from family farms to large corporate packers/processors is a policy decision, not an inevitable result of economic forces. Governments, at all levels, can make choices that will either turn agriculture over to distant corporations or retain it in the hands of local families.
- Although the corporate proponents of large hog barns promise jobs, economic development, and markets for feed grains, these corporate barns provide significantly fewer of these benefits than the family farm hog producers these corporations displace. Corporations employ fewer people per hog and spend less in their communities than family-farm hog producers.
- While large hog barns do not deliver promised economic benefits, they do pose real environmental threats to surface and groundwater.

Large hog farms also give off objectionable odors, increase fly populations, destroy the quality of life for surrounding residents, and lower property values. Although it is natural for communities to want to attract jobs, wealth, and capital for investment, transferring hog production from local families to corporations facilitates and accelerates the extraction of wealth and capital from rural areas. In short, after considering the pros and cons of corporate factory farms vs. the traditional family farm, the family farmer may conclude that it might be better to "stay small and stay put."

Fertilizers and Pesticides

The mainstays of high-yield agricultural are fertilizers and pesticides. The impact of these two practices on the environment has been significant, with each yielding different types of contaminants. We think of the application of fertilizers and pesticides to our soil as treating the soil. But, are we treating it or poisoning it? We are still trying to definitively answer this question. We do know that when it comes to fertilizer and pesticide applications and the long-term effects, we do not know what we do not know—we do not have any proof of the long-term effects. The impact of using these chemicals is only now becoming clear.

Accidental Spills

Disturbingly common, accidental spills of chemical products can be extremely damaging to any of the three environmental media—air, water, and soil. When chemical spills in the soil media are not discovered right away, the contaminant may migrate into and through the soil to the water table. As a general rule of thumb, we may assume that the impact of a chemical spill in soil (or any other medium) is directly related to the concentration present at the point and time of release, the extent to which the concentration increases or decreases during exposure, and the time over which the exposure continues.

Composting of Leaves and Other Wastes

Composting is a common practice for many homeowners (especially gardeners) who consider the contained and controlled decay of yard and vegetable wastes as an environmentally friendly way to dispose of or beneficially reuse them. When the feed materials (leaves, twigs, and other organics) have been treated with chemical pesticides and some fertilizers, however, composting this material may be harmful to the soil.

INDUSTRIAL PRACTICES AND SOIL CONTAMINATION

Contamination sources from industrial practices include spillage and leakage from underground storage tanks (USTs), oil field sites, chemical sites, geothermal sites, manufactured gas plants, mining sites, and many other industrial activities. As a result of the Persian Gulf and Iraq wars, we have also experienced on alarmingly large-scale contamination from environmental terrorism.

Underground Storage Tanks

Contamination from USTs generally involves petroleum products. Millions of USTs were installed in the 1950s and 1960s. Out of an estimated 3 million USTs located throughout the United States today, it is possible that more than 400,000 of them are leaking or have leaked petroleum products, with more expected to leak in the future (USEPA, 1992, 2009). In 2007, there were an estimated 627,201 active USTs in operation and 1,666,884 closed ones (USEPA, 2009). As these tanks age, problems with tank failure increase.

Contamination from Oilfield Sites

When we consider the problems with soil contamination from oilfield sites, which are a source of rather large volumes of hydrocarbon-contaminated soil resulting from past and existing oilfields, we learn again that our past actions affect our future. We are cleaning up contaminated locations now that were created sometimes decades earlier.

This problem, while affecting sites in many locations, is location specific; for example, past and present-day oil exploration and production activities located in remote parts of Oklahoma and Texas have taken place in remote areas with small populations and thus are not subject to intense public scrutiny. In these remote locations, disposing of hydrocarbon-contaminated soil is easy and inexpensive. In urban areas, remediation not only is more difficult to achieve but is also more expensive because of the increased costs associated with disposal.

The primary sources of soil pollution on petroleum-producing properties include oil wells, sumps, pits, dumps leakage from above-ground storage tanks, and spillage. Secondary sources include USTs, transformers, piping ratholes, well cellars, and pumping stations. Large stationary facilities used for the refining of petroleum have the potential to cause chronic pollution by the discharge of hydrocarbon-laden wastewaters and by frequent small spills. The primary hazardous constituents associated with oilfield properties include drilling mud and its constituents, methane, and crude oil. When crude contains certain constituents above maximum contaminant levels (e.g., arsenic, chloride, chromium, lead, polychlorinated biphenyls) and with flash points less than the minimum standard set by American Society for Testing and Materials (ASTM) for recycled products, it may be considered a hazardous waste.

Complete handling and processing ancillaries exist close to many oilfields—refineries, terminals, and pipelines. These also contribute to the overall volume of contaminated soil generated. Crude oil, refined products, and volatile organic compounds are the pollutants of primary concern.

Contamination from Chemical Sites

Annually, chemical sites generate and dispose of tens of thousands of tons of organic waste. Thousands of tons of this waste are untreated (residing in landfills, ponds, lagoons, and injection wells). A survey of chemical manufacturing companies during the period from 1950 to 1979 revealed that approximately 0.5 million tons of organic waste were incinerated and approximately 0.5 million tons were either recycled or reused (Spellman, 1998).

Contamination from Geothermal Sites

Geothermal energy lies deep within the Earth, past the Earth's mantle, which is usually 15 to 30 miles below the Earth's crust. The mantle is composed of a semimolten rock layer. Intense pressure from beneath the mantle, caused by molten rock of iron and nickel and decaying radioactive elements, helps warm the Earth's surface. Although geothermal energy usually lies too deep beneath the surface for cost-effective use, in certain areas the molten rock has risen closer to the Earth's surface through massive fractures in the crust. In these areas, underground reservoirs of dry steam, wet steam, and hot water form. These deposits can be drilled and their energy used to heat water, drive industrial processes, and generate electricity using the same techniques we use for petroleum sites. Geothermal operations provide a clear example of the close relationship between site usage and the potential for adverse environmental impact. The use of geothermal energy can have adverse environmental impacts, including (Kagel et al., 2007):

- Water pollution
- Gaseous emissions
- Noise pollution

- Land use
- Land subsidence
- Solids emissions
- Induced seismicity
- Induced landslides
- Water use
- Disturbance of natural hydrothermal manifestations
- Disturbance of wildlife habitat and vegetation
- Altering natural vistas
- Catastrophic events

Two hazardous constituents associated with geothermal plants are brine and lead-mine scale (Testa, 1997).

In the United States, because of potential environmental problems such as those listed above, the environmental impact of any type of power project is subject to many forms of regulation. All of the following laws and regulations play a role before any geothermal development project can be brought to fruition (Kagel et al., 2007):

- Clean Air Act
- National Environmental Policy Act
- National Pollutant Discharge Elimination System Permitting Program
- Safe Drinking Water Act
- Resource Conservation and Recovery Act
- Toxic Substance Control Act
- Noise Control Act
- Endangered Species Act
- Archaeological Resources Protection Act
- Hazardous Waste and Materials Regulations
- Occupational Safety and Health Act
- Indian Religious Freedom Act

Contamination from Manufactured Gas Plants

The practice of gas manufacture is not new. Manufactured gas plants (approximately 3000 in the United States) have been in operation since the late 1890s. These plants have been upgraded or have been completely redeveloped in one way or another. The production and disposal of tarry substances, primarily produced in the coal gasification processes (e.g., coal carbonization, carbureted water gas), are the most significant environmental soil pollution problems associated with manufactured gas plants. Other contaminants of concern include polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), coal tars, heavy metals, polychlorinated biphenyls (PCBs), pesticides, and phthalates in soil, groundwater, surface water, and sediment.

Contamination from Mining Sites

Mining operations often create land and water pollution problems. Erosion-causing sediment pollution is the most obvious and most thoroughly documented problem with surface mining. The Chesapeake Bay is not the fertile oyster-producing environment it was in the past. Although the initial blame for the Bay's decline was placed on nutrient-rich substances and chemical pollutants, recent studies of the Bay's tributaries and the Bay itself indicate that oysters may be suffering (literally suffocating) from sedimentation rather than nutrient contamination (Spellman, 2008).

The effects of mining sediments and mining wastes (from mining, milling, smelting, and leftovers) on soil are less known, because no serious study of the problem has occurred. Typical mining wastes include acid produced by oxidation of naturally occurring sulfides, asbestos produced in asbestos mining and milling operations, cyanide produced in precious metal heap-leaching operations, leach liquors produced during copper-dump leaching operations, metals from mining and milling operations, and radionuclides (radium) from uranium and phosphate mining operations.

Acid mine drainage as a soil contaminant source is well known and well documented (see Case Study 13.1). When oxygen and water react with sulfur-bearing minerals to form sulfuric acid and iron compounds, these compounds may directly affect plant life that absorbs them. Acid mine drainage can also indirectly affect the flora of a region by changing the nature of the soil minerals and microorganisms in the area. The solid-waste byproducts of mining cause other problems. Metals are always mixed with other materials in mining. These materials usually have little commercial value, and disposal becomes problematic. The unsightly piles of rock and rubble are prone to erosion. Leaching releases waste materials that allow environmental poisons entry into the soil.

Case Study 13.1. Acid Rock and Acid Mine Drainage

The chemical interactions among rock, soil, and water cause minerals to leach out of rock and into soil, surface water, and groundwater. Water sources and soil in areas of heavy mineralization where water travels over ore deposits can be heavily affected by mineralization, either naturally or through the eventual mining of the ores. In fact, mining sites are sometimes discovered through the surficial signs of natural acid rock drainage. Human activities, including building and highway construction, mining, quarrying, and logging, can increase the amount of mineral released into soil and water supplies. Biota in areas of high mineralization are affected by leachates with high metal toxicity and sulfide-bearing materials. Metal-tolerant plants grow in such areas, and the plant life on the fringes of these areas eventually overgrows acidic “kill zones.” Aquatic life is less adaptive, however, and creeks and lakes with high acid concentrations, whether through natural acid rock drainage or acid mining drainage, are often devoid of life. Although acid rock drainage and acid mining drainage produce similar effects, establishing a baseline for natural acid drainage allows geologists to plan mine development and predict and treat the eventual mine drainage (Downing and Mills, 1998).

CONTAMINATION FROM ENVIRONMENTAL TERRORISM AND ECOTERRORISM

Understandably, many human activities result in environmental contamination, usually as the result of accidents or poor planning, poor decision making, inferior design, shoddy workmanship, ignorance, or faulty equipment. Whenever we read, hear about, or witness environmental contamination, we generally assume that some factor of human error underlies the problem. At least, that was our assumption prior to the Persian Gulf War. Certainly the Gulf War changed this perception of error and accident as the sole causes of environmental pollution.

At the close of the Gulf War, almost half of Kuwait’s 1500 oil wells were releasing oil into the environment. Estimates suggest that 11 million barrels of oil were spilled or burned in 600 flaming wells. When more than 200 wells were capped, this amount was reduced to approximately 6 million barrels by the end of that summer. The burning oil created massive amounts of air pollution, and quantities of oil spilled into the Persian Gulf, a very fragile shallow ocean environment. The harmful effects to the atmosphere and Persian Gulf were only part of the problem, however. Many pools of oil formed, some of them up to 4 feet deep, collectively containing an estimated 20 million barrels of oil (Andrews, 1992). While the environmental terrorism that occurred during and at the end of the Gulf War is a perfect example of humans' unexplainable disregard for the environment in which we live, history shows us that it is only one of many deliberate incidents that have occurred. Today, one thing seems certain: our current view of terrorism, environmental terrorism, and ecoterrorism has been modified considerably by recent events.

When someone mentions terrorism today, most of us instantly picture fully loaded and deliberately guided airplanes crashing into tall buildings, military installations, or a farm field somewhere, anywhere. Collateral to and almost always mentioned in the same breath as terrorism is "homeland security." According to Tom Ridge, first Secretary of the Department of Homeland Security, "You may say homeland security is a Y2K problem that doesn't end January 1 of any given year" (Henry, 2002). Ridge, a U.S. political figure who served as a member of the U.S. House of Representatives (1983–1995), as Governor of Pennsylvania (1995–2001), as Assistant to the President for Homeland Security (2001–2003), and as the first Secretary of Homeland Security (2003–2005), got it right. Homeland security is an ongoing problem that must be dealt with 24/7. Simply, there is no magic on/off switch that we can use to control the threat of terrorism in the United States or elsewhere.

The threat to our security not only is ongoing but is also universal, including potential and real threats from within—from our own citizens. Consider the American Timothy McVeigh, for example, who blew up the Government Building in Oklahoma City in 1995, killing almost 200 people, including several children. McVeigh, who bombed the building in revenge for the FBI's Waco, Texas, raid, thought the Army (he was a former decorated U.S. Army veteran) had implanted a chip in his butt to track his movements, according to reports. It is interesting to note that McVeigh, who was no doubt suffering from some type of severe disturbance, acted primarily alone. Actually, he is the exception that proves the rule—most terrorist acts on America are planned by groups. Consider the scenario that follows for another exception. Note that the incident described in Case Study 13.2 occurred in 1991, before McVeigh, before the first attack on the World Trade Center, before 9/11, and prior to the anthrax attacks.

Case Study 13.2. Revenge Is Mine, Sayeth Daniel[*]

Daniel, tall, lean, mean, and evil, stood on the rail tracks outside the water treatment plant's western fence line, peering through the 8-foot chain-link fence surrounding the plant site at the 55-ton rail tank car inside the plant. His gaze flashed from right to left, left to right, and back to the rail car. He was being careful, watchful, and deliberate. He was well aware of the plant operator's schedule, her hourly rounds; he had worked the same plant, same sampling route, and same job for 5 years before his "unlawful" termination. He had been terminated for several reasons but primarily because he failed to treat processed water with chlorine for disinfection. "Adding poisonous chlorine to good ol' drinking water is a commie plot," he always said.

He thought, "Those frog-faced managers said I was greedy, heartless, predatory, unethical, lazy, buffoonish, dysfunctional, and totally incompetent—a real basket case, one of them said. Well, I will show them."

As the last rays of sunshine struck his back (he did not feel those warming rays; his body was cold, dry, and ready), he glanced down at the cardboard box at his feet. Then, having heard something, he crouched down a bit and peered inside the plant again—nothing stirred, not even his breath, just lengthening shadows. Upright again, he looked down at the box again, filled with 12 bottles of yellow-gold liquid. The sight of the bottles warmed his coldness a bit. As he stood there waiting for the right moment, for the sun to meet the horizon, his long, sharp-looking face almost grimaced into a smile as he thought about those 12 bottles of death at his feet.

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[*] This case study is adapted from Spellman, F.R., *A Guide to Compliance for Process Safety Management/Risk Management Planning (PSM/RMP)*, Technomic, Lancaster, PA, 1997.

Just a week earlier, when he was convinced his master plan would work (failure was not an option), he had fashioned his crude incendiary weapons. The Molotov cocktails (Daniel liked to call them "homemade frag") were carefully put together using tall, glass bottles partly filled with gasoline with a touch of sugar to help the gasoline cling to the target. The mouth of each bottle was stopped up with a cork, and a cloth rag was fixed securely around each mouth.

The target of these cocktails? The 55-ton rail car, fully loaded, of course, with deadly chlorine gas. In Daniel's mind, this was the perfect scenario. He could already foresee that yellow-green mushroom cloud of death crossing the plant site, aided by the wind, which seemed to be freshening as the sun touched the horizon.

Looking all around to ensure he was alone, that no one was near the rail car, no one was behind him, and his path of escape was clear, he pulled the small whiskey flask filled with gasoline and the disposable lighter from his coat pocket. Quickly, he poured gas on each of the 12 bottle wicks and put the closed flask back into his pocket. He picked up the first bottle, lit the rag, looked around, and threw the lighted bottle over the fence toward the railroad car. He missed. The first bottle landed in the tall grass, next to a stack of scrap wood and junk; it just sat there, though he could see the lighted wick in the darkening plant. He lit another wick and threw. He repeated this procedure several times until the box was empty. He took one last glimpse at his work and noticed that two or three of the bottles had actually struck the metal of the tank car, bursting and flaming instantly. His work was done. It was time to haul ass; he did.

Meanwhile …

The last rays of the setting sun touched the running waters of the large river that coursed its way through the downtown region of a large metropolitan area. A plant operator at the 100-mgd water treatment plant, located in the city along the same river bank, was walking the plant site making her rounds. Stopping at a sample point, she pulled a sample, then deposited the sample and its bottle into the carrying tray. Grabbing the tray, she proceeded down the long winding stairway from the #3 rapid sand filter. At the foot of the stairs she stepped onto the gravel path and proceeded toward the final effluent sampling point. She walked along the path and then turned to her right. Straight ahead, just behind the 55-ton chlorine tank car, she noticed an orange glow. Recognizing the orange glow for the brush fire that it was, the operator dropped the sample tray and ran the 250 feet to the plant's main control center to alert the shift lead operator about the brush fire near the chlorine tank car. While she dialed 911, the lead operator activated the site emergency alarm and then used his portable radio to direct a plant assistant operator to meet him at the tank car.

With the plant's emergency alarm siren wailing throughout the plant site and the neighborhood, the lead operator and assistant stood together approximately 100 feet from the chlorine tank car. They could see the brush fire was growing in strength; it was being fed by a brisk wind.

The lead operator wondered what to do next—hell, what to do *first*; his mind was blank for a second, but then a series of thoughts ran through his mind. First, he understood the gravity of the situation: A growing fire was about to engulf 55 tons of chlorine. Second, he realized there was no way he and the assistant operator could move the tank car out of harm's way, although it appeared to him that the tank was already engulfed in flames. Third, he realized the spur line the tank car was positioned on was heavily overgrown with brush (just a few weeks earlier he had directed a former employee, Daniel, to cut the overgrowth and remove the pile of wood near the rail car). As the lead operator and assistant advanced a few yards closer to the tank car, the lead operator noticed another problem. A plant maintenance crew had stacked a pile of wooden cement forms next to the spur line, within a few feet of the tank car; these forms were on the same side of the car where fire was quickly approaching from the end not already aflame. The lead operator knew he would have to act fast to prevent an extremely dangerous situation, the total engulfment of the tank car.

He had to do something.

He did.

The lead operator directed the assistant to go over to the nearest building, the nonpotable water pump house, and bring a fully charged fire hose back to the fire with him, then the lead operator darted off in the opposite direction, toward the chemical handling building, to get another fire hose.

About 5 minutes later both of the operators, manning two fully charged 1.5-inch fire hoses, approached the tank car from the side opposite where the brush fire had already reached the spur and had ignited the wood cement forms; the fire was beginning to grow, to burn with purpose.

Standing to one side the operator directed his fire hose at the midsection of the chlorine tank car body while at the same time the assistant, at the other end of the tank car, began directing a steady stream of nonpotable water in the same general area. The operator could feel the heat from the growing fire.

A few minutes later the entire stack of wood cement forms was burning, generating such intense heat that both operators had to move back a few feet from the car. The tank car emergency relief valve, having reached its design activation pressure, lifted, releasing a controlled stream of deadly chlorine gas to the atmosphere.

Along with the plant alarm siren, the operators could hear the sirens of emergency response vehicles approaching the plant as the tank care emergency relief valve failed completely. A bad situation just got worse. Now, instead of releasing a controlled amount of chlorine gas, the entire contents of the tank car were escaping full force in a steady stream of yellow-green death, all 55 tons.

About six-tenths of a mile away from the water treatment plant, several evening classes at the university were in progress when the emergency relief valve on the 55-ton chlorine tank car failed, The 400 college students heard the emergency alarm siren at the water treatment plant and then the other sirens as emergency vehicles raced by the university campus toward the plant, but they paid them no mind. They had heard these alarms many times before; emergencies in this central city were a common occurrence.

Meanwhile, back at the plant, the operators were now fully engulfed by the chlorine's yellow-green cloud of death; they were about to take their last breaths. In the plant control room, the operator who had discovered the fire and sounded the alarm had been busy. Not only had she notified the authorities about the emergency at the plant but she had also called the plant manager and chief operator and filled them in about the fire.

When she heard the emergency responder's sirens, she ran outside just in time to see the fire department and local hazardous materials (hazmat) team enter the plant site through the front gates. However, because darkness had set in, she did not see the dense yellow-green cloud of chlorine gas that she walked right into. Instantly overcome by the choking chlorine gas, she fell to her knees, coughing and gasping for air. Instead of air, she filled her lungs with deadly chlorine gas; she died 5 minutes later.

The emergency responders were not familiar with the plant site they had entered; they had not been invited to tour the plant to learn the layout of the site; however, from information provided to the 911 operator, the emergency responders did know about the tank car full of chlorine. From knowledge they had gained through their training, they understood the danger involved with chlorine gas and fire. What they did not know, however, was that the fire had already reached the tank car and that the tank car emergency relief valve had already activated and released its entire load of chlorine into the atmosphere.

These firefighters and hazmat responders knew their jobs, though. They had been properly trained in hazardous materials emergency response procedures, so they were cautious as they entered the plant site. They were also alert enough to recognize, with the help of their spotlights, that the yellow-green cloud of death was moving directly toward them. It didn't take long before the fire captain in charge of this emergency situation gave the order for his responders to retreat to safer ground; they did.

Meanwhile, at the university, classes had ended and students poured out of their classrooms. Several students left the building to go home, while others stepped outside for a few minutes to have a smoke before the start of their next class.

At about the same time emergency responders were exiting the plant site to set up a command post in a safe zone (approximately 1.6 miles from the plant), the same brisk wind that had steered the fire toward the tank car and stoked the fire there was pushing the ground-hovering poisonous gas toward the front entrance of the college buildings where students were joking and smoking.

Within a few minutes the chlorine cloud came face-to-face with the college students. Several of the students survived the chlorine gas with only minor respiratory irritation. A few were more seriously affected; they were rushed to a local hospital. An even smaller number of students, those in the parking lot fronting the school, were more profoundly affected; later, three of these students died.

During daylight the next day, after the chlorine had dissipated and no longer was an issue, and for several days after this incident, investigators and other interested viewers had little trouble following the path the deadly chlorine cloud had taken. Its 1.5-mile path was clearly marked by dead grass, flowers, insects, bushes, trees, cats, dogs, raccoons, squirrels, and ducks. After an extensive criminal investigation, Daniel was charged, tried, and fried in the electric chair—obviously, he had forgotten or never had been privy to that old Chinese saying: "He who seeks revenge should dig two graves." Local newspapers reported the incident as "Daniel's Revenge: The Actions of a Deranged Eco-Terrorist." One news source called Daniel's actions "environmental terrorism." Daniel's entire legal process, including execution, was complete one day prior to September 11, 2001.

What Is Terrorism?

If we were to ask 100 different individuals to define terrorism, it might be surprising to many and not to some that we would likely receive 100 different definitions. As a case in point, consider the following: If we were to ask 100 different individuals to describe the actions of Daniel in the railroad tank car incident, how do you think they would they describe him and his actions? You might be surprised. In 2000 and again in 2002, pre- and post-9/11, 100 randomly selected Old Dominion University environmental health juniors and seniors (students ranging in age from 20 to 46 years old) were asked to read about Daniel's chlorine tank car incident and reply to a nonscientific survey questionnaire. The three questions and the students' responses are shown in Table 13.1. From the Old Dominion University survey, it is clear that the students' perceptions of Daniel's actions in the chlorine tank car incident shifted dramatically from pre-9/11 to post-9/11. For example, before 9/11, when asked to select the best descriptor to characterize Daniel, "crazy" and "insane" ranked quite high; however, after 9/11, the students' perceptions shifted away from crazy and insane toward "terrorist." Likewise, "madness" and "workplace violence" ranked high in the students' pre-9/11 descriptions of Daniel's actions; however, his actions post-9/11 overwhelmingly were described as "terrorism."

It is interesting to note that the year 2000 group completed the survey prior to the September/October 2001 anthrax attacks and before the 9/11 events but after such events as the World Trade Center attack of 1993 and Timothy McVeigh's 1995 mass murder of the occupants of the government building in Oklahoma City, Oklahoma. This may help to explain why these students were somewhat reluctant to describe Daniels's actions as terrorism or to label him as a terrorist. After studying this apparent anomaly (in the author's view) for several years, it has become obvious that terrorism, like environmental pollution, is a personal judgment call. Consider, for example, two neighbors living next door to a foul-smelling chemical plant. One of the neighbors works full time at the plant, and the other neighbor works elsewhere. Each morning when the neighbor who does

TABLE 13.1
Student Perceptions of Daniel's Actions

Students' Response Descriptors[a]	Number of Responses Before 9/11 (2000)	After 9/11 (2002)
Question 1: In your opinion, Daniel was …		
Crazy	22	12
A disgruntled former employee	10	2
Insane	32	4
Misguided	1	0
A cold-blooded murderer	3	5
A misfit	1	0
Deranged	6	4
A lunatic	5	6
A bully	17	10
A terrorist	3	57
Not sure	0	0
Totals	100	100
Question 2: In your opinion, Daniel's actions are best described as …		
Madness	45	5
Frustration	9	2
Desperation	4	0
Dysfunctional thinking	2	0
Legitimate concern	1	0
Threatening	6	1
Terrorism	5	79
Workplace violence	20	0
Not sure	8	13
Totals	100	100
Question 3: If you described Daniel's actions as terrorism, are they best described as generic terrorism, ecoterrorism, or environmental terrorism?		
Generic terrorism		29
Ecoterrorism		10
Environmental terrorism		40

[a] Student response descriptors were provided to the students by the instructor.

not work at the plant steps outside his house to go to work, he has learned to hold his nose against the horrendous odor emanating from the plant site. There is absolutely no doubt in his mind that he lives next door to a pollution source. On the other hand, when the other neighbor, the full-time employee of the plant, steps outside his home to go to the plant to work his shift he smells the same odor his neighbor does but he does not smell pollution; instead, he detects the sweet smell of money in the bank and job security. Thus, terrorism, like pollution, may be a judgment call. That is, unless you happen to be a victim of terrorism.

Terrorism by Any Other Name Is …

From the preceding discussion we might want to sum up terrorism as being relative, a personal judgment. But is it? What is terrorism, really? Take your choice. Seemingly, there is an endless list of definitions. Let's review a few of these definitions.

Standard Dictionary Definition of Terrorism

After reviewing several dictionaries, a fairly standard definition of terrorism is "the unlawful use or threatened use of force or violence by a person or an organized group against people or property with the intention of intimidating or coercing societies or governments, often for ideological or political reasons." The *National Strategy for Homeland Security* (OHS, 2006) defines terrorism as "any premeditated, unlawful act dangerous to human life or public welfare that is intended to intimidate or coerce civilian populations or governments." The U.S. State Department defines terrorism as "premeditated, politically motivated violence perpetrated against noncombatant targets by subnational groups or clandestine agents" (22 USC §2656f(d)). The Federal Bureau of Investigation defines terrorism as "the unlawful use of force or violence against persons or property to intimidate or coerce a Government, the civilian population, or any segment thereof, in furtherance of political or social objectives" (FBI, 2001). Note that the FBI divides terrorism into two categories: (1) *domestic* (homegrown), involving groups operating in and targeting the United States without foreign direction, and (2) *international*, involving groups that operate across international borders or have foreign connections.

Well, at this point, the obvious question is do you now know what terrorism it? That is, can you definitely define it? If you can't, you are not alone—not even the U.S. government can definitively define it. Maybe we need to look at other sources—views from the real experts on terrorism.

Here, for example, is Osama bin Laden's view on terrorism: "Wherever we look, we find the U.S. as the leader of terrorism and crime in the world. The U.S. does not consider it a terrorist act to throw atomic bombs at nations thousands of miles away [Japan during World War II], when those bombs would hit more than just military targets. Those bombs rather were thrown at entire nations, including women, children, and elderly people" (Bergen, 2002).

Another view on terrorism comes from Ramzi Ahmed Yousef, who helped organize the first terrorist attack on the World Trade Center, in a statement made at his sentencing hearing:

> You keep talking also about collective punishment and killing innocent people to force governments to change their policies; you call this terrorism when someone would kill innocent people or civilians in order to force the government to change its policies. Well, when you were the first one who invented this. …
>
> You were the first one who killed innocent people, and you are the first one who introduced this type of terrorism to the history of mankind when you dropped an atomic bomb which killed tens of thousands of women and children in Japan and when you killed over a hundred thousand people, most of them civilians, in Tokyo with fire bombings.
>
> You killed them by burning them to death. And you killed civilians in Vietnam with chemicals as with the so-called Orange agent. You killed civilians and innocent people, not soldiers, innocent people every single war you went. You went to wars more than any other country in this century, and then you have the nerve to talk about killing innocent people.
>
> And now you have invented new ways to kill innocent people. You have so-called economic embargo which kills nobody other than children and elderly people, and which other than Iraq you have been placing the economic embargo on Cuba and other countries for over 35 years. …
>
> The government in its summations and opening said that I was a terrorist. Yes, I am a terrorist and I am proud of it. And I support terrorism so long as it was against the United States Government and Israel, because you are more than terrorists; you are the one who invented terrorism and using it every day. You are butchers, liars and hypocrites.

An Old Cliché on a Terrorist

> One man's terrorist is another man's freedom fighter.

In Question 3 of the Old Dominion University survey (see Table 13.1), students who characterized Daniel's actions as terrorism were asked to select the type of terrorism: generic terrorism, ecoterrorism, or environmental terrorism. As shown in Table 13.1, the 79 students' selections varied. What the table does not show is why the students made the choices they did. In this regard, when asked specifically why they answered as they did none of them gave specific answers. Indeed, some of the students said they made their selections based on what they perceived to be the best selection, the best descriptor. None of the students queried was able to definitively distinguish between the three descriptor terms used.

So, what is the difference between the terms *terrorism*, *environmental terrorism*, and *ecoterrorism*? To this point, we have already defined terrorism in several different ways. To define environmental terrorism, we turn to Chalecki's (2001) definition: "The unlawful use of force against *in situ* environmental resources so as to deprive populations of the benefit(s) and/or destroy other property." In contrast, ecoterrorism is the violent destruction of property in the interest of saving the environment from human encroachment and destruction. More concisely, environmental terror involves targeting natural resources. Ecoterrorism involves targeting the build environment such as roads, buildings, and trucks, ostensibly in defense of nature resources.

Again, from the preceding points of view, it can be seen that defining terrorism or the terrorist is not straightforward and never easy. Even the standard dictionary definition leaves us with the vagaries and ambiguities of other words typically associated with terrorism such as in the definitions of *unlawful* and *public welfare* (Sauter and Carafano, 2005).

At this point, the reader may wonder, "Why should we care? What difference does it make how we define a terrorist or terrorism?" Definitions are important because, in order to prepare for the terrorism contingency, domestic or international, we must have some feel, as with any other problem, for what it is we are dealing with. We are fighting a war of ideas. We must attempt to understand both sides of the argument, even though the terrorist's side makes no sense to an American or other freedom-loving occupant of the globe.

Finally, although it is difficult to pinpoint an exact definition of terrorism, we certainly have little difficulty in identifying it when we see it, feel it, or suffer from it. Consider, for example, the earlier account of Daniel's actions and the chlorine disaster. Put yourself in the place of those college students who were simply leaving campus buildings to cross the parking lot to their cars to make the journey home. In particular, put yourself in the place of one of those female students who was pregnant and who, as she approached her parked car, looked up and saw that yellow-green cloud of death racing with the wind toward her, eventually surrounding her, and then killing her. She could not have known that an American terrorist had caused the act of terrorism on U.S. soil that killed her. No, she did not know that. There is one thing she knew for certain; she knew that crushing feeling of terror as she struggled to breathe. Thus, by any other name terrorism is best summed up as an absolute feeling of *Terror*—nothing judgmental about that—just Terror with a capital T.

HAZARDOUS SUBSTANCES

> The most alarming of all man's assaults upon the environment is the contamination of air, earth, rivers, and sea with dangerous and even lethal materials. This pollution is for the most part irrecoverable; the chain of evil it initiates not only in the world that must support life but in living tissues is for the most part irreversible. In this now universal contamination of the environment, chemicals are the sinister, and little-recognized partners of radiation in changing the very nature of the world—the very nature of life.
>
> **Carson (1962)**

Rachel Carson was able to combine the insight and sensitivity of a poet with the realism and observations of science more adeptly than anyone before her. Famous for her classic and highly influential book *Silent Spring*, it seems strange to us today that such a visionary as Carson was (after the publication of her *magnum opus*) ostracized, vilified, laughed at, lambasted, accused of having a bell-jar view of reality, and disregarded. To those guilty of the sins that she revealed, Carson was an enemy to be discredited—and silenced. She was not, however, disregarded by those who understood. To these concerned folks with a conscience, her message was clear: waste, if not properly treated and handled, threatens not only human life in the short term but also the environment as a whole in the long term. Her plea was also clear: Stop poisoning the Earth.

Examined with the clear vision of retrospect, the environmental missionary Rachel Carson was well ahead of her time. The fears she expressed in 1962 were based on limited data but have since been confirmed. Rachel Carson was right. In this section, the hazards of hazardous substances (some of which drew Rachel Carson to pen and paper) are discussed. The nature of the substance, the problem, and the possible consequences are illustrated.

AMERICA: A THROWAWAY SOCIETY

Earlier in the text, a small portrait of American society was displayed. This portrait underscores a characteristic that might be described as habit, trend, custom, or practice—the tendency we have to discard those objects we no longer want. We simply throw them away—so much so and so often that we even call ourselves a "throwaway society." When something is no longer of value because it is broken, worn out, out of style, or no longer needed for whatever reason, we think discarding it should not be a big issue. But it is—particularly when the item we throw away is a hazardous substance—persistent, nonbiodegradable, and poisonous. What is the magnitude of the problem with hazardous substance or waste disposal? Let's take a look at a few facts:

- Hazardous substances, including industrial chemicals, toxic waste, pesticides, and nuclear waste, are entering the marketplace, the workplace, and the environment in unprecedented quantities.
- The United States produces almost 300 million metric tons of hazardous waste each year, or about one ton for every person in the country.
- Through pollution of air, soil, and water supplies, hazardous wastes pose both short- and long-term threats to human health and environmental quality.

WHAT IS A HAZARDOUS SUBSTANCE?

Hazardous wastes can be informally defined as a subset of all solid and liquid wastes that are disposed of on land rather than being shunted directly into the air or water and which have the potential to adversely affect human health and the environment. We have the tendency to think of hazardous wastes as resulting mainly from industrial activities, but households also play a role in the generation and improper disposal of substances that might be considered hazardous wastes. Hazardous wastes, via Bhopal and other disastrous episodes, have been given much attention, but surprisingly little is known of their nature and the actual scope of the problem.

Unfortunately, defining a *hazardous substance* is largely a matter of "pick and choose," with various regulatory agencies and pieces of environmental legislation defining that term and related terms somewhat differently. Many of the terms are used interchangeably. Even experienced professionals in environmental health and safety fields, such as certified hazardous materials managers, sometimes interchange and interrelate these terms, although the terms are generated by different federal agencies and different pieces of legislation and have somewhat different meanings, depending on the nature of the problem addressed. To understand the scope of the dilemma we face in defining hazardous substance, let's take a look at the terms commonly used today, used interchangeably, and often thought to mean the same thing.

A *hazardous material* is a substance (gas, liquid, or solid) capable of causing harm to people, property, and the environment. The U.S. Department of Transportation (DOT) uses the term *hazardous materials* to cover nine categories identified by the United Nations Hazard Class Number System:

1. Explosives
2. Gases (compressed, liquefied, dissolved)
3. Flammable liquids

4. Flammable solids
5. Oxidizers
6. Poisonous materials
7. Radioactive materials
8. Corrosive materials
9. Miscellaneous materials

Hazardous substances is a term used by the USEPA for chemicals that, if released into the environment above a certain amount, must be reported and, depending on the threat to the environment, for which federal involvement in handling the incident can be authorized. The USEPA lists hazardous substances in 40 CFR Part 302, Table 302.4. The Occupational Safety and Health Administration (OSHA) uses the term *hazardous substance* in 29 CFR 1910.120 (which resulted from Title I of the Superfund Amendments and Reauthorization Act and covers *emergency response*) differently than does the USEPA. Hazardous substances as defined by OSHA include every chemical regulated by both the DOT and the USEPA.

Extremely hazardous substances is a term used by the USEPA for chemicals that must be reported to the appropriate authorities if released above the *threshold reportable quantity* (RQ). The list of extremely hazardous substances is identified in Title III of SARA of 1986 (40 CFR Part 355). Each substance has a threshold reporting quantity.

Toxic chemicals is a termed used by the USEPA for chemicals whose total emissions or releases must be reported annually by owners and operators of certain facilities that manufacture, process, or otherwise use listed toxic chemicals. The list of toxic chemicals is identified in Title III of SARA.

Hazardous chemicals is a term used by OSHA to denote any chemical that poses a risk to employees if they are exposed to it in the workplace. Hazardous chemicals include a broader group of chemicals than the other chemical lists.

To form the strongest foundation for understanding hazardous waste and because the Resource Conservation and Recovery Act (RCRA) definition for a hazardous substance can also be used to describe a hazardous waste, we use the RCRA definition. RCRA defines something as a hazardous substance if it possesses any of the following four characteristics: *reactivity*, *ignitability*, *corrosiveness*, or *toxicity*:

- *Ignitability* refers to the characteristic of being able to sustain combustion and includes the category of flammability (ability to start fires when heated to temperatures less than 140°F or less than 60°C).
- *Corrosive* substances (or wastes) may destroy containers, contaminate soils and groundwater, or react with other materials to cause toxic gas emissions. Corrosive materials pose a specific hazard to human tissue and aquatic life where the pH levels are extreme.
- *Reactive* substances may be unstable or have a tendency to react, explode, or generate pressure during handling. Pressure-sensitive or water-reactive materials are included in this category.
- *Toxicity* is a function of the effect of hazardous materials (or wastes) that may come into contact with water or air and be leached into the groundwater or dispersed in the environment.

Toxic effects that may occur to humans, fish, or wildlife are the principal concerns here. Toxicity, until 1990, was tested using a standardized laboratory test called the *extraction procedure*, or EP toxicity test. The EP toxicity test was replaced in 1990 by the *toxicity characteristics leaching procedure* (TCLP), because the EP toxicity test failed to adequately simulate the flow of toxic contaminants to drinking water. The TCLP is designed to identify wastes likely to leach hazardous concentrations of particular toxic constituents into the surrounding soils or groundwater as a result of improper management. The TCLP extracts constituents from the tested waste in a manner designed

TABLE 13.2
Maximum Concentrations of Contaminants for TCLP Toxicity Test

Contaminant	Regulatory Level (mg/L)	Contaminant	Regulatory Level (mg/L)
Arsenic	5.0	Lead	5.0
Barium	100.0	Lindane	0.4
Benzene	0.5	Mercury	0.2
Cadmium	1.0	Methoxychlor	10.0
Carbon tetrachloride	0.5	Methyl ethyl ketone	200.0
Chlordane	0.03	Nitrobenzene	2.0
Chlorobenzene	100.0	Pentachlorophenol	100.0
Chloroform	6.0	Pyridine	5.0
Chromium	5.0	Selenium	1.0
Cresol	200.0	Silver	5.0
2,4-Dichlorobenzene	10.0	Tetrachloroethylene	0.7
1,4-Dichlorobenzene	7.5	Toxaphene	0.5
1,5-Dichloroethane	0.5	Trichloroethylene	0.5
2.4-Dinitrololuene	0.13	2,4,5-Trichlorophenol	400.0
Endrin	0.02	2,4,6-Trichlorophenol	2.0
Heptachlor	0.008	2.4,5-TP (Silvex)	1.0
Hexachlorobenzene	0.13	Vinyl chloride	0.2
Hexachloroethane	3.0		

Source: USEPA, 40 CFR 261.24, Toxicity characteristic, U.S. Environmental Protection Agency, Washington, DC, 1990.

to simulate leaching actions that occur in landfills. The extract is then analyzed to determine if it possesses any of the toxic constituents listed in Table 13.2. If the concentrations of the toxic constituents exceed the levels listed in the table, the waste is classified as *hazardous*.

HAZARDOUS WASTES

The U.S. Environmental Protection Agency uses the term *hazardous wastes* for chemicals regulated under the Resource Conservation and Recovery Act (40 CFR 261.33). Hazardous wastes in transportation are regulated by the DOT (49 CFR 170–179). For the purposes of this text, we define a hazardous waste as any hazardous substance that has been spilled or released to the environment. For example, chlorine gas is a *hazardous material*; when chlorine is released to the environment, it becomes a *hazardous waste*. Similarly, when asbestos is in place and undisturbed, it is a hazardous material; when it is broken, breached, or thrown away, it becomes a hazardous waste.

What Is a Hazardous Waste?

Recall our general rule of thumb that states that any hazardous substance spilled or released to the environment is no longer classified as a hazardous substance but as a hazardous waste. The USEPA uses the same definition for hazardous waste as it does for hazardous substance. The four characteristics described in the previous section (reactivity, ignitability, corrosivity, or toxicity) can be used to identify hazardous wastes as well as hazardous substances.

The USEPA lists substances that it considers hazardous wastes. These lists take precedence over any other method used to identify and classify substances as hazardous (i.e., if a substance is listed in one of USEPA's lists described below, legally it is a hazardous substance, no matter what). USEPA-listed hazardous wastes are organized into three categories: *nonspecific source wastes*, *specific source wastes*, and *commercial chemical products*; all listed wastes are presumed hazardous regardless of their concentrations. The USEPA developed these lists by examining different types of wastes and chemical products to determine whether they met any of the following criteria:

- Exhibit one or more of the four characterizations of a hazardous waste
- Meet the statutory definition of hazardous waste
- Are acutely toxic or acutely hazardous
- Are otherwise toxic

The three categories of waste are summarized briefly below:

- *Nonspecific source wastes* are generic wastes commonly produced by manufacturing and industrial processes. Examples from this list include spent halogenated solvents used in degreasing and wastewater treatment sludge from electroplating processes, as well as dioxin wastes, most of which are considered "acutely hazardous" wastes because of the danger they present to human health and the environment.
- *Specific source wastes* are wastes from specially identified industries such as wood preserving, petroleum refining, and organic chemical manufacturing. These wastes typically include sludges, still bottoms, wastewaters, spent catalysts, and residues—for example, wastewater treatment sludge from pigment production.
- *Commercial chemical products* (also called "P" or "U" list wastes because their code numbers begin with these letters) are wastes from specific commercial chemical products, or manufacturing chemical intermediates. They include chemicals such as chloroform and creosote, acids such as sulfuric and hydrochloric, and pesticides such as DDT and kepone (40 CFR 261.31–33).

Note that the USEPA ruled that any waste mixture containing a listed hazardous waste is also considered a hazardous waste—and must be managed accordingly. This applies regardless of what percentage of the waste mixture is composed of listed hazardous wastes. Wastes derived from hazardous wastes (residues from the treatment, storage, and disposal of a listed hazardous waste) are considered hazardous waste, as well (40 CFR 261.31). Hazardous wastes are derived from several waste generators. Most of these waste generators are in the manufacturing and industrial sectors and include chemical manufacturers, the printing industry, vehicle maintenance shops, leather products manufacturers, the construction industry, metal manufacturing, and others. These industrial waste generators produce a wide variety of wastes, including strong acids and bases, spent solvents, heavy-metal solutions, ignitable wastes, cyanide wastes, and many more.

From the pollution scientist's perspective, any hazardous waste release that could alter the environment in any way is of major concern. The specifics of their concern lie in acute and chronic toxicity to organisms, bioconcentration, biomagnification, genetic change potential, etiology, pathways, change in climate and/or habitat, extinction, persistence, and esthetics (visual impact).

Remember that when a hazardous substance or hazardous material is spilled or released into the environment it becomes a hazardous waste. Because specific regulatory legislation is in place regarding hazardous wastes, responding to hazardous waste leak and spill contingencies, and the proper handling, storage, transportation, and treatment of hazardous wastes, this distinction is important—the goal being, of course, protecting the environment and ultimately, protecting ourselves.

HAZARDOUS WASTE LEGISLATION

A few people (Rachel Carson for one) could have predicted that a disaster on the scale of Bhopal was ripe to occur—but humans are strange in many ways. We may know that a disaster is possible, is likely, could happen, is predictable. We predict it—but do we act? Do we act before someone dies?

No. Not often. Not often enough. We don't think about the human element. We forget the innocents of the world—that is, until they're gone, after they suffer, after they die, after we can no longer help them. We know that life is not always fair, but ideally we strive to make it more so. So, what can we do? We legislate, of course. Because of Bhopal and other similar, but less catastrophic chemical spill events, the U.S. Congress (pushed by public concern) developed and passed certain environmental laws and regulations to regulate hazardous substances and wastes in the United States. This section focuses on the two regulatory acts most crucial to the current management programs for hazardous wastes. The first, mentioned earlier, is the *Resource Conservation and Recovery Act* (RCRA). Specifically, RCRA provides guidelines for prudent management of new and future hazardous substances and wastes. The second act (more briefly mentioned) is the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA), otherwise known as *Superfund*, which deals primarily with mistakes of the past: inactive and abandoned hazardous waste sites.

Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) is the United State's single most important law dealing with the management of hazardous waste. RCRA and its amendment, *Hazardous and Solid Waste Amendments* (HSWA-1984), deal with the ongoing management of solid wastes throughout the country—with emphasis on hazardous waste. Keyed to the waste side of hazardous materials, rather than broader issues dealt with in other acts, RCRA is primarily concerned with land disposal of hazardous wastes. The goal is to protect groundwater supplies by creating a "cradle-to-grave" management system with three key elements: a tracking system, a permitting system, and control of disposal (Masters, 1991):

1. *Tracking system*, a manifest document accompanying any waste that is transported from one location to another
2. *Permitting system*, which helps ensure safe operation of facilities that treat, store, or dispose of hazardous wastes
3. *Disposal control system*, comprised of controls and restrictions governing the disposal of hazardous wastes onto, or into, the land

The RCRA regulates five specific areas for the management of hazardous waste, with a focus on treatment, storage, and disposal (Griffin, 1989):

1. Identifying what constitutes a hazardous waste and classifying each
2. Publishing requirements for generators to identify themselves, which includes notification of hazardous waste activities and standards of operation for generators
3. Adopting standards for transporters of hazardous wastes
4. Adopting standards for treatment, storage, and disposal facilities
5. Providing for enforcement of standards through a permitting program and legal penalties for noncompliance

Arguably, RCRA is our single most important law dealing with the management of hazardous waste—it certainly is the most comprehensive piece of legislation that the USEPA has promulgated to date.

CERCLA

The mission of the Comprehensive Environmental Response, Compensation, and Liabilities Act of 1980 is to clean up hazardous waste disposal mistakes of the past and to cope with emergencies of the present. It is often referred to as the Superfund law. As a result of its key provisions, a large trust fund (about $1.6 billion) was created; later, in 1986, when the law was revised, this fund was increased to almost $9 billion. The revised law is known as the Superfund Amendments and Reauthorization Act of 1986 (SARA). Key elements of CERCLA include the following:

1. CERCLA authorizes the USEPA to deal with both short-term (emergency situations triggered by a spill or release of hazardous substances) as well as long-term problems involving abandoned or uncontrolled hazardous waste sites for which more permanent solutions are required.
2. CERCLA set up a remedial scheme for analyzing the impact of contamination on sites under a hazard ranking system. From this hazard ranking system, a list of prioritized disposal and contaminated sites is compiled; this list is the National Priorities List (NPL). The NPL identifies the worst sites in the nation, based on such factors as the quantities and toxicity of wastes involved, the exposure pathways, the number of people potentially exposed, and the importance and vulnerability of the underlying groundwater.
3. CERCLA forces those parties who are responsible for hazardous waste problems to pay the entire cost of cleanup.
4. Title III of SARA requires federal, state, and local governments and industry to work together in developing emergency response plans and reporting on hazardous chemicals. This requirement is commonly known as the Community Right-to-Know Act, and it allows the public to obtain information about the presence of hazardous chemicals in their communities and releases of these chemicals into the environment.

THE BOTTOM LINE

Many human activities adversely affect our soil. Some anthropogenic activities are deliberate, some unintentional; others are unexpected and unwanted byproducts of necessary activities. All have an impact on soil. Advancements in technology have made our lives more comfortable, safer, healthier, and in many cases more enjoyable. Some would say that progress is not without cost. This statement is correct—but what costs do they refer to? Can we afford the consequences if these costs include more Bhopals, Times Beaches, Love Canals, or another *Exxon Valdez*? If such disasters are "to be included as a cost of progress," then we must say that the cost outweighs the gain. What we must do to ensure a balance between technological progress and its environmental results is to use technological advances to ensure that "progress" is not too costly—or life threatening—to both our environment and to ourselves. How we can remediate the adverse changes we cause in soil is the focus of the next chapter. Moreover, the next chapter discusses the technologies currently available for handling and disposing of hazardous wastes in ways that ensure we "progress" safely.

DISCUSSION QUESTIONS

1. Discuss transport mechanisms and how they affect flow regime. What other elements affect the movement of pollutants through soil?
2. What are the most common origins of soil pollution? Why?
3. How does air pollution contaminate soil?
4. What special pollution problems are caused by stockpiling and mining?
5. Discuss the problems associated with underground storage tanks. Include both old and new USTs.
6. Industry has created special problems of soil pollution. What are the most serious, and why?
7. Discuss the problems associated with acid rock drainage and acid mine drainage.
8. In your own words, write a definition for each of the key terms that are listed in this chapter. Compare your definitions with those in the text and glossary.
9. In what way is hazardous waste a social problem?
10. What is a hazardous waste? Explain.
11. Explain the term "throwaway society." Does it apply to your hometown?
12. Differentiate between hazardous waste, hazardous substance, and toxic chemical.
13. To be a hazardous waste, does a substance have to be listed by the USEPA first? Explain.

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14 Soil Pollution Remediation

> The response to subsurface contamination in the United States, as in many other countries, has been a massive effort to define the extent of contamination and to remediate the subsurface—starting with the most contaminated sites. This environmental campaign has been driven by governmental regulations dealing with waste handling and disposal, as well as with many other potentially contaminating activities. One side effect of this endeavor has been a boom in the employment market for engineers and environmental scientists that specialize in detection, monitoring, and remediation of subsurface contamination. A new industry has been created and the performance of this work seems sure to continue well into the twenty-first century.
>
> **Kehew (1995)**

> How to handle society's toxic chemical waste now ranks among the top environmental issues in most industrial countries. Without concerted efforts to reduce, recycle, and reuse more industrial waste, the quantities produced will overwhelm even the best treatment and disposal systems.
>
> **Postel (1987)**

> That happiness is to be attained through limitless material acquisition is denied by every religion and philosophy known to humankind, but is preached incessantly by every American television set.
>
> **Bellah (1975)**

INTRODUCTION

Problems are associated with soil or subsurface remediation; available soil remediation technologies, although often very effective, are not the perfect solutions to the problem of soil pollution. The first problem concerns the fact that soil pollution remediation practices are a still developing branch of environmental science and engineering—lessons are still being learned. Another, more obvious problem has to do with timing and expediency. Soil pollution remediation is the very last procedure in the sequence of combating soil pollution, because action is taken only when we realize the problem exists—after the spill or release of pollutants into the soil. In water and air pollution, we can often limit or prevent pollution damage from occurring at all by collecting the pollutant at the source before it enters the media. In soil pollution, often not only has the damage been done but it is also years old and presents even more challenges to our ability to remediate the contamination.

That the damage is done is our next problem in a nutshell. We are often faced with having no exact knowledge that a pollutant spill exists in the first place. Underground storage tanks (USTs), for example, are not visible and give us no early (or even later) indication of leakage; we have no way of knowing that an older UST is spilling its contents into the subsurface. This is one reason why regulations have been changed so that monitoring equipment must be installed on all new UST installations to enable us to detect such leaks. But, what about the several hundred thousand USTs that were installed without monitoring or leak detection equipment? Many of the USTs installed in the 1950s are no longer in service. They have been abandoned. We do not even know their locations or what they contain, or if they still contain anything at all.

Another problem with current soil pollution remediation technologies is that in some cases we must rework the landscape to institute remediation. The obvious problem with this is erosion. In many places, erosion has stabilized in a particular area, and the last thing the local landscape needs is to have its stability or equilibrium disturbed by soil pollution remediation techniques, resulting in new episodes of erosion and compounding the pollution problem.

Enough time has passed and enough soil pollution remediation has been practiced to indicate that remediation practices can be very time consuming and expensive and often yield less than satisfactory results. Some rehabilitation practices implemented proved to be meaningless because the practice performed was unsuited to the type of pollutant and morphology of the soil; they were expensive and wasteful.

Despite such a gloomy picture of soil pollution remediation, many of the practices have also indicated positive results. Remediation of a pollutant within a medium as complex as soil (the subsurface) is no easy undertaking; there is no guarantee of positive results for all cases. Consider Case Study 14.1.

Case Study 14.1. Remediation as a Growth Industry?

Because of the regulatory programs of the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), better known as Superfund, and the 1976 Resource Conservation and Recovery Act (RCRA), better known as the Cradle-to-Grave Act, remediation is an accepted entry in the environmental vocabulary. The growth potential of this new field attracted the attention of venture capitalists, who attempted to gain a foothold in this developing technological field (MacDonald (1997):

> In the early 1990s, venture capitalists began to flock to the market for groundwater and soil cleanup technologies, seeing it as offering significant new profit potential. The market appeared large; not only was $9 billion per year being spent on contaminated site cleanup, but existing technologies were incapable of remediating many serious contamination problems.

From these comments, soil remediation technology would appear to be a booming industry with unlimited potential, a virtually without a doubt, can't-miss proposition. But, because inherent problems limit its potential, remediation technology is a double-edged sword.

Numerous remediation technologies (also commonly known as *innovative cleanup technologies*) have been developed and become commercially available since CERCLA and RCRA were put into place. We briefly discuss these technologies in this chapter, especially those designed and intended to clean up sources of subsurface contamination caused by underground storage tanks (USTs) and contaminated waste sites. Green remediation objectives and strategies are also discussed. Although USTs and their contributions to soil pollution were discussed briefly in the preceding chapter, it is important to also discuss remediation procedures and technology for failed USTs because these units have been the primary cause of most of the contamination events and have led to the greatest remediation efforts. Regulators and private industries involved with their cleanup have produced enormous volumes of information on this remediation practice, and the techniques used for UST remediation are transferable to other types of soil pollution problems. The goals of regulatory agencies monitoring UST cleanup efforts are generally going to include removing every molecule of contamination (no matter what the contaminant) and restoring the landscape to its natural condition, but doing so is highly unlikely and beyond logical and practical reason.

USTS: THE PROBLEM

The biggest problem associated with USTs is that no one knows the exact number of UST systems installed in the United States. Current estimates range in the millions. Not being able to find the tanks for which we have no records (especially those where the locations have changed use) is a

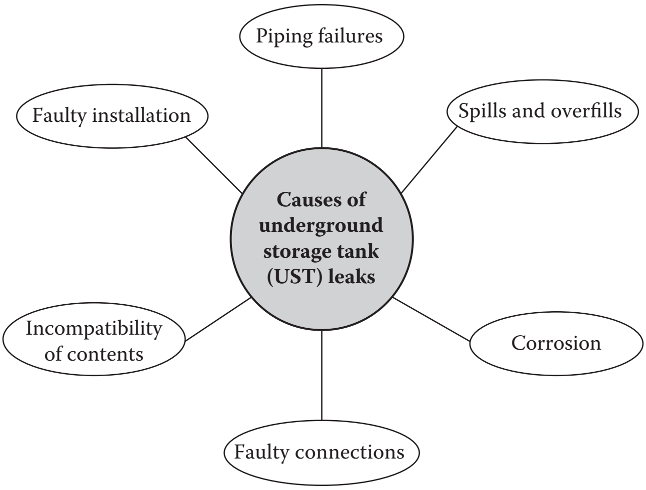

FIGURE 14.1 Causes of UST leaks.

problem that allows an unknown number of old, unlined tanks to literally disintegrate undetected. We know thousands of these tanks must exist and their probable condition, but we do not know where they are. We are aware, however, of thousands of tanks that are currently leaking, including ancillaries such as piping. USTs leak for several reasons (see Figure 14.1).

Corrosion Problems

Corrosion is the most common cause of tank failure. Most older tanks are single-shell construction, made of unprotected bare steel. Many leaked in the past (and have been removed, we hope), are leaking at present, or will certainly leak in the future if they are not removed or rehabilitated. Even a small leak, if undetected or ignored, causes large amounts of petroleum product to enter the subsurface. Most unknown USTs are this type.

Faulty Construction

Any material item is only as good as its construction, workmanship, and materials. USTs are no different. Poor construction and workmanship will cause failure, although the results of such failure are not simple. Proper monitoring equipment can at least indicate that leakage is occurring. Older tanks with no monitoring equipment could be emitting small quantities from a minor leak, undetected, over the course of years.

Faulty Installation

Without careful handling of the tank itself and any appurtenances during installation, failure can result. Tank beds must be specially prepared to receive the tank for burial, and adequate backfilling ensures that no possible movement of the tank can occur after it is placed in the ground. Underground movement for whatever reason can damage the tank, especially fiberglass reinforced plastic (FRP) tanks, and can jar loose pipe connections or cause pipe joints to separate. Failure to use special care in this installation process results in leaks. Underground leak detection devices must also be carefully and correctly installed. Quick discovery of a leaking tank is best so remediation can be initiated quickly, before a minor spill turns into a major environmental contamination incident.

PIPING FAILURES

Piping failure is one of the most common causes of larger UST spills. Metal piping used to connect tanks or to connect tanks to delivery pumps, or for whatever reason, presents the danger of corrosion from rust or from electrolytic action. Threaded pipes (or other metal parts made electrically active by threading) have a strong tendency to corrode if not properly coated or otherwise protected against electrolytic action. Usually *cathodic protection* is installed to negate electrolytic action. Another common cause of piping failures is poor workmanship. Improperly fitted piping joints (both threaded and PVC types), incomplete tightening of joints, construction accidents, and improper installation of cover pads are frequent problems.

SPILLS AND OVERFILLS

Any UST facility can be the site of environmental pollution as the result of spills and overfills, usually caused by human error. The U.S. Environmental Protection Agency (USEPA) has promulgated tank filling procedures in its 40 CFR 280 regulations and the National Fire Protection Association (NFPA) has issued tank filling guidelines (NFPA-385), but spills from overfilling still occur frequently. UST overfilling is bad enough in itself, but environmental contamination problems are compounded by repeated spills or unreported spills. Petroleum products or hazardous wastes can literally saturate the spill area, intensifying soil corrosiveness (Blackman, 2001).

COMPATIBILITY OF CONTENTS AND UNDERGROUND STORAGE TANK

Placing highly corrosive materials into containers not rated to contain them is asking for trouble. New chemicals (including fuels) are constantly under development and entering the marketplace. Developing such fuels is usually meant to achieve improved air quality, but improving air quality at the expense of water and soil makes no sense. Many USTs currently in use are FRP tanks, installed to replace unprotected, bare steel tanks. FRPs are rated or modified by using a different liner to safely store the fuel products now commonly used. When a new, exotic blend of fuel is developed and placed in a FRP-type tank that proves incompatible, problems occur. Incompatibility problems include blistering, internal stress, cracking, and underfilm corrosion. The American Petroleum Institute put together a standard to help prevent FRP-constructed or -lined tank problems. The standard should be referred to when existing tanks are used for nonstandard fuel products.

UST RISK ASSESSMENT

Hydrocarbon spillage or disposal problems are complex. The risk assessment process can help reduce the complexity of the problem and allow scientists, regulatory officials, and industrial managers to evaluate the public health risks associated with the hydrocarbon releases (or any other toxic chemical release) to soil and groundwater. The risk assessment process (Figure 14.2) consists of four steps (Blackman, 2001; Ehrhardt et al., 1986; ICAIR, 1985):

1. *Toxicological evaluation* (hazard identification)—This step should answer the question, "Does the chemical have an adverse effect?" The factors to consider during the toxicological evaluation for each contaminant include routes of exposure (ingestion, absorption, and inhalation), types of effects, reliability of data, dose, mixture effects, and the strength of evidence supporting the conclusions of the toxicological evaluation.
2. *Dose–response evaluation*—When a chemical has been toxicologically evaluated and the result indicates that the chemical is likely to cause adverse effects, determining the potency of the chemical is the next step. The dose–response curve describes the relationship between degree of exposure to a chemical (dose) and the magnitude of the effect (response) in the exposed organism.

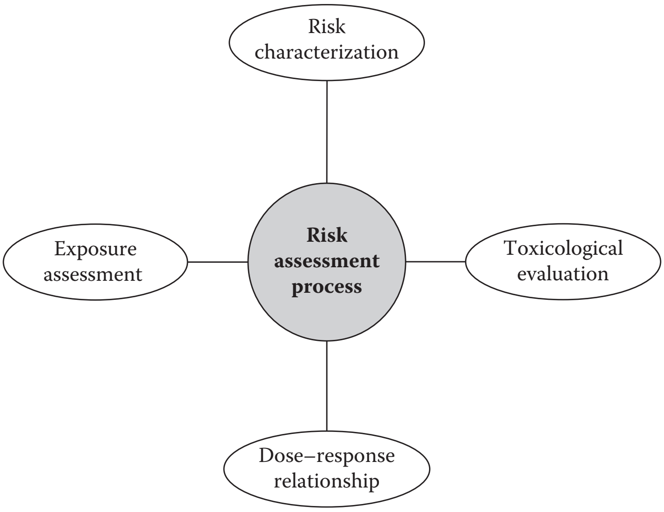

FIGURE 14.2 Risk assessment elements.

3. *Exposure assessment*—Estimates are made of the actual or potential human exposure magnitude, the exposure frequency and duration, and the potential exposure pathways.
4. *Risk characterization*—Adverse health effects are estimated under the conditions of exposure found and described in the exposure assessment.

UST EXPOSURE PATHWAYS

Determining exposure pathways resulting from the performance of the remediation option chosen to mitigate a particular UST leak or spill is as important as assessing the risk and evaluating the findings. Exposure pathways that may be encountered during site excavation, installation, operations, maintenance, and monitoring fall into two categories: (1) direct human exposure pathways, and (2) environmental exposure pathways. These two categories are further divided into primary and secondary exposure pathways. Primary exposure pathways directly affect site operations and personnel (e.g., skin contact during soil sampling) or directly affect cleanup levels to be achieved by remediation technology. For example, when soil impact is the chief issue at a site, soil impact sets the cleanup level and corresponding time frame when cleanup stops. Secondary exposure pathways occur during site operations and exhibit significant decreases with time as treatment progresses (e.g., wind-blown dust) (EPRI-EEI, 1988).

REMEDIATION OF UST-CONTAMINATED SOILS

Preliminary steps must be taken before petroleum-contaminated soil remediation is possible. Soil sampling confirms that a tank is actually leaking and determines the extent of contamination. Upon leak discovery, any petroleum product remaining in the UST should be pumped out into holding tanks or containers because of the potential damage to the tank (and further spillage) during removal. The tank area then is excavated and the tank removed. After sampling and tank removal, what type of remediation technology to employ in the actual cleanup effort must be determined.

Various organizations, environmental industries, and regulatory agencies perform technical investigations and evaluations of the various aspects of remediation methods for petroleum hydrocarbons in soil, fate and behavior of petroleum hydrocarbons in soil, and economic analyses. The electric utility industry is at the forefront of conducting such studies, because it owns and

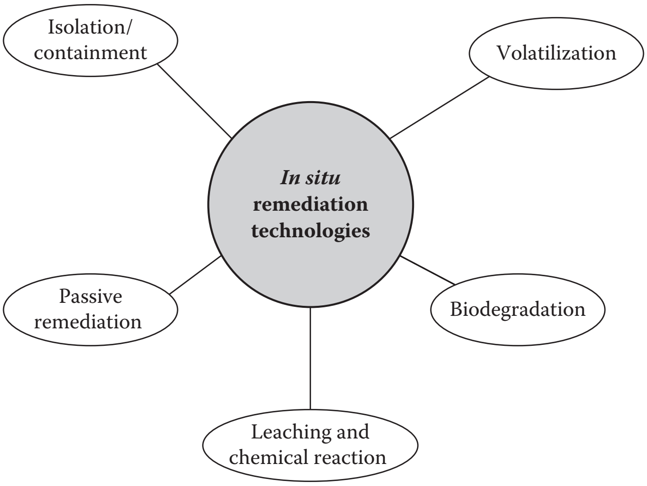

FIGURE 14.3 *In situ* volatilization (ISV).

operates many USTs and other facilities for using, storing, or transferring petroleum products, primarily motor and heating fuels. USEPA developed federal regulations for reducing and controlling environmental damage from UST leakage, and many states and localities have developed and implemented strict regulations governing USTs and remedial actions for product releases to soil and groundwater.

The Electric Power Research Institute (EPRI), Edison Electric Institute (EEI), and Utility Solid Waste Activities Group (USWAG) in a cooperative effort conducted a technical investigation. From their findings, they developed a report entitled *Remedial Technologies for Leaking Underground Storage Tanks* (EPRI-EEI, 1988), which focused on one of the major components of the technical investigation. The report described and evaluated available technologies for remediating soil and groundwater that contain petroleum products released from underground storage tank leaks. A general introduction to existing cleanup technology, this report still serves as a reference for feasible method determination; it also provides a description of basic elements and discusses selection and implementation factors for a remedial program. The available technologies for remediating petroleum-product-contaminated soil and groundwater are divided into two categories: *in situ* treatment and non-*in situ* treatment (i.e., the treatment of soil in place and the treatment of soil removed from the site, respectively). Each of the remedial technologies (see Figures 14.3 and 14.4) is briefly described in the following sections, using information adapted from the 1988 report.

IN SITU TECHNOLOGIES

With *in situ* technologies, because no excavation is required, exposure pathways are minimized. Only exposure pathways that could result from the actual streams produced by the technologies are an issue, eliminating those associated with handling and transport.

In Situ Volatilization

In situ volatilization (ISV) (also known as *in situ* air stripping) uses forced or drawn air currents through in-place soil to remove volatile compounds. ISV has a successful track record for both effectiveness and cost efficiency. A common ISV system used to enhance subsurface ventilation and volatilization of volatile organic compounds consists of the following operations:

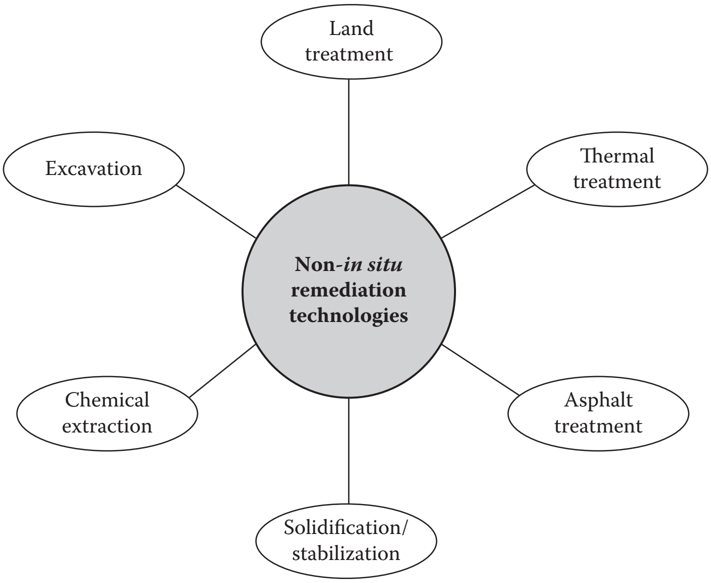

FIGURE 14.4 Non-*in situ* remediation technologies.

1. A preinjection air heater warms the influent air to raise subsurface temperatures and increase the volatilization rate.
2. Injection or induced draft forces established air flow through the unsaturated zone.
3. Slotted or screened pipe allows air flow through the system but restricts entrainment of soil particles.
4. A treatment unit (usually activated carbon) is used to recover volatilized hydrocarbon, minimizing air emissions.
5. Miscellaneous air flow meters, bypass and flow control valves, and sampling ports are generally incorporated into the design to facilitate air flow balancing and assess system efficiency.

Four types of factors influence volatilization of hydrocarbon compounds from soils: soil, environment, chemical, and management (Jury, 1986).

The *soil factors* include water content, porosity and permeability, clay content, and adsorption site density:

1. *Water content* influences the rate of volatilization by affecting the rates at which chemicals can diffuse through the vadose zone. An increase in soil water content will decrease the rate at which volatile compounds are transported to the surface via vapor diffusion.
2. *Soil porosity* and *permeability* factors relate to the rate at which hydrocarbon compounds volatize and are transported to the surface. A function of the travel distance and cross-sectional area available for flow, diffusion distance increases and cross-sectional flow area decreases with decreasing porosity.
3. *Clay content* affects soil permeability and volatility. Increased clay content decreases soil permeability, which inhibits volatilization.
4. *Adsorption site density* refers to the concentration of sorptive surface available from the mineral and organic contents of soils. An increase in adsorption sites indicates an increase in the ability of soil to immobilize hydrocarbon compounds in the soil matrix.

Environmental factors include temperature, wind, evaporation, and precipitation:

1. *Temperature* increase increases the volatilization of hydrocarbon compounds.
2. *Wind* increase decreases the boundary layer of relatively stagnant air at the ground–air interface, which can assist volatilization.
3. *Evaporation* of water at the soil surface is a factor controlling the upward flow of water through the unsaturated zone, which can assist volatilization.
4. *Precipitation* provides water for infiltration into the vadose zone.

Chemical factors are critical in affecting how various hydrocarbon compounds interact with the soil matrix. The primary chemical properties that affect the susceptibility of chemicals to *in situ* volatilization include solubility, concentration, octanol–water partition coefficient, and vapor pressure. *Management factors* related to soil management techniques (e.g., fertilization, irrigation) decrease leaching, increase soil surface contaminant concentrations, or maximize soil aeration and assist volatilization.

Site-specific conditions (e.g., soil porosity, clay content, temperature) drive the effectiveness of *in situ* volatilization techniques. Pilot studies and actual experience confirm the following effects:

- *In situ* volatilization has been successful for remediation in an unsaturated zone containing highly permeable sandy soils with little or no clay.
- Recovery periods are typically on the order of 6 to 12 months.
- Gasoline (which is light and volatile) has the greatest recovery rate.
- *In situ* volatilization can be used in conjunction with product recovery systems.
- Ultimate cleanup levels are site dependent and cannot be predicted; thus, they are usually set by regulatory agencies.

In Situ Biodegradation

The naturally occurring microorganisms in soil degrade contaminants to other forms in *in situ* biodegradation. Most petroleum hydrocarbons degrade to carbon dioxide and water by microbial processes (Grady, 1985). Stimulating microbial growth and activities primarily through the addition of oxygen and nutrients, as well as factors such as temperature and pH, influence the microbial rate of growth in this process. Documentation and significant background information related to successful land treatment of refinery waste indicate that biodegradation has proven to be an efficient and cost-effective method for the reduction of hydrocarbons in soil. Heyse et al. (1986) described the biodegradation process as follows:

1. A submersible pump transports groundwater from a recovery zone to a mixing pump.
2. Nutrients such as nitrogen, phosphorus, and trace metals are added to the water in a mixing tank. These nutrients are then transported by the water to the soil to support microbial activity.
3. Hydrogen peroxide is added to the conditioned groundwater from the mixing tank just prior to reintroduction to the soil. As hydrogen peroxide decomposes, it provides the needed oxygen for microbial activity.
4. Groundwater is pumped to an infiltration gallery or injection well, which reintroduces the conditioned water to the aquifer or soils.
5. Groundwater flows from the infiltration galleries or injection wells through the affected area and then back to the recovery wells. The flow of the water should contact all soils containing degradable petroleum hydrocarbons.
6. The water is drawn to the recovery well and pumped to the mixing tank to complete the treatment loop.

7. Groundwater in which hydrocarbon concentrations have been reduced to very low levels is often sent through a carbon adsorption process for removal of the residual hydrocarbons.

Environmental factors that affect biodegradation in soils include temperature and microbial community:

1. *Temperature* increase (up to 104°F) results in an increase in the biodegradation of petroleum fractions due to increased biological activity (Bossert and Bartha, 1984).
2. *Microbial communities* already present are utilized by most *in situ* biodegradation schemes; however, attempts have been made to supplement these populations with additional organisms or engineered organisms.

Chemical factors affect biodegradation in that biodegradation is impossible if the substrate chemical concentrations are too high; however, a substantial substrate (target compound) presence ensures that microbes metabolize the target compound. The solubility of a compound in water also limits biodegradation, because most microbes need moisture to acquire nutrients and avoid desiccation.

Soil factors include the fact that proper aerobic conditions are required for the degradation of hydrocarbons in soil. Too much moisture (saturation) limits oxygen levels and can hinder biological activity. Bossert and Bartha (1984) reported that a moisture content between 50 and 80% of the water-holding capacity is considered optimal for aerobic activities. Oxygen transfer is a key factor in *in situ* biodegradation processes; soils must be fairly permeable to allow this transfer to occur. Soil pH directly affects the microbial population supported by the soil; biodegradation is usually greater in a soil environment with a pH of 7.8. For optimal biodegradation of petroleum hydrocarbons to occur, nutrients (nitrogen and phosphorus) in the proper amounts are required.

Environmental Effectiveness

Although the historical record for this technology is limited, the effectiveness of *in situ* biodegradation is dependent on the same site-specific factors as other *in situ* technologies. Several case studies suggest that:

- *In situ* biodegradation is most effective for situations involving large volumes of subsurface soils.
- Significant degradation of petroleum hydrocarbons normally occurs in the range of 6 to 18 months (Brown et al., 1986).
- *In situ* biodegradation has most often been used for the remediation of groundwaters impacted by gasoline.
- Research suggests that limited biodegradation of benzene or toluene may occur under anaerobic conditions (Wilson et al., 1986).
- In soils, the remedial target level for *in situ* biodegradation could be in the low milligram/liter (parts per million) level for total hydrocarbons (Brown et al., 1986).

In Situ Leaching and Chemical Reaction

The *in situ* leaching and chemical reaction process uses water mixed with a surfactant (a surface-active substance such as soap) to increase the effectiveness of flushing contaminated soils in an effort to leach the contaminants into the groundwater. The groundwater is then collected downstream of the leaching site, through a collection system, for treatment and/or disposal.

Environmental Effectiveness

The *in situ* leaching and chemical reaction process is not commonly practiced. Few performance data on its environmental effectiveness are available.

In Situ Vitrification

The *in situ* vitrification process employs electrical current passed through electrodes (driven into the soil in a square configuration), which produces extreme heat and converts soil into a durable glassy material. The organic constituents are pyrolized in the melt and migrate to the surface, where they combust in the presence of oxygen. Inorganics in the soil are effectively bound in the solidified glass (Johnson and Cosmos, 1989).

Environmental Effectiveness

Organic materials are combusted or destroyed by the high temperatures encountered during the vitrification process. The *in situ* vitrification process is a developing technology, and the jury is still out as far as determining its environmental effectiveness.

In Situ Passive Remediation

The *in situ* passive remediation process is the easiest to implement and the least expensive, mainly because it involves no action at the site; however, it is generally unacceptable to the regulatory agencies. It relies upon several natural processes to destroy the contaminant. These natural processes include biodegradation, volatilization, photolysis, leaching, and adsorption.

Environmental Effectiveness

Passive remediation depends on a variety of site-specific and constituent-specific factors, so its environmental effectiveness must be decided on a case-by-case basis.

In Situ Isolation or Containment

Isolation or containment methods work to prevent the migration of liquid contaminant or leachates containing contaminants further into the soil, which is accomplished by separating the contamination area from the environment by installation of impermeable barriers to retain liquid containments within the site. The effectiveness of these methods is usually contingent upon the presence of impervious layers beneath the contaminant to be contained and attaining a good seal at both the vertical and horizontal surfaces. The containment devices discussed in this section adequately isolate the contamination. In these methods, however, the contaminant is not destroyed, merely contained. Containment methods include the following:

- *Slurry walls*—Fixed underground physical barriers are formed in an excavated trench by pumping slurry, usually a bentonite or cement and water mixture.
- *Grout curtains*—Formed in a similar manner, suspension grouts composed of Portland cement or grout are injected under pressure to form a barrier.
- *Sheet piling*—Construction involves physically driving rigid sheets, pilings of wood, steel, or concrete into the ground to form a barrier.

Environmental Effectiveness

Isolation or containment systems effectively physically prevent or impede migration, but the contaminant is not removed or destroyed.

Case Study 14.2. Phytoremediation, an Innovative Treatment Technology

A remediation process known as *phytoremediation* uses plants and trees to clean up soil and water contamination. Phytoremediation processes are aesthetically pleasing, solar-energy driven, cost effective, and passive. This process could transform the ways industry and government agencies treat long-term pollution problems. Laboratory-designed hybrid poplar trees, for example, planted on contaminated sites safely store chemical contaminants in plant tissues or metabolize them into less volatile compounds. The trees then release these byproducts through evapotranspiration processes. Phytoremediation techniques must occur on a plant-oriented time frame and often take several years to complete, but tests show that this extremely cost-effective method in some cases may work as well as the costly soil vitrification and groundwater filtration processes. Phytoremediation can also be used along with mechanical clean-up methods (Anon., 1998).

Agricultural specialists have known for years that certain plants remove certain compounds from the soil. The concept of crop rotation is based on this knowledge. Phytoremediation uses that information to specifically target particular compounds and pollutants in the soil. Individual species (sometimes genetically altered to enhance absorption capabilities) or a combination of species are planted on the site, allowed to grow, and then harvested, incinerated, or composted. The process can be repeated as often as needed to bring the pollutant levels down to acceptable levels. Considerations include the depth of the root systems; trees obviously reach farther into the soil than smaller plants. Tree roots that reach down to the water table can take in large quantities of water. Poplar trees planted along stream beds in agricultural areas reduce the amount of fertilizer and herbicides that enter streams and groundwater. Trees planted on top of landfills suck up rainwater that otherwise might seep through the landfill, picking up contaminants and leaching out into groundwater supplies.

Phytoremediation is often used as the last step in combination with other processes to clean out the last traces of contaminants. This technique is most useful in shallow soils and for areas with lower contamination levels, and researchers are investigating other ways to employ phytoremediation techniques. Still in question are the effects of the food chain and at what levels the contaminants collect in plant materials. The levels of toxins that might be re-released into the environment with autumn leaf fall, from tree mulch, or firewood incineration must still be explored.

NON-*IN SITU* TECHNOLOGIES

Non-*in situ* techniques require the removal (usually by excavation) of contaminated soils. These soils can be either treated onsite or hauled away for treatment. Non-*in situ* techniques create additional exposure pathways associated with the handling and transport of contaminated soil. The non-*in situ* technologies for soils include land treatment, thermal treatment, asphalt incorporation, solidification and stabilization, chemical extraction, and excavation.

Land Treatment

Affected soils are removed and spread over an area to enhance naturally occurring processes, including volatilization, aeration, biodegradation, and photolysis. Through tilling and cultivating of soils, biological degradation of hydrocarbon compounds can be speeded up. Basic land treatment operation includes these steps:

1. The area to be used for land treatment is prepared by removing surface debris, large rocks, and brush.
2. The area is graded to provide positive drainage and is surrounded by a soil berm to contain runoff within the land treatment area.
3. The pH is adjusted (e.g., by the use of lime) to create a neutral pH.
4. If the site is deficient in nutrients, fertilizer is added.
5. The petroleum-contaminated soil is spread uniformly over the surface of the prepared area.
6. The contaminated material is incorporated into the top 6 to 8 inches of soil (to increase contact with microbes) with a tiller, disc harrow, or other plowing device.

7. Reapplication of soils that contain petroleum products is carried out at proper intervals to replenish the hydrocarbon supply.
8. Hydrocarbon levels, nutrient levels, and soil pH are monitored to ensure that the hydrocarbons are properly contained and treated in the land treatment area.

Environmental Effectiveness

The effectiveness of land treatment or land farming depends greatly on site-specific conditions. Experience with treating petroleum compounds using this technology confirms that

- Land treatment is effective for degrading hydrocarbon compounds.
- Continuous treatment of petroleum-laden soils can result in the accumulation of metals in the soil matrix.
- Ultimate degradation rates are site dependent and cannot be predicted.

Thermal Treatment

Thermal treatment, a method of treating contaminated soils that requires special equipment, is capable of providing complete destruction of the petroleum contaminant. In thermal treatment, contaminated soils are removed from the ground and exposed to excessive heat in an incinerator. Currently available incinerator types include rotating kilns, fluidized bed incinerators, fixed kilns or hearths, rotating lime or cement kilns, and asphalt plants.

Environmental Effectiveness

The effectiveness of high-temperature incineration for the destruction of petroleum-laden soil is well documented. Destruction and removal efficiencies of 99% can be expected.

Asphalt Incorporation and Other Methods

Asphalt incorporation, a recently developed remedial technology, goes beyond remediation. Asphalt incorporation is actually a reuse or recycling technology. In asphalt incorporation, the containment entrained in soil is used in beneficial reuse (to make asphalt, cement products, and bricks), not simply destroyed or disposed of. Asphalt incorporation and other reuse or recycling technologies involve the assimilation of petroleum-laden soils into hot or cold asphalt processes, wet or dry cement production processes, or brick manufacturing. The petroleum-laden soils are mixed with other constituents to make the final product, while the petroleum contaminants are either volatilized during some treatments or trapped within the substance, thereby limiting contaminant migration. Converting asphalt into asphalt concrete or bituminous concrete involves producing a material that is plastic when being worked and that sets up to a predictable hardness sufficient for its end use. Incorporating contaminated soil into bituminous end products is accomplished by two conventional processes, cold-mix asphalt (CMA) processes and hot-mix asphalt (HMA) processes (Testa, 1997).

Cold-mix asphalt (also called *environmentally processed asphalt*) is produced by a mobile or in-place process. Soils polluted with a variety of contaminants (including petroleum hydrocarbons) serve as the fine-grained component in the mix, along with asphalt emulsion and specific aggregates. A wide range of cold-mix asphaltic products is possible. To enhance the stability of the end product, the mix is usually augmented with lime, Portland cement, or fly ash. Incorporation is accomplished physically by either mixed-in-place methods for large quantities or windrowing for smaller quantities. Advantages of the CMA process include the following:

1. Can process a variety of contaminants
2. Can incorporate large volumes of contaminated soil
3. Offers flexible mix design and specifications
4. Is a mobile process, and processing can occur onsite
5. Is subject to minimal weather restrictions

6. Is cost effective
7. Produces products that can be stockpiled and used when needed
8. Can occur onsite

Disadvantages include the following:

1. Any volatiles present must be controlled.
2. Small volumes of contaminated soil may not be economically viable for mobile plants.

Hot-mix asphalt processes involve incorporating petroleum-laden soils into hot asphalt mixes as a partial substitute for aggregate. This mixture is most often applied to pavement. HMA is produced conventionally using either batch or drum mixing processes. The usual processes entail both mixing and heating to produce pavement material. During the incorporation process, the mixture (which includes the contaminated soils, usually limited to 5% of the total aggregate feed at any one time) is heated. This volatilizes the more volatile hydrocarbon compounds at various temperatures. Compound migration is limited by incorporating the remainder of the compounds into the asphalt matrix during cooling. Advantages of using the HMA process include the following:

1. The time required to dispose of hydrocarbon-laden material is limited only by the size of the batching plant (material may be excavated and stored until it can be used).
2. It can process small volumes of affected soil easily.

Disadvantages include the following:

1. Not being able to apply the product immediately after processing
2. Potential for elevated emissions
3. Emission restrictions
4. Incomplete burning of light-end hydrocarbons that can affect the quality of end products

Raw materials (including limestone, clay, and sand) are incorporated into the *cement production process* and are then usually fed into a rotary kiln. Contaminated soil is then introduced along with the raw materials or dropped directly into the kiln. The mix is heated to up to 2700°F. Petroleum-laden soil chemically breaks apart during this process, while inorganic compounds recombine with raw materials and form clinkers—dark, hard, golf-ball-sized nodules of rapidly formed Portland cement, which are mixed with gypsum and ground to a fine powder (Testa, 1997). Advantages of this approach include the following:

1. The technology is in place and has been tested.
2. Raw materials are readily available.
3. Water solubility and water permeability are relatively low.
4. It can accommodate a wide variety of contaminants and material.

Disadvantages include the following:

1. Odorous material limitations
2. Wide range of volume increase
3. Both technical and aesthetic material restrictions

Petroleum-laden soil can be used as an ingredient in *brick production*. The contaminated soil replaces either the shale or firing clay normally used in brick manufacturing processes. The contaminated soil, along with shale or clay, is incorporated into a plasticized mixture, molded into brick, dried, and preheated. Then the brick is fired at 1700 to 2000°F for approximately 12 hours in the kiln. High temperatures and residence times in the kiln destroy organics and incorporate them into the vitrified end product. Advantages of the brick manufacturing process include:

1. Fine-grained, low permeability soils can be accommodated.
2. The technology is in place and has been tested.
3. Processing can occur onsite.

The disadvantage is that this process is restricted primarily to petroleum hydrocarbons and fly ash.

Solidification or Stabilization

Solidification or stabilization of petroleum-laden soils immobilizes contaminants by either encapsulating or converting them but does not physically change the contaminant. This practice is not commonly used for soils because the contaminants are not destroyed. Solidification or stabilization processes can be performed on- or offsite. Various stabilizers and additives are mixed with the contaminated material. A generalized process for the manufacture of pozzolanic material (burned shale or clay resembling volcanic dust that will chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties) using fly ash has been used with some success (Mehta, 1983). Used most frequently to stabilize oily wastes and sludges contained in surface impoundments, solidification or stabilization processes accomplish this in two ways. The stabilizing agent is added directly to sections of *in situ* surface impoundments and thoroughly mixed. As each section solidifies, it forms a base that allows the equipment to reach further into the impoundment.

The second method involves excavation of the sludges in the impoundment, following this procedure (Musser and Smith, 1984):

1. Earth-moving machines level piles of kiln dust into 6- to 12-inch-deep layers.
2. A machine lifts the sludge from the impoundment and places it on top of the kiln dust.
3. Machines mix the two materials together, and a pulverizing mixer is driven over the mixture until homogeneity is achieved.
4. The mixture is allowed to dry for about 24 hours and is then compacted and field tested.

The layers are then stacked to build an in-place landfill, or the semisolidified sludge can be trucked to another landfill location.

Chemical Extraction

Excavated contaminated soils are washed to remove the contaminants of concern in the process of chemical extraction. Accomplished in a washing plant, this process uses a water/surfactant or a water/solvent mixture to remove contaminants. Soil is excavated, then washed. This process increases product recovery and is a proven method for the removal of hydrocarbon contaminants from the soil.

Excavation

Excavation, physically removing the contaminated soil for disposal at a hazardous waste or other disposal landfill site, has been the mainstay of site remediation for several decades. Recently, though, the practice has been discouraged by newer regulations that favor alternative onsite waste treatment technologies. Considered a storage process today, not a treatment process, excavation raises issues of future liability for the responsible parties concerning final soil disposal. Landfills are quickly reaching their fill limits, with fewer and fewer new landfilling sites being authorized for construction and operation. This makes onsite treatment a much more attractive prospect. Excavation takes little time to complete and allows for thorough cleanup of the site; however, worker and operator safety considerations, the production of dust and odor, and the relatively high costs associated with the excavation, transportation, and ultimate disposal of the soil make it a less than ideal choice (USEPA, 1985).

ECONOMIC OUTLOOK FOR SOIL REMEDIATION

Earlier in this chapter, we quoted Jacqueline MacDonald as saying that, "In the early 1990s venture capitalists began to flock to the market for groundwater and soil cleanup technologies, seeing it as offering significant new profit potential." Although MacDonald's comments present new innovative environmental cleanup enterprises in a positive light, remediation technology is not a sure-fire, can't-lose venture. The market's apparent promise has been offset by actual experience. In real-life situations, investments in remediation technologies have not necessarily paid off. In fact, many early venture capitalists who invested in remediation technology lost in a big way. MacDonald went on to point out that, "Today, capital investors are wary … because the market is too volatile and sluggish."

Even with the incentives offered by a strong economy and increased spending on hazardous waste site cleanup, we see a decline in private investment in innovative technologies for cleanup of groundwater and soil. A National Research Council report (National Research Council, 1997) observed that total venture capital investments in all industries increased by 87% between 1992 and 1995. Over the same time period, venture capital funding for remediation and other environmental technologies decreased by nearly 70%.

Why is investment in innovative technology for cleanup of groundwater and soils waning? The recent trend toward cleaning up the environment (especially hazardous waste sites in the United States) would suggest higher interest. Two key factors have constrained the U.S. remediation technologies market, according to the National Research Council: (1) segmentation and (2) no connection or reward between rapid cleanup of contaminated sites and the site owners' financial self-interests. The many regulatory programs overseeing contaminated sites create the segmentation problem. These various programs have areas of overlap and different requirements for remediation technology approval, all of which must be met. Remediation technology is expensive; the multiple demonstrations required by each of these programs to prove that the technology works to the satisfaction of regulators magnify the expense many times. Often, small companies lack the cash flow to wait out the delays.

The second problem is the result of unseen rewards for delays in site cleanup. Corporate financial managers have found that to delay cleanup through litigation is less expensive than cleaning up a contaminated site: "Most small companies cannot meet payroll and other costs without a steady stream of income generated on a predictable basis" (MacDonald, 1997). When bottom-line costs increase, even environmentally conscious, well-meaning companies avoid committing the additional time and money required by such projects. See Case Study 14.3.

Case Study 14.3. Brownfields

The U.S. Environmental Protection Agency (USEPA, 2017) defines brownfields as abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination. Sites suitable for brownfield restoration typically are contaminated at lower levels than those on USEPA's National Priority List of sites containing hazardous substances. Restoring brownfield sites helps to slow down the development of "greenfield" sites for urban growth. Building on suburban and rural sites, away from city centers, encourages urban sprawl, and leaving abandoned industrial sites vacant contributes to urban decay, causing economic, environmental, and social problems in the adjacent areas. Liability issues, concerns over expected cleanup levels, and delays in approved permits make redevelopment of brownfield sites a challenge for the public and private entities who might ordinarily wish to take on such projects.

ANIMAL FEEDING OPERATIONS AND ANIMAL WASTE TREATMENT*

Waste problems and innovative solutions are not new; for example, the solution to animal waste pile-up in ancient Greek animal housing was first formulated by Hercules, arguably the planet's first environmental engineer. The Hercules engineering principle states: "The solution to pollution is dilution." This is the principle that Hercules applied when he cleaned up the royal Aegean stables that had not been cleaned for at least 30 years. He cleaned the stables by diverting the flow of two upstream rivers and directing the combined flow through the stables. Today we would call this "flushing."

This flushing idea of Hercules worked so well in cleaning the stables, that the same idea was later applied in the design of human toilets and sewer systems. As the world became industrialized, the Hercules idea was applied just as successfully in the dispersion of air pollutants through tall chimneys. These chimneys are not different from the sewer pipes that take the waste away from the source. Note that the Hercules principle, that the solution to pollution is dilution, has ample scientific support. It should also be noted that, although treating today's massive quantities of animal waste from concentrated animal feeding operations (CAFOs) is certainly a Herculean task, unfortunately he is no longer around to solve current problems.

Fast-forwarding from mythical times back to the present, the fact is that animal waste problems and solutions are not new. For example, field spreading of human and animal wastes has been done in both nomadic and pasture social systems. The early Chinese practiced intentional manure conservation and reuse. In Iceland, slotted floors (allowing waste material to drop below the floor surface) go back at least 200 years. From at least the 19th century, dairy operations producing wastes from scores of animals were contained in one building. Huge poultry centers with wastes concentrated in a small area have been around for decades, as have some very large swine and beef units.

Figuratively speaking and in general, animal manure deposited by animals managed by standard grazing livestock methods does not create serious environmental problems, especially if the farmer limits herd size to numbers the acreage can support without environmental damage, restricts livestock access to stream beds, and applies practices that include preventing soil erosion, such as by using greenbelts for waterways and shoreline planting. Accidentally stepping into such deposits is an occupational hazard, of course.

It is important to understand that manure deposited by a large herd of animals that is not assimilated through the soil surface and is carried off by storm runoff into local streams or other water bodies is not a common occurrence, and small-farm animal manure waste is not the problem we are addressing. Agribusiness and large-scale, factory-farming practices have created a different farm category in CAFOs, the livestock version of factory crop farming which produces a massive quantity of manure. In the 1920s, no one was capable of spilling millions of gallons of manure into a local stream in a single event. Such an event is possible today because of the piling up of too much manure in one place; simply put, the piling up is the result of greater concentration and reduced diversity in farm operations (Ikerd, 1998).

Agribusinesses do not use traditional pastures and feeding practices. Typically, the manure is removed from the livestock buildings or feedlots and stored in stockpiles or lagoon or pond systems until it can be spread on farm fields, sold to other farmers as fertilizer, or composted. When properly designed, constructed, and managed, CAFO-produced manure is an agronomically important and environmentally safe source of nutrients and organic matter necessary for the production of food, fiber, and good soil health. Experience has demonstrated that when properly applied to land, at proper levels, manure will not cause water quality problems. When properly stored or deposited in holding lagoons or ponds, properly conveyed to the disposal outlet, and properly applied to the appropriate end use, potential CAFO waste environmental problems can be mitigated.

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[*] This section is adapted from Spellman, F.R. and Whiting, N.E., *Environmental Management of Concentrated Animal Feeding Operations (CAFOs)*, CRC Press, Boca Raton, FL, 2007.

But, CAFOs must be monitored and controlled. CAFOs are inherently potential sources of contaminants (pollutants) to the three environmental media of air, water, and soil. Let's take a look at manure handling and storage practices recommended by the U.S. Department of Agriculture and USEPA (1998) that should be employed to prevent water pollution from CAFOs. In addition to water pollution prevention, it should be noted that manure and wastewater handling, storage, and subsequent application and treatment practices should also consider odor and other environmental and public health problems.

- *Divert clean water*—Siting and management practices should divert clean water from contact with feed lots and holding pens, animal manure, or manure storage systems. Clean water can include rainfall falling on roofs of facilities, runoff from adjacent lands, or other sources.
- *Prevent leakage*—Construction and maintenance of buildings, collection systems, conveyance systems, and permanent and temporary storage facilities should prevent leakage of organic matter, nutrients, and pathogens to ground or surface water.
- *Provide adequate storage*—Liquid manure storage systems should safely store the quantity and contents of animal manure, as well as the wastewater produced, contaminated runoff from the facility, and rainfall. Dry manure, such as that produced in certain poultry and beef operations, should be stored in production buildings or storage facilities or otherwise stored in such a way so as to prevent polluted runoff. Location of manure storage systems should consider proximity to water bodies, floodplains, and other environmentally sensitive areas.
- *Manure treatments*—Manure should be handled and treated to reduce the loss of nutrients to the atmosphere during storage, to make the material a more stable fertilizer when land applied, or to reduce pathogens, vector attraction, and odors, as appropriate.
- *Management of dead animals*—Dead animals should be disposed of in a way that does not adversely affect ground or surface water or create public health concerns. Composting, rendering, and other practices are common methods used to dispose of dead animals.

MANURE TREATMENT

According to Sutton and Humenik (2003), "Advanced technologies are being developed for the biological, physical, and chemical treatment of manure and wastewaters. Some of these greatly reduce constituents in the treated solids and liquids that must be managed on the farm. Byproduct recovery processes are being developed that transform waste into value-added products that can be marketed off the farm." See Case Study 14.4.

Case Study 14.4. Animal Waste Treatment—Lagoons

Primarily because it is an economical means of treating highly concentrated wastes from confined livestock operations, the most widespread and common treatment technique for managing animal waste is the use of lagoons. In the late 1960s, considerable attention was paid to the impact of lagoons on surface water quality; since the 1970s, that attention has shifted to the potential impacts on groundwater quality. Unfortunately, these lagoons are prone to leaks and breakage, and groundwater has been contaminated with bacteria from them. The lagoons can also be overrun by floods that push the wastes into streams, lakes, and oceans. North Carolina, with its concentration of factory farms, has experienced massive water contamination due to its waste lagoons. The storage lagoons for factory farms are often stinking manure lakes the size of several football fields, containing millions of gallons of liquefied manure. A single animal factory can generate the waste equivalent of a small town.

DID YOU KNOW?

From Case Study 14.4, it should be apparent that lagoons have the unpredictable potential to affect both groundwater and surface water.

Several studies have been conducted on the effectiveness of factory farm lagoons, specifically on lagoon liners, in preventing environmental damage. Consider the following review of studies on effective lagoon construction vs. defective construction.

Sewell et al. (1975) found in his studies on an anaerobic dairy lagoon that the lagoon bottom sealed within 2 months of start up, and little or no pollutants were found in the groundwater after that time. Ritter et al. (1984) studied a two-stage anaerobic swine lagoon for 4 years and determined that the contaminant concentration increased in wells (50 meters from the lagoon) the first year and then steadily decreased afterwards. Their data led them to speculate that biological sealing takes place over a period of time depending on the loading rate to a lagoon. Collins et al. (1975) studied three swine lagoons, each within a high-water-table area. They found that there was no significant effect on groundwater beyond 3 meters from the lagoon edge. Miller et al. (1985) studied the performance of beef lagoons in sandy soil and found that the lagoons had effectively sealed within 12 weeks of the addition of manure. Humenik et al. (1980) summarized research conducted by others on the subject of lagoon sealing and concluded that the studies indicated that lagoon sealing may be expected within about 6 months, after which the area of seepage impact becomes restricted to approximately 10 meters.

On the other hand, Hegg et al. (1978, 1981) collected data from a dairy lagoon and from newly established swine lagoons and found that some of the monitoring wells became contaminated while others did not. This led them to conclude that seepage does not occur uniformly over the entire wetted perimeter of the lagoon but at specific unpredictable sites where sealing has not taken place. Similarly, Ritter et al. (1980) monitored an anaerobic two-stage swine lagoon for 2 years and found that one of the wells showed contamination which indicated localized seepage, while the other monitoring well indicted the lagoon system produced a minimum impact on groundwater quality as sealing had gradually taken place.

In many states, notwithstanding the USDA and USEPA manure handling, storage, and treatment recommendations, lawsuits against CAFOs for unsound environmental practices demonstrate that CAFO operations are still creating problems. In short, regulations and legislation have fallen behind CAFO creation and operation, enforcement of existing regulations is spotty, and problems associated with CAFOs are still being identified—although you can be sure that those who neighbor CAFOs can identify some big issues, both environmental and social. In this book, we discuss these “big issues” in detail.

WASTE CONTROL TECHNOLOGY

One of the most challenging and pressing environmental dilemmas confronting pollution scientists (and many others) is what we should do with all of the solid and hazardous wastes our throwaway society produces. In simple (and simplistic) terms, we could say that we should shift from a throwaway society to a recycling one, which would help restore a gain in our living standards. We could also say that, because disposing hazardous waste is so expensive and risky, to make the situation better we should follow RCRA’s waste management hierarchy (in descending order of desirability) to (1) stop producing waste in the first place; (2) if we cannot avoid producing it, then produce only minimum quantities; (3) recycle it; (4) if it must be produced but cannot be recycled, then treat it; (5) if it cannot be rendered nonhazardous, then dispose of it in a safe manner; and (6) once it is disposed of, continuously monitor it for adverse effects to the environment.

This approach has merit. The question is, though, is it realistic? To a point, yes. We have developed several different strategies to curb the spread of hazardous substances or wastes. One approach is treatment of hazardous wastes to neutralize them or make them less toxic, but, again, a better strategy would be to reduce or eliminate the use of toxic substances and the generation of hazardous waste. To a degree, we can accomplish this, but to think that we can simply do away with all of our hazardous materials, processes that use hazardous materials, and processes that produce hazardous materials is, at the present time, wishful thinking.

What we need to do is refine our waste reduction programs as much as possible and develop technologies that will better treat waste products that we are not able to replace, do away with, or reduce. We have such technologies and practices available to us today. Environmental science and technology can be put to work to develop and use measures and practices by which hazardous chemical wastes can be minimized, recycled, treated, and disposed. We review these measures, practices, and technologies in this section.

WASTE MINIMIZATION

Waste minimization (or source reduction measures) is accomplished in a variety of ways and includes feedstock or input substitution, process modifications, and good operating practices. Note that before any source reduction measure can be put into place considerable amounts of information must be gathered.

One of the first steps to be taken in the information-gathering process is determining the exact nature of the waste produced. The waste must initially be characterized and categorized by type, composition, and quantity, a task accomplished by performing a *chemical process audit* or *survey* of the chemical process. Keep in mind that during this information-gathering survey, it is important to look closely for any off-specification input materials that might produce defective outputs; any inadvertent contamination of inputs, process chemical, and outputs; and any obsolete chemicals (which should be properly disposed of). During the survey, particular attention should be given to problem areas—excessive waste amounts per unit of production, excessive process upsets or bad batches, or frequent off-specification inputs. The effect of process variables on the wastestream created and the relationship of waste-stream composition to the input chemicals and process methods used should be examined. For example, determine exactly how much process water is used. Can the amount of water used be reduced? Can process water be reused? Questions like these should be addressed during the chemical process survey (Lindgren, 1989).

To determine the feasibility of reuse, recycling, materials recovery, waste transfer, or proper methods of waste disposal, the exact nature of the waste must also be determined, which is usually accomplished by sampling the wastestream and then analyzing the sample in the laboratory. The nature of the waste can yield valuable information about the industrial process and the condition of process equipment.

Substitution of Inputs

After completing the chemical process survey, the information gathered may suggest or justify the substitution of certain chemicals, process materials, or feedstock to enable the process hazardous wastes to be reduced in volume or no longer be produced. Note that input substitutions are often inseparable from process modifications. A few specific examples of possible input substitutions include the following:

- Use of synthetic coolants in place of emulsified oil coolants
- Use of water-based paints instead of solvent-based paints
- Use of non-cyanide-based electroplating solutions
- Use of cartridge filters in lieu of earth filters

Process Modifications

One of the key benefits derived by performing a chemical process audit or survey is that audits often point to or suggest modifications to production systems that work to minimize hazardous wastestream production. Whenever a chemical process can be made more efficient, a reduction in the volume and toxicity of the residuals usually results.

Good Operating Practices

Reducing wastage, preventing inadvertent releases of chemicals, and increasing the useful lifetime of process chemicals are all directly related to *good operating practices*. Ensuring good operating practices by workers can only be accomplished through effective worker training. This training should not only include proper process operations but also effective spill response training.

Recycling

Various strategies have been developed to *recycle* (and thus minimize) the volume of hazardous wastes to dispose of. These strategies recover or recycle resources, either materials or energy, from the wastestream. The key point to note in chemical process recycling is that the product must receive some processing before reuse. Wastes generally recognized as having components of potential value include the following:

- Flammable and combustible liquids
- Oils
- Slags and sludges
- Precious metal wastes
- Catalysts
- Acids
- Solvents

From the list above, we can see that one such recycling or recovery effort involves the reclamation of organic solvents. Usually accomplished by using highly effective distillation techniques, solvents contaminated with metals and organics are heated to produce a liquid phase and a vapor phase. Lighter components with high volatiles rise to the top of the liquid phase and begin to vaporize. By carefully controlling the temperature of the waste mixture, the desired substance can be vaporized and recovered by condensation, leaving the heavier contaminants behind. What remains is a concentrated, highly toxic mixture (far reduced in volume) referred to as *still bottoms*. Bottoms may contain usable metals and other solvents. As distillation technology improves, more of these bottom materials will be recovered and possibly reused.

TREATMENT TECHNOLOGIES

Because of the 1984 and 1991 amendments to RCRA, hazardous wastes must be treated prior to ultimate disposal in a landfill. Even with process modifications, material substitution, and recycling, some portions of some wastestreams may still be hazardous and must be properly contained. These hazardous waste components require additional treatment that takes place in vessels (tanks), reactors, incinerators, kilns, boilers, or impoundments. At the present time, several technologies are available for the treatment of hazardous wastestreams. In this section, we discuss a few examples, including biological treatment, thermal treatment, activated carbon sorption, electrolytic recovery techniques, air stripping, stabilization and solidification, filtration and separation, and ultimate disposal treatment systems. Note that some of these treatment techniques were covered in greater detail earlier, such as *in situ* and non-*in situ* soil contamination treatment; some of the technologies discussed here combine two of more of these basic technologies.

Biological Treatment

Several biological treatment processes are available for treating liquid hazardous wastestreams (contaminated soils and solids are more difficult to treat), including activated sludge, aerobic lagoons, anaerobic lagoons, spray irrigation, trickling filters, and waste stabilization ponds. These processes are normally associated with biological treatment of municipal and industrial wastewater and are generally used for removal of organic pollutants from wastewater. Generally effective on wastewaters with low-to-moderate concentrations of simple organic compounds and lower concentrations of complex organics, these are generally ineffective in attacking mineral components and useless against heavy metals. Biological treatment of toxic organic components requires considerably more sophisticated operational control (including pretreatment) than is necessary with nontoxic wastewaters. Microorganisms used in biological treatment processes can easily be destroyed by rapid increases in the rate of feed. Acclimation and development of a functional population of biota may require considerable time, and the system is continuously subject to upset (Blackman, 1993).

The two biological processes used for treatment of toxic waste are *aerobic processes* (treatment in the presence of oxygen, or conventional aeration) and *anaerobic processes* (treatment in the absence of oxygen, such as in a simple septic tank). In aerobic treatment, organisms require both an energy source and a carbon source for growth, and both affect what type of organisms will grow in a particular environment. Many hazardous wastestreams satisfy both basic requirements, and if appropriate nutrients are present a thriving organic population for waste treatment can exist. Under these conditions, if pH and temperature are controlled, substances that are toxic to the active organisms can be eliminated.

The most important aspect limiting the applicability of aerobic biological treatment of hazardous waste is the biodegradability of the waste—its conversion by biological processes to simple inorganic molecules and to biological materials. Biodegradability of a particular waste is very system specific, and the correct conditions for successful treatment (*detoxification*, or biological conversion of a toxic substance to one less toxic) must be maintained to encourage the correct microbe mixture.

Anaerobic treatment of toxic wastestreams has been effectively practiced on many different types of toxic wastestreams. This form of treatment is basically a *fermentation* process in which organic waste is both oxidized and reduced.

Thermal Processes

Thermal treatment processes (*incineration*) are commonly used to treat both liquids and solids to either destroy the hazardous components or allow disposal of the process residue or treated waste in a USEPA-approved hazardous waste landfill. During incineration, carbon-based (organic) materials are burned at high temperatures (typically ranging from 1500 to 3000°F) to break them down, chiefly into hydrogen, carbon, sulfur, nitrogen, and chlorine. These constituent elements then combine with oxygen to form inorganic gases such as water vapor, carbon dioxide, and nitrogen oxides. After combustion, the gases pass through a pollution control system to remove acidic gases and particulate matter prior to being released to the atmosphere. Hazardous wastes incineration serves two purposes: (1) to permanently reduce or eliminate the hazardous character of the waste, and (2) to substantially reduce the volume of the waste being disposed. Waste characteristics and treatment requirements determine the incinerator design to accommodate liquid or solid wastes. Temperature, turbulence, and retention time (commonly known as the three T's of incineration) are the prime factors determining incineration treatment design for both solid and liquid wastes. Hazardous waste incinerators are regulated by USEPA and require a permit for operation. To receive an operating permit, an incineration facility must demonstrate a 99.99% destruction and removal efficiency (DRE) for each principal organic hazardous constituent in the feed material. Non-*in situ* thermal processes (primarily incinerators) include designs such as liquid injection and boilers, rotary kilns, fluidized beds, and catalytics. More sophisticated and less common types of thermal treatment systems include wet oxidation, pyrolytic, and plasma processes. Some of these processes can be conducted *in situ*—with steam injection, radiofrequency heating, and vitrification (molten glass treatment) processes.

Activated Carbon Sorption

Organic substances may be removed from aqueous hazardous wastestreams with *activated carbon* by *sorption*, which is the transfer of a substance from a solution to a solid phase. In *adsorption*—a final chemical reaction that forms a cementitious precipitated sludge, not to be confused with *absorption*, which is defined as a physical process that does not chemically stabilize a waste material—chemical substances are removed from the wastestream onto a carbon matrix. The carbon may be used in either granular or powdered form, depending on the application. The effectiveness of activated carbon in removing hazardous constituents from aqueous streams is directly proportional to the amount of surface area of the activated carbon; in some cases, it is adequate for complete treatment. It can also be applied to pretreatment of industrial hazardous wastestreams prior to follow-up treatment. Activated carbon sorption is most effective for removing from water those hazardous waste materials that are not water soluble.

Electrolytic Recovery Techniques

The electrolytic recovery technique (used primarily for recovery of metals from process streams, to clean process waters, or to treat wastewaters prior to discharge) is based on the *oxidation–reduction* reaction, where electrode surfaces are used to collect the metals from the wastestream. Typically, an electrolytic recovery system consists of a treatment vessel (e.g., tank) with electrodes, an electrical power supply, and a gas handling and treatment system. Recovered metal must be removed from the electrodes periodically when the design thickness is achieved for the recovered metal.

Air Stripping

The air stripping technique for removing hazardous constituents from wastestreams, although not particularly effective, has been used for many years. Stripping is a means of separating volatile components from less volatile ones in a liquid mixture by partitioning the more volatile materials to a gas phase of air or steam. In air stripping, the moving gas is usually ambient air, which is used to remove volatile dissolved organic compounds from liquids including groundwaters and wastewaters. Additional treatment must be applied to the exhaust vapors to destroy or capture the separated volatiles. The process is driven by the concentration gradient between air and liquid phase equilibrium for particular molecules according to *Henry's law*, which states that at constant temperature the weight of gas absorbed by a given volume of a liquid is proportional to the pressure at which the gas is supplied.

Stabilization and Solidification

Stabilization and solidification are techniques used to convert hazardous waste from the original form to a physically and chemically more stable material. Accomplished by reducing the mobility of hazardous compounds in the waste prior to its land disposal, stabilization and solidification are particularly useful when recovery, removal, or converting hazardous components (as required by RCRA) from a waste prior to disposal in a landfill is not possible. A wide variety of stabilization and solidification treatment processes use Portland cement as a binding agent. Waste–concrete composites can be formed that have exceptional strength and excellent durability and that retain wastes very effectively (Blackman, 1993). Stabilization and solidification treatment processes improve handling and physical characteristics and result in a reduction of solubility or limit the leachability of hazardous components with a waste.

Filtration and Separation

Filtration and separation hazardous waste treatment processes are physical processes. Filtration, the separation of solid particles from a liquid stream through the use of semiporous media, is driven by a pressure difference across the media. This pressure difference is caused by gravity, centrifugal force, vacuum, or elevated pressure. Filtration applied to hazardous waste treatment falls into two categories: clarification and dewatering. *Clarification* takes place when liquids of less than 200 ppm are placed within a clarifier, and the solids are allowed to settle out, producing a cleaner effluent. *Dewatering* is performed on slurries and sludges. The goal of dewatering is to concentrate the solids into a semisolid form for further treatment or land disposal.

ULTIMATE DISPOSAL

Most of us are familiar with open dumps; however, you might not be familiar with some of the dumping practices that occurred because of environmental legislation of the 1970s, which placed increasingly stringent controls on releases to the atmosphere and to the nation's waterways. To protect our atmosphere and our waterways, the legislative mindset of the 1970s drove us to dump hazardous materials into open dumps. Land disposal is safer and more appropriate, but we are now well aware that the land is not a bottomless sink that can be used to absorb all of our discards. We have learned that we must pretreat our wastes to detoxify them, to degrade them, to make them less harmful, to make them more Earth friendly—before we deposit them on or in the ground, the soil, the land—our Earth. Regardless of the treatment, destruction, and immobilization techniques used, some residues that must be contained somewhere will always remain from hazardous wastes. This "somewhere" can include burial in land, deep wells, surface impoundments, waste piles, and landfills. In this section, we discuss each of these ultimate disposal methods.

Deep-Well Injection

The practice of deep-well injection is not new, as it was used in the 1880s by the petroleum industry to dispose of saltwater produced when drilling for oil; however, disposing of hazardous materials by deep-well injection is a relatively recent development. The USEPA estimates that about 9 billion gallons of all of the hazardous waste produced in the United States (about 22% of the total produced) is injected deep into the ground. Most of the deep-well injection sites are located in the Great Lakes region and along the Gulf coast.

Deep-well injection involves the injection of liquid waste under pressure to underground strata isolated by impermeable rock where geologists believe they will be contained permanently, isolated from aquifers and typically at a depth of more than 700 meters below the surface. A high-pressure pump forces the hazardous liquids into pores in the underground rock, where they displace the water, oil, and gases already there. Sandstone and other sedimentary rock formations are used because they are porous and allow the movement of liquids.

In theory, when properly constructed, operated, and monitored, deep-well injection systems may be the most environmentally sound disposal method for toxic and hazardous wastes currently available. As with anything else, though, that in theory is "perfect" or affords us the "best available technology," deep-well injection has its problems. Although the wastes are stored at a depth below the groundwater table, fractures in the underground geology could allow waste to go where it is not wanted—namely, into the groundwater. The biggest problem with deep-well injection is all of the unknowns. We are not certain of the exact fate of hazardous substances after injection—another example of the "we don't know what we don't know" syndrome.

Because of our uncertainty about the results of our hazardous waste disposal practices, the 1984 amendments to RCRA ban unsafe, untreated wastes from land disposal. For those land disposal facilities allowed to accept hazardous substances, the USEPA (1986) implemented some restrictions:

- Liquids are banned from landfills.
- Underground injection of hazardous waste is banned within 1/4 mile of a drinking water well.
- More stringent structural and design conditions are required for landfills and surface impoundments, including two or more liners, leachate collection systems above and between the liners, and groundwater monitoring.
- Cleanup or corrective action is required if hazardous waste leaks from a facility.

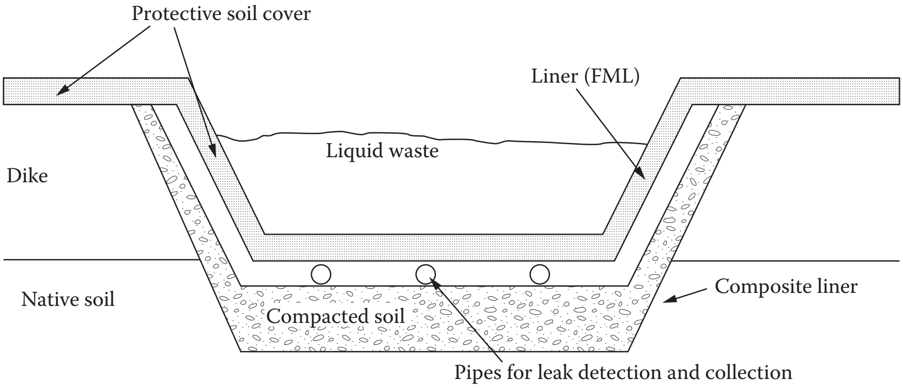

FIGURE 14.5 Surface impoundments.

- Disposal facilities must provide information on the pathways of potential human exposure to hazardous substances.
- Location standards must be protective of human health and the environment.

Surface Impoundments

Surface impoundments are diked or excavated areas used to store liquid hazardous wastes (see Figure 14.5). Because most surface impoundments are temporary, relatively inexpensive to construct, and allow easy access for treatment, they have been popular for many years. Unfortunately, in the past, surface impoundments were poorly constructed (literally quickly dug out or diked and put into operation), poorly sited (built on a thin layer of permeable soil that allowed leachate to infiltrate to groundwater), located too close to sources of high-quality drinking water (wells or running water sources), and either not monitored at all or poorly monitored. In 1984, the USEPA estimated that, of the more than 180,000 surface impoundments surveyed, prior to 1980 only about 25% were lined and fewer than 10% had monitoring systems.

Because of the problems associated with poor siting, construction, and management of the early surface impoundments, USEPA regulations have toughened the requirements for construction of new surface impoundments. Under the 1984 Hazardous and Solid Waste Amendments (HSWA), for example, the USEPA began requiring that new surface impoundments must include

- The installation of two or more liners
- A leachate collection system between liners
- Groundwater monitoring

Provisions must be made to prevent liquid escaping from overfilling or run-on and to prevent erosion of dams and dikes. During construction and installation, liners must be inspected for uniformity, damage, and imperfections. These liners must also meet permit specifications for materials and thickness.

Waste Piles

Waste piles are normally associated with industrial sites, where common practice for years was to literally pile up industrial waste and later, when the pile became too large to ignore, dispose of it into a landfill. Industrial practice has been to list such piles as “treatment” piles, and even 40 CFR 264/265, subpart L, refers to such piles as treatment or storage units. The environmental problem with such piles is similar to the problems we discussed related to mining waste. Like mining waste, industrial waste piles are subject to weather exposure, including evaporation of volatile components to the atmosphere and wind and water erosion. The most significant problem related to industrial waste piles is related to precipitation—leaching of contaminants (producing leachate), which may percolate into the subsurface. The RCRA specifications for waste piles are similar to those for landfills (to be discussed in the next section) and are listed in 40 CFR 264/265, subpart L. Under the RCRA guidelines, the owner or operator of a waste pile used for storage or treatment of noncontainerized solid hazardous wastes is given a choice between compliance with either the waste pile or landfill requirements. If the waste pile is used for disposal, it must comply with landfill requirements. The waste pile must be placed on an impermeable surface, and if leachate is produced a control and monitor system must be in place. Waste piles must also be protected from wind dispersion.

Landfilling

Landfilling wastes has a history of causing environmental problems, including fires, explosions, production of toxic fumes, and storage problems when incompatible wastes are commingled (see Figure 14.6). Landfills also have a history of contaminating surface and groundwaters (USEPA, 1990). *Sanitary landfills* are designed and constructed to dispose of municipal solid wastes only. Not designed, constructed, or allowed to be operated for disposal of bulk liquids or hazardous wastes, landfills that can legally receive hazardous wastes are known as *secure landfills*.

Under RCRA, the design and operation of hazardous waste landfills have become much more technically sophisticated. Instead of the past practice of gouging out a huge maw from the subsurface and then dumping countless truckloads of assorted waste materials (including hazardous materials) into it until full, a hazardous waste landfill is now designed as a modular series of three-dimensional control cells. Design and operating procedures have evolved to include elaborate safeguards against leakage and migration of leachates. Secure landfills for hazardous waste disposal are equipped with double liners (see Figure 14.7). Leakage detection, leachate collection and monitoring, and groundwater monitoring systems are required. Liners used in secure landfills must meet regulatory specifications; for example, the upper liner must consist of a 10- to 100-mil-thick *flexible-membrane liner* (FML), usually made of sheets of rubber or plastic. The lower liner is usually FML, but recompacted clay 3 feet thick is also acceptable.

Secure landfills must be constructed to allow the collection of leachate (usually via perforated drainage pipes with an attached pumping system) that accumulates above each liner. Leachate control is critical. To aid in this control process (especially from leachate produced by precipitation), a low-permeability cap must be placed over completed cells. When the landfill is finally closed, a cap that will prevent leachate formation via precipitation must be put in place. This cap should be

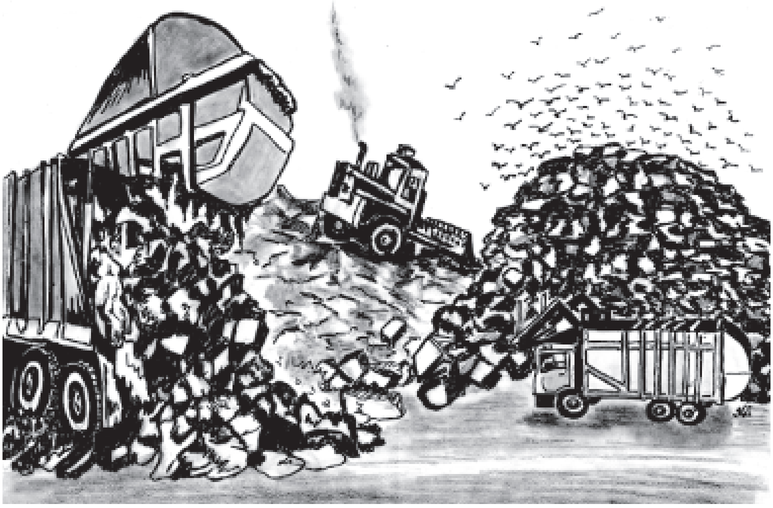

FIGURE 14.6 Landfilling operation. (Illustration by F.R. Spellman and Kathern Welsh.)

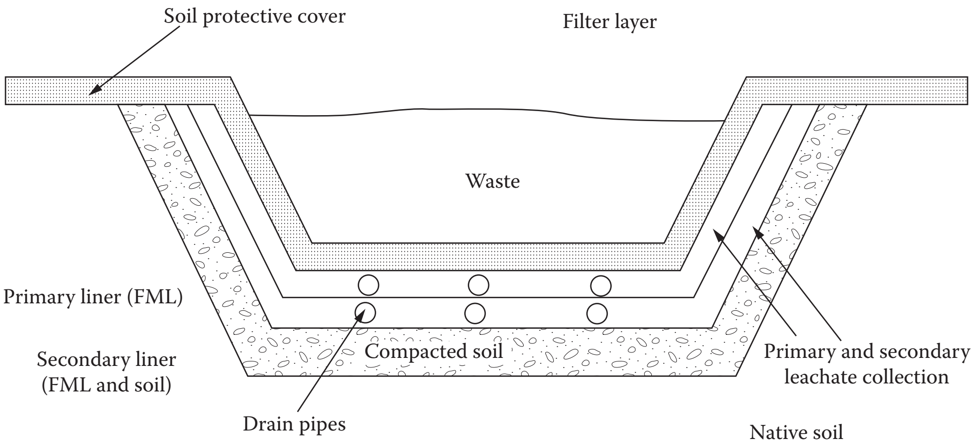

FIGURE 14.7 Cross-section of a secure landfill double-liner system.

sloped to allow drainage away from the wastes. When a landfill is filled and capped, it cannot be completely abandoned, ignored, or forgotten. The site must be monitored to ensure that leachate is not contaminating the groundwater. This is accomplished by installing test wells downgradient to detect any leakage from the site.

GREEN REMEDIATION*

Green remediation is the practice of considering all environmental effects of remedy implementation and incorporating options to maximize the net environmental benefit of cleanup actions. Green remediation reduces the demand placed on the environment during cleanup actions, otherwise known as the "footprint" of remediation, and avoids the potential for collateral environmental damage. The potential footprint encompasses impacts long known to affect environmental media:

- Air pollution caused by toxic or priority pollutants such as particulate matter and lead
- Water-cycle imbalance within local and regional hydrologic regimes
- Soil erosion, nutrient depletion, and subsurface geochemical changes
- Ecological diversity and population reductions
- Emission of carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and other greenhouse gases contributing to climate change

Strategies for green remediation rely on sustainable development whereby environmental protection does not preclude economic development, and economic development is ecologically viable today and in the long run. Use of green remediation best management practices helps to accelerate the pace of environmental protection in accordance with the USEPA's strategic plan for improving environmental performance of business sectors. Green remediation builds on environmentally conscious practices already used across business and public sectors and promotes incorporation of state-of-the-art methods for

- Conserving water
- Improving water quality
- Increasing energy efficiency

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* This section is adapted from USEPA, *Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites*, U.S Environmental Protection Agency, Washington, DC, 2008.

DID YOU KNOW?

Opportunities to increase sustainability exist throughout the investigation, design, construction, operation, and monitoring phases of site remediation regardless of the selected cleanup remedy. As cleanup technologies continue to advance and incentives evolve, green remediation strategies offer significant potential for increasing the net benefit of cleanup, saving project costs, and expanding the universe of long-term property use or reuse options without compromising cleanup goals (USEPA, 2008).

- Managing and minimizing toxics
- Managing and minimizing waste
- Reducing emission of criteria air pollutants and greenhouse gases

Increasing concerns regarding climate change have prompted major efforts across the globe to reduce greenhouse gas emissions caused by activities such as fossil fuel consumption. Accordingly, one category of the USEPA's evolving practices for green remediation places greater emphasis on approaches that reduce energy consumption and greenhouse gas emissions, such as

- Designing treatment systems with optimum efficiency and modifying as needed
- Using renewable resources such as wind and solar energy to meet power demands of energy-intensive treatment systems or auxiliary equipment
- Using alternative fuels to operate machinery and routine vehicles
- Generating electricity from byproducts such as methane gas or secondary materials
- Participating in power generation or purchasing partnerships offering electricity from renewable resources

Green remediation strategies also reflect increased recognition of the need to preserve the Earth's natural hydrological cycle. Best management of remediation activities includes water conservation measures, stormwater runoff controls, and recycling of treatment process water. Green remediation focuses on maximizing the net environmental benefit of cleanup while preserving remedy effectiveness as part of the USEPA's primary mission to protect human health and the environment. Site-specific strategies must consider the unique challenges and characteristics of a site; no single solution exists. At all sites, however, key opportunities for integrating core elements of green remediation can be found when designing and implementing cleanup measures. Regulatory criteria and standards serve as the foundation for building green practices.

DID YOU KNOW?

Best management practices for green remediation help balance key elements of sustainability:

- Resource conservation measured by *water intensity*, the amount of water necessary to remove one pound of contaminant, or by *soil intensity*, the amount of soil displaced or disturbed to remove one pound of contaminant
- *Material intensity* measured by the amount of raw materials extracted, processed, or disposed of for each pound of for each pound of contaminant treated
- *Energy efficiency* measured by the amount of energy needed to remove one pound of contaminant

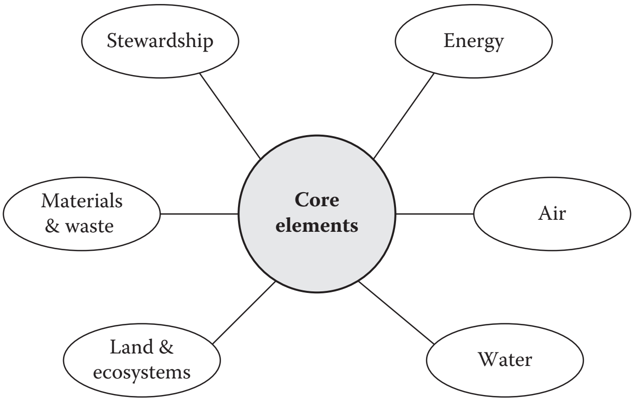

FIGURE 14.8 Best management practices of green remediation balance core elements of a cleanup project.

CORE ELEMENTS OF GREEN REMEDIATION

Green remediation results in effective cleanups minimizing the environmental and energy footprints of site remediation and revitalization. Sustainable practices emphasize the need to more closely evaluate core elements of a cleanup project, compare the site-specific value of conservation benefits gained by different strategies of green remediation, and weigh the environmental trade-offs of potential strategies. Green remediation addresses six core elements (see Figure 14.8).

Energy Requirements of the Treatment System

- Consider use of optimized passive-energy technologies (with little or no demand for external utility power) that enable all remediation objectives to be met.
- Look for energy-efficient equipment and maintain equipment at peak performance to maximize efficiency.
- Periodically evaluate and optimize the energy efficiency of equipment with high energy demands.
- Consider installing renewable energy systems to replace or offset electricity requirements otherwise met by the utility.

Air Emissions

- Minimize the use of heavy equipment requiring high volumes of fuel.
- Use cleaner fuels and retrofit diesel engines to operate heavy equipment, when possible.
- Reduce atmospheric release of toxic or priority pollutants (ozone, particulate matter, carbon monoxide, nitrogen dioxide, sulfur dioxide, and lead).
- Minimize dust export of contaminants.

Water Requirements and Impacts on Water Resources

- Minimize freshwater consumption, and maximize water reuse during daily operations and treatment processes.
- Reclaim treated water for beneficial use such as irrigation.
- Use native vegetation requiring little or no irrigation.
- Prevent impacts such as nutrient loading on water quality in nearby water bodies.

Land and Ecosystem Impacts

- Use minimally invasive *in situ* technologies.
- Use passive energy technologies such as bioremediation and phytoremediation as primary remedies or “finishing steps,” where possible and effective.

- Minimize soil and habitat disturbance.
- Minimize bioavailability of contaminants through adequate contaminant source and plume controls.
- Reduce noise and lighting disturbance.

Material Consumption and Waste Generation

- Use technologies designed to minimize waste generation.
- Reuse materials whenever possible.
- Recycle materials generated at or removed from the site whenever possible.
- Minimize natural resource extraction and disposal.
- Use passive sampling devices producing minimal waste, where feasible.

Long-Term Stewardship Actions

- Reduce emissions of CO_2, N_2O, CH_4, and other greenhouse gases contributing to climate change.
- Integrate an adaptive management approach into long-term controls for a site.
- Install renewable energy system to power long-term cleanup and future activities on redeveloped land.
- Use passive sampling devices for long-term monitoring, where feasible.
- Solicit community involvement to increase public acceptance and awareness of long-term activities and restrictions.

GREEN REMEDIATION TECHNIQUES

Green remediation requires close coordination of cleanup and reuse planning. Reuse goals influence the choice of remedial action objectives, cleanup standards, and the cleanup schedule. In turn, those decisions affect the approaches for investigating a site, selecting and designing a remedy, and planning future operation and maintenance of a remedy to ensure its protectiveness.

Site cleanup and reuse can mutually support one another by leveraging infrastructure needs, sharing data, minimizing demolition and earth-moving activities, reusing structures and demolition material, and combining other activities that support timely and cost-effective cleanup and reuse. Early consideration of green remediation opportunities offers the greatest flexibility and likelihood for related practices to be incorporated throughout a project life. Although early planning is optimal, green strategies such as engineering optimization can be incorporated at any time during the site investigation, remediation, or reuse.

Geophysical techniques such as ground-penetrating radar could be used at some sites to reduce the need for direct measurement of stratigraphic units. The feasibility of using geophysical methods for these purposes depends heavily on site conditions and the nature of contamination. Geophysical surveys result in much smaller environmental footprints than invasive techniques for site investigations, including cone penetrometer test rigs.

Best management practices include the use of passive sampling techniques for monitoring the quality of the air, sediment, and groundwater or surface water over time. In contrast to traditional methods involving infrequent and invasive spot-checking, these methods provide for steady data collection at lower costs while generating less waste. Passive techniques for water sampling rely on ambient flow-through in a well without well pumping or purging, avoiding the need for disposal of large volumes of water that require management as hazardous waste. For some contaminants, however, passive devices for obtaining groundwater samples are ineffective (ITRC, 2009).

Remote data collection significantly reduces onsite field work and associated labor costs, fuel consumption, and vehicular emissions. For example, water quality data on streams in acid mine drainage areas can be monitored automatically and transmitted to project offices through solar-powered telemetry systems. This approach can be used for site investigations as well as site monitoring once treatment is initiated. Renewable energy-powered systems with battery backup can be used to operate meteorological stations, air emission sensors, and mobile laboratory equipment. Remote systems also provide quick data access in the event of treatment system breakdown.

Green remediation builds on methods used in the *triad decision-making approach* to site cleanup: systematic planning, dynamic work strategies, and real-time measurement systems. The approach advocates onsite testing of samples with the submission of fewer samples to offsite laboratories for confirmation. The need for less offsite confirmation saves resources otherwise spent in preserving, packing, and shipping samples overnight to a laboratory. The number of required field samples also can be lowered through comprehensive review of historical information. The triad approach allows for intelligent decision making regarding the location and extent of future sampling activities based on the results of completed analytical sampling. This dynamic work strategy significantly minimizes unnecessary analytical samples.

THE BOTTOM LINE

The innovative remediation technology we need to clean up contaminated soils is available, but we lack two important elements: the regulatory pressure to require its use and the financial incentives for companies to remediate sites quickly. Ensuring profitability for venture capitalists to invest in innovative cleanup technology would mean that soil remediation would move forward much more quickly—to the advantage of the environment. RCRA's waste management hierarchy sums up what could, should, would happen with waste—any kind of waste—in the best of all possible worlds. Although it is idealistic and too simple to say we *should* follow these standards, in practical terms we benefit in the long term by striving to achieve them. Regulating problem wastes, developing safe and environmentally friendly ways to dispose of them, and using the technologies we develop to control the future of such wastes are in the best interests of us all.

DISCUSSION QUESTIONS

1. What financial considerations are at work in the allocation of funding for soil remediation?
2. What are the chief causes of underground storage tank failure?
3. What are the advantages and disadvantages of phytoremediation?
4. What are exposure pathways, and how do they affect how contaminants are assessed for risk?
5. What is the history of the legislation that affects soil remediation?
6. What are the advantages and disadvantages of *in situ* technologies?
7. What are the advantages and disadvantages of non-*in situ* technologies?
8. What advantages (both social and environmental) do brownfields offer a community?
9. How are the hazardous wastes that are generated in your state disposed of?
10. How does a sanitary landfill differ from a secure landfill?
11. Summarize the various ways of disposing of hazardous wastes.
12. What are the advantages of landfilling?
13. Can leachate leak from a secure hazardous waste landfill? If so, how?

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15 Pollution and the 21st Century

> Never doubt that a small group of thoughtful committed citizens can change the world; indeed, it's the only thing that ever has.
>
> **—Margaret Mead**

In this concise and limited text, we have presented a basic, pragmatic treatment of the science of environmental pollution. One of the least appreciated and most central of all environmental issues is the fact that we are beyond the day that we could simply pollute our environment, pick up stakes, and move on to another location.

Although it has focused on the United States, this text considers the global implications of local pollution and stresses both individual and corporate responsibility. As we prepare for the future, two salient factors seem clear: (1) We have come to realize that how we treat planet Earth is something that those who follow us will be destined to live with, and (2) we have developed and continue to develop methodologies to remediate our mistakes, including environmental pollution.

Both of these factors are favorable; they portend a future lifestyle that will continue to be fulfilling (and also healthy) for all of us and for those who follow. This is not to say that all the problems we face today will somehow be miraculously solved by our stepping from this decade into the new one. Instead, it says that we can learn from our mistakes and take steps to ensure that we do not repeat them.

When you get right down to it, isn't this the essence of the human experience?

The purpose of this text is more than just to point out the obvious aspects of pollution and some of pollution's effects; it was also designed to alert us to the fact that the burning issue concerning pollution is that we do not know what we do not know about its long-term effects. The truth (call it convenient or inconvenient) is that this is a scary thought. While we should not panic, we do have a need and call for concern. Although public awareness is important, we must remember that when we say "public" we mean everyone: government, industry, environmental, social, and political groups, as well as the enormous body of ordinary people (most of whom are marginally concerned).

Our throwaway society sees the Earth as a place of unlimited resources, unlimited space, and unlimited potential to absorb our discards—our contaminants. Aligned with our fellow citizens in a worrisome mentality that pervades society, we profess that by increasing production, consumption, and technology the road to a better life for everyone will be smoothly paved, well marked, and without detour.

In the past, our mobility allowed us to pollute one area and then move on to another. From the earliest times, this has been the human methodology, our pattern, especially when dealing with an environment we have fouled (from cave to forest to inner city). Today we might call this a frontier mentality. The problem is, of course, that we are short on frontier (and we wish to be more careful with the frontier we have left) and heavy on overcrowding, pollution, feel-good voodoo science, and a myriad of other environmental problems stemming from too much and too rapid growth and increasing populations.

When we speak of feel-good voodoo science, we speak of the radical effort to chain science and technology to the whipping post of criticism and lay on the lash for all the evils befalling Earth related to environmental problems—a trendy and inaccurate mindset. Another mindset professes the view (via blind faith) that technological innovation will eventually come to our rescue—that we will solve these problems because we have solved problems before. Indeed, from a historical perspective, technology has helped to eradicate disease, expand our resource base, and raise our standard of living. Although past technological success may portend well for the future, our optimism must be tempered by the inherent limitations of technological research and development. We may indeed, be able to solve these problems—but not by merely thinking we can.

Human beings are resilient. When we are blown down by hurricane-force winds, flooded out by raging waters, or forced to abandon our homes due to volcanoes or earthquakes, when pestilence enters the land and kills off many—the survivors bounce back. We have learned to adapt to the natural whims of nature; we recover, eternally optimistic, and go forward.

The question is can we bounce back from our own mistakes? Mistakes that cause lands to subside, rivers to overflow their banks and natural floodplains, droughts to parch the land, pestilence to reign unabated, air to be thick enough to see it and choke with one breath, soil to be so poisoned that even the lowest plant forms cannot grow, waters to be so foul they harbor disease? Do we have the same resilience against our own folly as we do against the occurrence of natural disasters?

To formulate solutions, we must first understand the problems. We must ask questions and determine answers. Another question we have to ask is would it not be wiser to unchain science and technology from the whipping post and harness them to industry and government to help us solve environmental challenges facing us now and in the future? Yes. Through the proper use of science and technology we can solve any problem; we can sustain Earth and life within it. We can solve any problem? Absolutely. Do human beings ever really think otherwise? If so, then we certainly have lost our resiliency and any hope for a sustainable future.

Thus, it logically follows that to solve the problems facing us today and in the future we must work toward the same goal—to reach the same end. We have arrived at a tipping point in Earth's environmental history. The future habitability of Earth will be determined by decisions made and actions taken by this generation, by the people who are with us today.

What we must do can be compared to what an efficient wastewater treatment plant does. When we produce waste (and we can't avoid producing waste), we must treat it so the end product is sent back to its natural environment cleaner than it was in the first place.

Sound farfetched?

It isn't. We do it constantly and consistently in wastewater treatment. The question then becomes why can't we do that with all the wastes we produce?

The author thinks that this goal is possible, especially if the scientific, political, social, and monetary commitment that must be made is made … and it will be.

Why? What other choice do we have?

Glossary

Abiotic: The nonliving part of the physical environment (e.g., light, temperature, soil structure).

Absorption: (1) Movement of a chemical into a plant, animal, or soil. (2) Any process by which one substance penetrates the interior of another substance; in chemical spill cleanup, this process applies to the uptake of chemical by capillaries within certain sorbent materials.

Absorption units: Devices or units designed to transfer the contaminant from a gas phase to a liquid phase.

Accidental spills: The unintended release of chemicals and hazardous compounds or materials into the environment.

Acid: A hydrogen-containing corrosive compound that reacts with water to produce hydrogen ions; a proton donor; a liquid compound with a pH less than or equal to 2.

Acid mine drainage: The dissolving and transporting of sulfuric acid and toxic metal compounds from abandoned underground coal mines to nearby streams and rivers when surface water flows through the mines.

Acid rain: Precipitation made more acidic from falling through air pollutants (primarily sulfur dioxide) and dissolving them.

Acidic deposition: See *Acid rain*.

Adiabatic: Without loss or gain of heat; when air rises, air pressure decreases and expands adiabatically in the atmosphere. Because the air can neither gain nor lose heat, its temperature falls as it expands to fill a larger volume.

Adiabatic lapse rate: The temperature profile, or lapse rate, used as a basis for comparison for actual temperature profiles (from ground level) and hence for predictions of stack gas dispersion characteristics.

Adsorption: (1) Process by which one substance is attracted to and adheres to the surface of another substance without actually penetrating its internal structure. (2) Process by which a substance is held (bound) to the surface of a soil particle or mineral in such a way that the substance is only available slowly.

Adsorption site density: The concentration of sorptive surface available from the mineral and organic contents of soils. An increase in adsorption sites indicates an increase in the ability of the soils to immobilize hydrocarbon compounds in the soil matrix.

Advanced wastewater treatment: Any treatment that follows primary and secondary wastewater treatment.

Advective wind: The horizontal air movements resulting from temperature gradients that give rise to density gradients and subsequently pressure gradients.

Aerobic: Living in the air; opposite of *anaerobic*.

Aerobic processes: Biotechnology production and effluent treatment processes that are dependent on microorganisms that require oxygen for their metabolism. For example, water in an aerobic stream contains dissolved oxygen; therefore, organisms using this can oxidize organic wastes to simple compounds.

Afterburners: A device that includes an auxiliary fuel burner and combustion chamber to incinerate combustible gas contaminants.

Aggregate: Clusters of soil particles.

Agricultural sources: Both organic and inorganic contaminants usually produced by pesticides, fertilizers, and animals wastes, all of which enter water bodies via runoff and groundwater absorption in areas of agricultural activity.

Air: The mixture of gases that constitutes the Earth's atmosphere.

Air currents: Air moving upward and downward.

Air mass: A large body of air with particular characteristics of temperature and humidity. An air mass forms when air rests over an area long enough to pick up the conditions of that area.

Air pollutants: Generally includes sulfur dioxide, hydrogen sulfide, hydrocarbons, carbon monoxide, ozone, and atmospheric nitrogen but can include any gaseous substance that contaminates air.

Air pollution: Contamination of the atmosphere with any material that can cause damage to life or property.

Air stripping: A mass transfer process in which a substance in solution in water is transferred to solution in a gas.

Airborne contaminants: Any contaminant capable of dispersion in air or capable of being carried by air to other locations.

Airborne particulate matter: Fine solids or liquid droplets suspended and carried in the air.

Albedo: The fraction of received radiation reflected by a surface.

Algae: A large and diverse assemblage of eucaryotic organisms that lack roots, stems, and leaves but have chlorophyll and other pigments for carrying out oxygen-producing photosynthesis.

Aliphatic hydrocarbon: Compound comprised of straight-chain molecules as opposed to a ring structure.

Alkalinity: (1) The concentration of hydroxide ions. (2) The capacity of water to neutralize acids because of the bicarbonate, carbonate, or hydroxide content. Usually expressed in milligrams per liter of calcium carbonate equivalent.

Alkanes: A class of hydrocarbons (gas, solid, or liquid, depending on carbon content). The solids (paraffins) are a major constituent of natural gas and petroleum. Alkanes are usually gases at room temperature (methane) when containing less than 5 carbon atoms per molecule.

Alkenes: A class of hydrocarbons (also called *olefins*) common in petroleum products; they are sometimes gaseous at room temperature but usually liquid. Alkenes are generally more toxic than alkanes and less toxic than aromatics.

Alkynes: A class of hydrocarbons (formerly known as *acetylenes*) comprised of unsaturated compounds characterized by one or more triple bonds between adjacent carbon atoms. Lighter alkenes, such as ethylene, are gases; heavier ones are liquids or solids.

Amoebae (pl.), amoeba (sing.): One of the simplest living animals, consisting of a single cell and belonging to the protozoa group. The body consists of colorless protoplasm. Its activities are controlled by the nucleus, and it feeds by flowing around and engulfing organic debris. It reproduces by binary fission. Some species of amoebae are harmless parasites.

Anabolism: The process of building up cell tissue, promoted by the influence of certain hormones; the constructive side of metabolism as opposed to catabolism.

Anaerobic: Not requiring oxygen.

Anaerobic process: Any process (usually chemical or biological) carried out without the presence of air or oxygen, such as in a heavily polluted watercourse with no dissolved oxygen present.

Analysis: The separation of an intellectual or substantial whole into its constituent parts for individual study.

Animal feedlots: A confined area where hundreds or thousands of livestock animals are fattened for sale to slaughterhouses and meat producers.

Animal wastes: The dung (fecal matter) and urine of animals.

Anthropogenic sources: Generated by human activity.

Anticyclone: High-atmosphere areas characterized by clear weather and the absence of rain and violent winds.

Apoenzyme: The protein part of an enzyme.

Aqueous solution: Solution in which the solvent is water.

Aquifer: Any rock formation containing water. The rock of an aquifer must be porous and permeable to absorb water.

Aromatic hydrocarbons: Class of hydrocarbons considered to be the most immediately toxic; found in oil and petroleum products; soluble in water (antonym, *aliphatic*).

Asphalt incorporation: Soil remediation/recycling process whereby contaminated soil is removed from the site and fed into an asphalt-making process as part of the aggregated filler substance.

Atmosphere: The layer of air surrounding the Earth's surface.

Atom: A basic unit of physical matter indivisible by chemical means; the fundamental building block of chemical elements composed of a nucleus of protons and neutrons surrounded by electrons.

Atomic number: Number of protons in the nucleus of an atom. Each chemical element has been assigned a number in a complete series from 1 to 100+.

Atomic orbitals/electron shells: The region around the nucleus of an atom in which an electron is most likely to be found.

Atomic weight: The mass of an element relative to its atoms.

Auger: A tool used to bore holes in soil to capture a sample.

Automatic samplers: Devices that automatically take samples from a wastestream.

Autotrophic: An organism that can synthesize organic molecules needed for growth from inorganic compounds using light or another source of energy.

Autotrophs: See *Autotrophic*.

Avogadro's number: The number of carbon atoms in 12 g of the carbon-12 isotope (6.022045×10^{23}). The relative atomic mass of any element, expressed in grams, contains this number of atoms.

Bacilli (pl.), bacillus (sing.): Members of a group of rodlike bacteria that occur everywhere in soil and air. Some are responsible for diseases such as anthrax or cause food spoilage.

Bacteria: One-celled microorganisms.

Bacteriophage: A virus that infects bacteria; often called a *phage*.

Baghouse filter: A closely woven bag for removing dust from dust-laden gas streams. The fabric allows passage of the gas with retention of the dust.

Bare rock succession: An ecological succession process whereby rock or parent material is slowly degraded to soil by a series of bioecological processes.

Base: A substance that when dissolved in water generates hydroxide (OH^-) ions or is capable of reacting with an acid to form a salt.

Beneficial reuse: The practice of reusing a typical waste product in a beneficial manner, such as, for example, wastewater biosolids to compost.

Benthic (benthos): A term originating from the Greek word for "bottom" that broadly includes aquatic organisms living on the bottom or on submerged vegetation.

Best available technology (BAT): Essentially, a refinement of best practicable means whereby a greater degree of control over emissions to land, air, and water may be exercised using currently available technology.

Binomial system of nomenclature: A system used to classify organisms; organisms are generally described by a two-word scientific name comprised of the *genus* and *species*.

Bioaccumulation: Biological concentration mechanism whereby filter feeders such as limpets, oysters, and other shellfish concentrate heavy metals or other stable compounds present in dilute concentrations in seawater or freshwater.

Biochemical oxygen demand (BOD): The amount of oxygen required by bacteria to stabilize decomposable organic matter under aerobic conditions.

Biodegradable: A material capable of being broken down, usually by microorganisms, into basic elements.

Biodegradation: The ability of natural decay processes to break down manmade and natural compounds to their constituent elements and compounds for assimilation in, and by, the biological renewal cycles. Wood, for example, is decomposed to carbon dioxide and water.

Biogeochemical cycles: *Bio* refers to living organisms and *geo* to water, air, rocks, or solids. *Chemical* is concerned with the chemical composition of the Earth. Biogeochemical cycles are driven by energy, directly or indirectly, from the sun.

Biological oxygen demand (BOD): The amount of dissolved oxygen taken up by microorganisms in a sample of water.

Biological treatment: Process by which hazardous waste is rendered nonhazardous or reduced in volume by the actions of microorganisms.

Biological treatment processes: Include such treatment processes as activated sludge, aerated lagoon, trickling filters, waste stabilization ponds, and anaerobic digestion.

Biology: The science of life.

Biosolids: A term that refers to water or sewage sludge. The biosolids treatment process normally includes conditioning, thickening, dewatering, disposal by incineration, composting, land application, or land burial.

Biosphere: The region of the Earth and its atmosphere in which life exists, an envelope extending from up to 6000 meters above to 10,000 meters below sea level that embraces all life from alpine plant life to the ocean depths.

Biostimulant: A chemical that can stimulate growth, such as phosphates or nitrates in a water system.

Biota: The animal and plant life of a particular region considered as a total ecological entity.

Biotic: Pertaining to life or specific life conditions.

Biotic index: The diversity of species in an ecosystem is often a good indicator of the presence of pollution: The greater the diversity, the lower the degree of pollution. The biotic index is a systematic survey of invertebrate aquatic organisms that is used to correlate with river quality. It is based on two principles: (1) Pollution tends to restrict the variety of organisms present at a point, although large numbers of pollution-tolerant species may persist, and (2) in a polluted stream, as the degree of pollution increases, key organisms tend to disappear in the order of stoneflies, mayflies, caddisflies, freshwater shrimp, bloodworms, and tubificid worms.

Blastospore: Fungi spores formed by budding.

Blowby: In an internal combustion engine, blowby occurs as gases from the piston ring area pass into the crankcase.

Boiling point: The temperature at which a substance changes from a liquid to a gas.

Brackish water: Water (nonpotable) containing between 100 and 10,000 ppm of total dissolved solids.

Brick manufacturing process: In this text, contaminated soil recycling/remediation process whereby contaminated soil is added to the mix used to make brick.

Brine: Water containing more than 100,000 ppm of total dissolved solids that can yield salt (NaCl) after evaporation.

Btu: British thermal unit, a measuring unit of heat.

Budding: Type of asexual reproduction in which an outgrowth develops from a cell to form a new individual. Most yeasts reproduce in this way.

Calorie: The amount of heat required to raise the temperature of 1 gram of water 1°C.

Capsules, bacterial: Organized accumulations of gelatinous material on cell walls.

Carbon adsorption: Process whereby activated carbon, known as the sorbent, is used to remove certain wastes from water by preferentially holding them on the carbon surface.

Carbon cycle: The atmosphere is a reservoir of gaseous carbon dioxide, but to be of use to life this carbon dioxide must be converted into suitable organic compounds, or *fixed*, as in the production of plant stems by the process of photosynthesis. The productivity of an area of vegetation is measured by the rate of carbon fixation. The carbon fixed by photosynthesis is eventually returned to the atmosphere as plants and animals die and the dead organic matter is consumed by the decomposer organisms.

Carbon dioxide: A colorless, odorless inert gas; a byproduct of combustion.

Carbon monoxide: A highly toxic and flammable gas that is a byproduct of incomplete combustion; very dangerous even in very low concentrations.

Carbonate hardness: Temporary hard water caused by the presence of bicarbonates; when water is boiled, the bicarbonates are converted to insoluble carbonates that precipitate as scale.

Catabolism: In biology, the destructive part of metabolism where living tissue is changed into energy and waste products.

Catalysis: The acceleration (or retardation) of chemical or biochemical reactions by a relatively small amount of a substance (the catalyst), which itself undergoes no permanent chemical change and which may be recovered when the reaction has finished.

Catalyst: A substance or compound that speeds up the rate of chemical or biochemical reactions.

Catalytic combustion: Operates by passing a preheated contaminant-laden gas stream through a catalyst bed that promotes the oxidation reaction at lower temperatures. The metal catalyst (usually platinum) is used to initiate and promote combustion at much lower temperatures than those required for thermal combustion.

Catalytic converter: A device fitted to the exhaust system of a motor vehicle to reduce toxic emissions from the engine. It converts harmful exhaust products to relatively harmless ones by passing the exhaust gases over a mixture of catalysts coated on a metal or ceramic honeycomb, a structure that increases the surface area and therefore the amount of active catalyst with which the exhaust gases will come into contact.

Catchment: The natural drainage area for precipitation; the collection area for water supplies or a river system. The notional line, or watershed, on surrounding high land defines the area.

Cell: The basic biological unit of plant and animal matter.

Cell membrane (cytoplasmic membrane): The lipid- and protein-containing, selectively permeable membrane that surrounds the cytoplasm in procaryotic and eucaryotic cells; in most types of microbial cell, the cell membrane is bordered externally by the cell wall. In microbial cells, the precise composition of the cell membrane depends on the species, on growth conditions, and on the age of the cell.

Cell nucleus: Contained within a eucaryotic cell, a membrane-lined body that contains chromosomes.

Cell wall: The permeable, rigid outermost layer of a plant cell composed mainly of cellulose.

Cement production process: A recycling/remediation technology for contaminated soil whereby the contaminated soil is added to the mix in cement production.

CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act of 1980; Superfund): Provides for cleanup and compensation and assigns liability for the release of hazardous substances into the air, land, or water.

Chemical bond: A chemical linkage that holds atoms together to form molecules.

Chemical change: A transfer that results from chemical bonds being made or broken.

Chemical equation: A shorthand method for expressing a reaction in terms of written chemical formulas.

Chemical extraction: Process in which excavated contaminated soils are washed to remove contaminants of concern.

Chemical formula: In the case of substances that consist of molecules, the chemical formula indicates the kinds of atoms present in each molecule and the actual number of them.

Chemical oxygen demand (COD): A means of measuring the pollution strength of domestic and industrial wastes based on the fact that all organic compounds, with few exceptions, can be oxidized by the action of strong oxidizing agents under acid conditions to carbon dioxide and water.

Chemical precipitation: Process by which inorganic contaminants (heavy metals from groundwater) are removed by the addition of carbonate, hydroxide, or sulfide chemicals.

Chemical process audit/survey: A procedure used to gather information on the type, composition, and quantity of waste produced.

Chemical reaction: A substance undergoes a chemical change and is no longer the same substance; it becomes one or more new substances.

Chemical weathering: A form of weathering brought about by a chemical change in the rocks affected; involves the breakdown of the minerals within a rock and usually produces a claylike residue.

Chemosynthesis: A method of making protoplasm using energy from chemical reactions, in contrast to the use of light energy employed for the same purpose in photosynthesis.

Chlorofluorocarbons (CFCs): Synthetic chemicals that are odorless, nontoxic, nonflammable, and chemically inert. CFCs have been used as propellants in aerosol cans, as refrigerants in refrigeration and air conditioners, and in the manufacture of foam packaging. They are partly responsible for the destruction of the ozone layer.

Chlorophyll: A combination of green and yellow pigments present in all "green" plants which captures light energy and enables the plants to form carbohydrate material from carbon dioxide and water in the process known as *photosynthesis*. Chlorophyll is found in all algae, phytoplankton, and almost all higher plants.

Chloroplasts: A structure (or organelle) found within a plant cell containing the green pigment chlorophyll.

Cilia: Small threadlike organs on the surface of some cells, composed of contractile fibers that produce rhythmic waving movements. Some single-celled organisms move by means of cilia. In multicellular animals, they keep lubricated surfaces clear of debris. They also move food in the digestive tracts of some invertebrates.

Clarification: The process of removing solids from water.

Clay content: The amount of clay (fine-grained sedimentary rock) within a soil.

Clean Air Act: Act passed by the U.S. government. Originally passed in 1963, it dealt with the control of smoke from industrial and domestic sources. It was extended in 1968 to control gas cleaning and heights of stacks of installations in which fuels are burned to deal with smoke from open industrial bonfires. The 1990 revision introduced wide-ranging reforms for all kinds of pollution from large or small mobile or stationary sources, including routine and toxic emissions ranging from power plants to consumer products.

Clean Water Act (CWA): A keystone environmental law credited with significantly cutting the amount of municipal and industrial pollution fed into the nation's waterways. More formally known as the Federal Water Pollution Control Act Amendments, passed in 1972, it stems originally from a much-amended 1948 law aiding communities in building sewage treatment plants and has itself been much amended, most notably in 1977 and 1987.

Clean zone: That point in a river or stream upstream before a single point of pollution discharge.

Climate: The composite pattern of weather conditions that can be expected in a given region. Climate refers to yearly cycles of temperature, wind, rainfall, and so on, not to daily variations.

Coal gasification process: The conversion of coal (via destructive distillation) to gaseous fuel.

Cocci (pl.), coccus (sing.): Member of group of globular bacteria, some of which are harmful to humans.

Cofactor: Nonprotein activator that forms a functional part of an enzyme.

Cold front: The leading portion of a cold atmospheric air mass moving against and eventually replacing a warm air mass.

Cold-mix asphalt process: A mobile or in-place process whereby contaminated soils are recycled or remediated by serving as the fine-grained component in the asphalt-making process.

Collector: See *Cyclone collector.*

Colloidal material: A constituent of total solids in wastewater that consists of particulate matter with an approximate diameter range of from 1 millimicron to 1 micron.

Color: A physical characteristic of water often used to judge water quality; pure water is colorless.

Combined wastewater: The combination of sanitary wastewater and stormwater runoff.

Combustion: In chemical terms, the rapid combination of a substance with oxygen, accompanied by the evolution of heat and usually light. In air pollution control, combustion or incineration is a beneficial pollution control process in which the objective is to convert certain contaminants to innocuous substance such as carbon dioxide and water.

Commercial chemical products: USEPA category listing of hazardous wastes (also called *P* or *U* listed wastes because their code numbers begin with these letters); includes specific commercial chemical products or manufacturing chemical intermediates.

Commercial sources of municipal solid waste (MSW): Solids generated in restaurants, hotels, stores, motels, service stations, repair shops, markets, office buildings, and print shops.

Community Right-to-Know Act: A part of SARA Title III under CERCLA that stipulates that a community located near a facility storing, producing, or using hazardous materials has a right to know about the potential consequences of a catastrophic chemical spill or release of chemicals from the site.

Composite sample: A sample formed by mixing discrete samples taken at periodic points in time or a continuous proportion of the flow. The number of discrete samples that make up the composite depends on the variability of pollutant concentration and flow.

Composting: A beneficial reuse biological process whereby waste (e.g., yard trimmings or wastewater biosolids) is transformed into a harmless humus-like substance used as a soil amendment.

Compound: A substance composed of two or more elements, chemically combined in a definite proportion.

Concentrated solution: Solute in concentration present in large quantities.

Condensation: Air pollution control technology used to remove gaseous pollutants from the wastestream; a process in which the volatile gases are removed from the contaminant stream and changed into a liquid.

Condenser: Air pollution control device used in a condensation method to condense vapors to a liquid phase either by increasing the system pressure without a change in temperature or by decreasing the system temperature to its saturation temperature without a pressure change.

Conduction: Flow of heat energy through a material without the movement of any part of the material itself.

Confined aquifer: Consists of a water-bearing layer sandwiched between two less permeable layers; water flow is restricted to vertical movement only.

Conidia: The asexual spores borne on aerial mycelia (Actinomycetes bacteria).

Construction and demolition sources of MSW: Generated at new construction sites by the razing of old buildings and at road repair and renovation sites (e.g., broken pavement).

Consumers: Organisms that cannot produce their own food and that eat by engulfing or predigesting the fluids, cells, tissues, or waste products of other organisms.

Contact condenser: Similar to a simple spray scrubber, it cools vapor streams by spraying liquid directly on the vapor stream.

Control of disposal: A system of controls and restrictions governing the disposal of hazardous wastes onto, or into, the land; a key element of RCRA's goal of protecting groundwater supplies.

Convection: Method of heat transfer whereby the heated molecules circulate through the medium (gas or liquid).

Cooling tower method: A treatment method used to treat thermally polluted water by spraying the heated water into the air and allowing it to cool by evaporation.

Corrosive: Refers to a substance that attacks and eats away other materials by strong chemical action.

Covalent bond: A chemical bond produced when two atoms share one or more pairs of electrons.

Cradle-to-Grave Act: See *RCRA*.

Crustacean: One of a class of arthropods that includes crabs, lobsters, shrimps, woodlice, and barnacles.

Cultural eutrophication: Overnourishment of aquatic ecosystems with plant nutrients resulting from human activities, including agriculture, urbanization, and industrial discharge.

Cyclone collector: In air pollution control, used to remove particles from gas streams by centrifugal force.

Cytochrome: A class of iron-containing proteins important in cell metabolism.

Cytoplasm: The jelly-like matter within a cell.

Decomposers: Organisms such as bacteria, mushrooms, and fungi that obtain nutrients by breaking down complex matter in the wastes and dead bodies of other organisms into simpler chemicals, most of which are returned to the soil and water for reuse by producers.

Decomposition: Process whereby a chemical compound is reduced to its component substances; in biology, the destruction of dead organisms either by chemical reduction or by the action of decomposers.

Deep-well injection: In waste control technology, the ultimate disposal of liquid hazardous waste under pressure to underground strata isolated by impermeable rock strata to a depth of about 700 meters.

Density: The ratio of the weight of a mass to the unit of volume.

Depletion: In evaluating ambient air quality, pertains to the fact that pollutants emitted into the atmosphere do not remain there forever.

Desertification: Creation of deserts by changes in climate or by human-aided processes.

Detoxification: Biological conversion of a toxic substance to one less toxic.

Dewatering: The physical or chemical process of removing water from sludge or biosolids.

Diatoms: Microscopic single-celled algae found in all parts of the world.

Diffusion: (1) Mixing of substances, usually gases and liquids, from molecular motion. (2) The spreading out of a substance to fill a space.

Dilute solutions: A solution weakened by the addition of water, oil, or other liquid or solid.

Dinoflagellates: Unicellular, photosynthetic protistan algae.

Direct flame combustion (flaring): Used in air pollution control technology to burn off process off-gases (e.g., methane).

Disinfection: Chemical or physical processes that effectively kill all organisms capable of causing infectious disease (e.g., chlorination is commonly employed for disinfection in wastewater treatment processes).

Dispersion: The dilution and reduction of concentration of pollutants in either air or water. Air pollution dispersion mechanisms are a function of the prevailing meteorological conditions.

Dissolved oxygen (DO): The amount of oxygen dissolved in a stream, river, or lake which indicates the degree of health of the body of water and its ability to support a balanced aquatic ecosystem.

DNAPLs (dense nonaqueous-phase liquids): Liquids such as carbon tetrachloride, creosote, trichloroethane, dichlorobenzene, and others that can contaminate groundwater supplies.

Domestic wastewater: Consists mainly of human and animal wastes, household wastes, small amounts of groundwater infiltration, and perhaps small amounts of industrial wastes.

Dose–response curve: A visual means of determining, based on collected data, the percent mortality compared to dose administered.

Dose–response evaluation: Toxicological evaluation of the potency of a chemical.

Dose–response relationship: Used by toxicologists as the basis for their toxicological considerations. A dose is administered to test animals and, depending on the outcome, is increased or decreased until a range is found where at the upper end all animals die and at the lower end all animals survive.

Drainage basin: The geographical region drained by a river or stream.

Dry adiabatic lapse rate: When a dry parcel of air is lifted in the atmosphere, it undergoes adiabatic expansion and cooling that result in a lapse rate (cooling) of 1°C/100 meters.

Dry tower method: A thermal pollution treatment technique whereby heated water is pumped through tubes and the heat is released into the air (similar to the performance of an automobile radiator).

Dumps: An open location where refuse and other waste materials are disposed of in a manner that does not protect the environment, is susceptible to open burning, or is exposed to the elements, vermin, or scavengers.

Dystrophic: Defective nutrition.

Ecological toxicology: The branch of toxicology that addresses the effect of toxic substances, not only on the human population but also on the environment in general, including air, soil, surface water, and groundwater.

Ecology: The study of the interrelationships of an organism or a group of organisms with their environment.

Ecosystem: A self-regulating natural community of plants and animals interacting with one another and with their nonliving environment.

Ecotoxicology: See *Ecological toxicology*.

Electrolytic recovery technique: Used primarily for recovery of metals from process streams, to clean process waters, or to treat wastewaters prior to discharge; based on the oxidation–reduction reaction where electrode surfaces are used to collect the metals from the wastestream.

Electron: A component of an atom that travels in a distant orbit around a nucleus.

Electron transport system: In metabolic transfer, a series of electron carriers that operate together to transfer electrons from donors such as NADH and $FADH_2$ to acceptors such as oxygen.

Electrostatic precipitation: Process using a precipitator to remove dust or other particles from air and other gases by electrostatic means. An electric discharge is passed through the gas, giving the impurities a negative electric charge. Positively charged plates are then used to attract the charged particles and remove them from the fast flow.

Elements: The simplest substance that cannot be separated into more simple parts by ordinary means. There are more than 100 known elements.

Emergency response: Relates primarily to OSHA's requirement under 29 CFR 1910.120 for chemical, industrial, storage, and waste sites to have a written emergency response plan for any covered chemical release or spill to the environment that could jeopardize the good health and well-being of any worker. USEPA also requires an emergency response plan for facilities handling, producing, or using covered chemicals in its risk management plan requirements. Contingencies for fire, natural disasters, terrorist attacks, and medical emergencies should also be included in emergency response plans.

Emergent vegetation: A subdivision of the littoral zone of a pond that encompasses the shoreline soil area and the immediate shallow water area where emergent plant life can take root under water, grow, and surface above the waterline.

Emergents: See *Emergent vegetation*.

Endergonic: A reaction in which energy is absorbed.

Endoplasmic reticulum: Within a eucaryotic cell, a system of membranes ramifying the cytoplasmic region; it forms the limiting boundaries, compartments, and channels whose lumina are completely isolated from the cytoplasm. It is a protein-containing lipid bilayer.

Energy: A system capable of producing a physical change of state.

Entropy: A measure of the disorder of a system.

Environment: All the surroundings of an organism, including other living things, climate, soil, etc.; in other words, the conditions for development or growth.

Environmental degradation: All the limiting factors that act together to regulate the maximum allowable size or carrying capacity of a population.

Environmental factors: Factors that influence volatilization of hydrocarbon compounds from soils, such as temperature, wind, evaporation, and precipitation.

Environmental science: The study of the human impact on the physical and biological environment of an organism. In its broadest sense, it also encompasses the social and cultural aspects of the environment.

Environmental toxicology: The branch of toxicology that addresses the effect of toxic substances not only on the human population but also on the environment in general, including air, soil, surface water, and groundwater.

Enzymes: Proteinaceous substances that catalyze microbiological reactions such as decay or fermentation. They are not used up in the process but speed it up greatly. They can promote a wide range of reactions, but a particular enzyme can usually only promote a reaction on a specific substrate.

Epilimnion: Upper layer of a lake; it is heated by the sun and is lighter and less dense than the underlying water.

Eucaryotic: An organism characterized by a cellular organization that includes a well-defined nuclear membrane.

Euphotic: The surface layer of an ocean, a lake, or other body of water through which sufficient sunlight reaches to allow photosynthesis.

Eutrophic lake: Lake with a large or excessive supply of plant nutrients (mostly phosphates and nitrates).

Eutrophication: Natural process in which lakes receive inputs of plant nutrients as a result of natural erosion and runoff from the surrounding land basin.

Evaporative emissions: The evaporative emission of fuel from internal combustion systems caused by diurnal loses, hot soak, and running losses.

Evapotranspiration: Combination of evaporation and transpiration that transforms liquid water in plant tissue and in the soil to water vapor in the atmosphere.

Excavation: The physical removal of soil to construct a burial site for contaminants (landfill) or the removal of contaminated soil by mechanical means.

Excavation and disposal: The removal of contaminated soil for treatment or ultimate disposal.

Exergonic: Releasing energy.

Exposure assessment: Measurement to estimate the magnitude of actual or potential human exposures, the frequency and duration of these exposures, and the pathways by which humans are potentially exposed.

Exposure pathways: Can be divided into the two categories of *direct human exposure pathways* and *environmental exposure pathways*. Each of these categories is further subdivided into primary and secondary exposure pathways. Primary pathways directly affect site operations and personnel (e.g., skin contact during soil sampling). Secondary exposure pathways occur as a minor component during site operations and exhibit significant decreases with time as treatment progresses (e.g., wind-blown dust).

Extraction procedure (EP): A standardized laboratory test used to test for toxicity; replaced in 1990 by the toxicity characteristics leaching procedure (TCLP).

Extraction well: Used to lower the water table, creating a hydraulic gradient that draws a plume of contamination to the well so the contaminant can be extracted.

Extremely hazardous substance: USEPA term for those chemicals that must be reported to the appropriate authorities if released above the threshold reporting quantity.

Facultative: Bacteria capable of growth under aerobic and anaerobic conditions.

Federal Water Pollution Control Act (Clean Water Act): Act concerned with controlling and regulating the amount of municipal and industrial pollution fed into the nation's water bodies.

Fermentation: The decomposition of organic substances by microorganisms or enzymes. The process is usually accompanied by the evolution of heat and gas and can be aerobic or anaerobic.

Fertilizer: Substance that adds essential nutrients to the soil and makes the land or soil capable of producing more vegetation or crops.

Filtration: Technique by which suspended solid particles in a fluid are removed by passing the mixture through a filter. The particles are retained by the filter to form a residue, and the fluid that passes through is known as the filtrate.

First law of thermodynamics: In any chemical or physical change, movement of matter from one place to another, or change in temperature, energy is neither created nor destroyed but merely converted from one form to another.

Flagella: A threadlike appendage that gives some bacteria motility; it extends outward from the plasma membrane and cell wall.

Flare: See *Direct flame combustion.*

Flexible-membrane liner (FML): Rubber or plastic liner used in sanitary landfills.

Floating leaf vegetation: Part of the littoral zone in a lake or pond where vegetation rooted under the surface allows stems to produce foliage that is able to reach and float on the water surface.

Fluoride: Fluoride salt is added to public drinking water supplies for improved resistance to dental caries.

Food chain: A sequence of transfers of energy in the form of food from organisms in one trophic level to organisms in another trophic level when one organism eats or decomposes another.

Food web: A complex network of many interconnected food chains and feeding interactions.

Formula weight: The sum of the atomic weight of all atoms that comprise one formula unit.

Friable: Readily crumbled in hand.

Front: In meteorology, the boundary between two air masses of different temperature or humidity.

Frustules: The distinctive two-piece wall of silica in diatoms.

Fumigation: Results when emissions from a smokestack that is under an inversion layer head downward, leading to greatly elevated downwind, ground-level concentrations of contamination.

Fungi: Saprophytic or parasitic organisms that may be unicellular or made up of tubular filaments and that lack chlorophyll.

Garbage: The generic name for waste emanating from households that contains mostly vegetable matter and paper.

Gas: In the widest sense, term applied to all aeriform bodies, the most minute particles of which exhibit the tendency to fly apart from each other in all directions. Normally, these gases are found in that state at ordinary temperature and pressure. They can only be liquefied or solidified by artificial means, either through high pressure or extremely low temperatures.

Gas laws: The physical laws concerning the behavior of gases. They include Boyle's law and Charles's law, which are concerned with the relationships among the pressure, temperature, and volume of an ideal (hypothetical) gas.

General biological succession: The process whereby communities of plant and animal species in a particular area are replaced over time by a series of different and usually more complex communities (also referred to as *ecological succession*).

Genome: A complete haploid set of chromosomes.

Genus: A group of species with many common characteristics.

Geology: The science of Earth, its origin, composition, structure, and history.

Geophysical testing: Used to evaluate the subsurface layers, locate the water table, and map contaminate contours using resistivity and conductivity meters.

Geosphere: Consists of the inorganic, or nonliving, portions of Earth which are home to all of the globe's organic, or living, matter.

Geothermal energy: The use of Earth's natural heat for human purposes; a form of alternative energy that is massive but difficult to tap.

Geothermal power: See *Geothermal energy.*

Global warming: The long-term rise in the average temperature of the Earth.

Glycolysis: One of three phases of the catabolism of glucose to carbon and water process.

Grab sample: An individual discrete sample collected over a period of time not exceeding 15 minutes.

Gram: The basic unit of weight in the metric system; equal to 1/1000th of a kilogram; approximately 28.5 grams equal 1 ounce.

Gravity: The force of attraction that arises between objects by virtue of their masses. On Earth, gravity is the force of attraction between any object in the Earth's gravitational field and the Earth itself.

Gravity settlers: Used for the removal of solid and liquid waste materials from gaseous streams. Consists of an enlarged chamber in which the horizontal gas velocity is slowed, allowing particles to settle out by gravity.

Greenhouse effect: Heat trapped in the atmosphere. Incoming short-wavelength solar radiation penetrates the atmosphere, but the longer wavelength outgoing radiation is absorbed by water vapor, carbon dioxide, ozone, and several other gases in the atmosphere and is reradiated to Earth, causing an increase in atmospheric temperature.

Greenhouse gases: The gases present in the Earth's atmosphere that cause the greenhouse effect.

Groundwater: Water collected underground in porous rock strata and soils; it emerges at the surface as springs and streams.

Grout curtain: Used in *in situ* isolation and containment; Portland cement or grout is injected under pressure to form a barrier against contaminant movement in soil.

Growth curve: A plot of bacterial growth cycles. The curve is divided into four phases designated as lag, exponential, stationary, and death. The lag phase, characterized by little or no growth, corresponds to an initial period of time when bacteria are first inoculated into a fresh medium. After the bacteria have adjusted to their new environment, a period of rapid growth (the exponential phase) follows; during this time, conditions are optimal, and the population doubles with great regularity. As the bacteria food supply begins to be depleted or as toxic metabolic products accumulate, the population enters the no-growth, or stationary, phase. Finally, as the environment becomes more and more hostile, the death phase is reached, and the population declines.

Guano: A substance composed chiefly of the dung of sea birds or bats; it accumulates along certain coastal areas or in caves and is used as fertilizer.

Habitat: The place or type of place where an organism or community of organisms naturally or normally thrives.

Hardness: A water quality parameter. Water that does not lather easily with soap and produces scale in pots, pans, and kettles contains certain salts of calcium and magnesium.

Hazardous and Solid Waste Act and Amendments: Part of RCRA that emphasizes the development and use of alternative and innovative treatment technologies that result in permanent destruction of wastes or reduction in toxicity, mobility, and volume. Land disposal is greatly restricted under the 1984 RCRA amendments.

Hazardous chemical: An explosive, flammable, poisonous, corrosive, reactive, or radioactive chemical requiring special care in handling because of hazards it poses to public health and the environment.

Hazardous material: A substance in a quantity or form posing an unreasonable risk to health, safety, or property when transported in commerce and that by its nature, containment, and reactivity has the capability for inflicting harm during an accident occurrence. Such a substance is characterized as toxic, corrosive, flammable, reactive, an irritant, or a strong sensitizer and thereby poisonous. It is a threat to health and the environment when improperly managed.

Hazardous substance: A USEPA term for certain listed chemicals; if they are released into the environment above a certain amount, the incident must be reported.

Hazardous waste: Waste materials or mixtures of waste that require special handling and disposal because of their potential to damage health and the environment.

Hazardous wastestream: A gaseous or liquid wastestream that contains any type of hazardous substance.

Heat: A condition of matter caused by the rapid movement of its molecules. Energy has to be applied to the material in sufficient amounts to create the motion and may be applied by mechanical or chemical means.

Heat balance: The constant trade-off that takes place when solar energy reaches the Earth's surface and is absorbed but then must return to space to maintain Earth's normal heat balance.

Heat islands: Large metropolitan areas where the heat generated has an influence on the ambient temperature (adds heat) in and near the area.

Heavy metals: A group of elements whose compounds are toxic to humans when found in the environment; examples are cadmium, mercury, copper, nickel, chromium, lead, zinc, and arsenic.

Henry's law: Governs the behavior of gases in contact with water.

Heterotroph: See *Heterotrophic*.

Heterotrophic: Refers to organisms that obtain their energy by consuming the tissue of other organisms.

Holoenzyme: A complete enzyme consisting of an apoenzyme and a coenzyme.

Horizon: In soil, a layer of soil approximately parallel to the soil surface and differing in properties and characteristics from adjacent layers below or above it.

Hot-mix asphalt process: A remedial technology whereby a contaminant entrained in soil is used in beneficial applications to make asphalt. In the hot-mix process, the petroleum-laden soil is added as part of the aggregate to hot asphalt and then mixed to make the final product.

Hot soak: Evaporative emissions caused by heat from an internal combustion engine after the engine is shut off.

Humidity: The amount of water vapor in a given volume of the atmosphere (absolute humidity), or the ratio of the amount of water vapor in the atmosphere to the saturation value at the same temperature (relative humidity).

Humus: That more or less stable fraction of the soil organic matter remaining after the major portions of added plant and animal residues are decomposed; usually dark in color.

Hydraulic gradient: The difference in hydraulic head divided by the distance along the fluid flow path. Groundwater moves through an aquifer in the direction of the hydraulic gradient.

Hydrocarbon: A chemical containing only carbon and hydrogen atoms. Crude oil is a mixture largely of hydrocarbons.

Hydrological cycle: The means by which water is circulated in the biosphere. Cooling in the atmosphere and precipitation over both land and oceans counterbalance evapotranspiration from the land mass plus evaporation from the oceans.

Hydrosphere: The portion of the Earth's surface covered by the oceans, seas, and lakes.

Hypha (sing.), hyphae (pl.): In fungi, a tubular cell that grows from the tip and may form many branches.

Hypolimnion: The cold, relatively dense bottom layer of water in a stratified lake.

Ideal gas: A hypothetical gas that obeys the gas laws exactly with regard to temperature, pressure, and volume relationships.

Igneous: Refers to rock formed by the cooling and solidification of hot, molten material.

Ignitability: One of the characteristics used to classify a substance as hazardous.

Impaction: In air pollution control technology, a particle collection process whereby the center of mass of a particle diverging from a fluid strikes a stationary object and is collected by the stationary object.

Impoundment: A lake classification; an artificially manmade lake made by trapping water from rivers and watersheds.

***In situ* biodegradation:** Uses naturally occurring microorganisms in soil to degrade contaminants to another form.

***In situ* isolation/contamination:** In soil remediation, this method prevents the migration of liquid contaminant or leachates containing contaminants.

***In situ* leaching and chemical reaction:** Soil remediation process whereby water mixed with a surfactant is used to leach contaminants from the soil into the groundwater. The groundwater is then collected downstream of the leaching site through a collection system for treatment and/or disposal.

***In situ* passive remediation:** The easiest to implement and least expensive remediation methodology because it involves no action at the site; it lets nature takes its course but is not readily or normally accepted by regulators.

***In situ* technologies:** Remedial technologies performed in place at the site.

***In situ* vitrification:** Electrical current is passed through electrodes driven into the soil to produce extreme heat and convert the soil into a durable glassy material. The organic constituents are pyrolized in the melt and migrate to the surface, where they combust in the presence of oxygen. Inorganics in the soil are effectively bound in the solidified glass.

***In situ* volatilization:** Commonly known as air stripping, this process uses forced air or drawn air currents through in-place soil to remove volatile compounds.

Incineration: The application of high temperatures (800 to 3000°F) to break down organic wastes into simpler forms and to reduce the volume of waste requiring disposal. Energy can be recovered from the incineration heat.

Inclusions: Storage granules often seen within bacterial cells.

Industrial practices: Practices that can lead to soil contamination, including contaminants from USTs, oilfield sites, chemical sites, geothermal sites, manufactured gas plants, mining sites, and environmental terrorism.

Industrial wastewater: Liquid wastes produced by industry.

Infiltration galleries: Technique used in the *in situ* biodegradation process to reintroduce conditioned groundwater to the soil or aquifer.

Infrared radiation: Invisible electromagnetic radiation of wavelength between about 0.75 mm and 1 mm (between the limit of the red end of the visible spectrum and the shortest microwaves).

Injection well: In groundwater remediation, type of well used to raise the level of the water table and to push a contaminated plume away from a potable water system (well).

Innovative cleanup technology: Any new or developing soil remediation technology.

Inorganic substance: A substance that is mineral in origin that does not contain carbon compounds, except as carbonates, carbides, etc.

Insolation: The amount of direct solar radiation incident per unit of horizontal area at a given level.

Institutional sources of MSW: Hospitals, schools, jails and prisons, and government centers are among the sources of municipal solid waste.

Interception: In particle collection technology, interception occurs when the particle's center of mass closely misses the object, but, because of its finite size, the particle strikes the object and is collected.

Interstate Commerce Clause: The clause in the U.S. Constitution upon which the federal government based its enactment of the Rivers and Harbors Act of 1988, enabling the U.S. Army Corps of Engineers to regulate and in some cases prohibit private and municipal dumping practices.

Ionic bonds: A chemical bond in which electrons have been transferred from atoms of low ionization potential to atoms of high electron affinity.

Irrigation: Artificial water supply for dry agricultural areas created by means of dams and channels.

Isobar: A line drawn on maps and weather charts linking all places with the same atmospheric pressure (usually measured in millibars).

Jet stream: A narrow band of very fast wind found at altitudes of 6 to 10 miles, in the upper troposphere or lower stratosphere.

Kelvin: Temperature scale used by scientists that begins at absolute zero and increases by the same degree intervals as the Celsius scale; that is, 0°C is the same as 273 K and 100°C is 373 K.

Krebs cycle or citric acid cycle: The final part of the chain of biochemical reactions by which organisms break down food using oxygen to release energy (respiration).

Land farming: Another name for land treatment whereby various contaminants are spread on soil and worked into the surface and subsurface to allow biodegradation to take place.

Land treatment: See *Land farming*.

Landfill: Land waste disposal site located without regard to possible pollution of groundwater and surface water resulting from runoff and leaching; waste is covered intermittently with a layer of earth to reduce scavenger, aesthetic, disease, and air pollution problems.

Landfilling: An ultimate disposal technique whereby solid and hazardous wastes are disposed of in excavated sites.

Lapse rate: The rate of change of air temperature with increasing height.

Latent heat of fusion: The amount of heat required to change 1 gram of a substance from the solid to the liquid phase at the same temperature.

Latent heat of vaporization: The amount of heat required to change 1 gram of a substance from the liquid to the gas phase at the same temperature.

Law of conservation of mass: In any ordinary physical or chemical reaction, matter is neither created nor destroyed but merely changes from one form to another.

Laxative effect: The consumption of hardwater combined with the presence of magnesium sulfates sometimes leads to the development of a laxative effect on new consumers.

Leach liquors: Refers to liquid leached from a substance via water circulation through or over it.

Leachate: The liquid formed when rainwater percolates downward through landfilled wastes, picking up contaminants that might then enter the surrounding environment.

Lead: A heavy metal, the accumulation of which in the organic tissues of animals and humans could lead to behavioral changes, blindness, and ultimately death.

Lead-mine scale: Generally occurs in geothermal process equipment such as in piping where scale buildup leads to process equipment failure.

Leaking Underground Storage Tank (LUST) Trust Fund: The 1986 U.S. UST cleanup fund.

Lentic: Calm; refers to lakes, ponds, and swamps.

Limited: Refers to growth regulated by such nutrients such as carbon, nitrogen, and phosphorus.

Limiting factors: Factors such as temperature, light, water, or a chemical that limit the existence, growth, abundance, or distribution of an organism.

Limiting nutrient: See *Limited*.

Limnetic: The open water surface layer of a lake through which sufficient sunlight reaches for photosynthesis.

Limnology: The study of lakes and other bodies of open freshwater in terms of their plant and animal biology and their physical properties.

Liquid: A state of matter between a solid and a gas.

Liter: A metric unit of volume, equal to 1 cubic decimeter (1.76 pints).

Lithosphere: The Earth's crust; the layers of soil and rock that comprise the Earth's crust.

Litter: The intact and partially decayed organic matter lying on top of the soil; discards thrown about without regard to the environment.

Littoral: The shallow zone near the shore of a body of water.

LNAPLs: Light nonaqueous-phase liquids (e.g., gasoline, heating oil, kerosene).

Loam: The textural class name for soil with a moderate amount of sand, silt, and clay. Loam soils contain approximately 7 to 27% clay, 28 to 50% silt, and 23 to 52% sand.

Lotic: Running freshwater systems (e.g., rivers or streams).

Magma: Molten rock material within the Earth's core.

Management factors: Management techniques (e.g., fertilization, irrigation) employed in land and soil management that work to decrease leaching, increase soil surface contaminant concentrations, or maximize soil aeration against volatilization.

Manifest: See *Tracking system*.

Mass: The quantity of matter and a measurement of the amount of inertia that a body possesses.

Mass balance equations: Used to track pollutants from one place to another.

Materials balance: The law of conservation of matter says that everything has to go somewhere and is neither created nor destroyed in the process.

Mature pond: A pond that has reached maturity; characterized by being carpeted with rich sediment, having aquatic vegetation extending out into open water, and being home to a great diversity of plankton, invertebrates, and fishes.

Maximum contaminant levels (MCLs): Primary drinking water standard and maximum contaminant levels allowed based on health-related criteria.

Maximum sustainable yield: The highest rate at which a renewable resource can be used without impairing or damaging its ability to be fully renewed.

Melting point: The temperature at which a substance changes from solid to liquid.

Meromictic: Refers to chemically stratified lakes in which different dissolved chemicals are partly mixed.

Mesosome: A common intracellular structure found in the bacterial cytoplasm; an invagination of the plasma membrane in the shape of tubules, vesicles, or lamellae.

Mesosphere: An atmospheric layer that extends from the top of the stratosphere to about 56 miles above the Earth.

Mesotrophic lakes: Lakes intermediate in characteristics between oligotrophic and eutrophic lakes.

Metabolic transformation: Refers to the assembly-line of activities that occur in microorganisms during the processing of raw materials into finished products.

Metabolism: The chemical processes of living organisms; a constant alternation of building up and breaking down. Green plants, for example, build up complex organic substances from water, carbon dioxide, and mineral salts (photosynthesis). Also, digestion partially breaks down complex organic substances ingested as food by animals so they can be utilized by their bodies.

Metalloids: An element that exhibits the properties of both metals and nonmetals.

Metals: Elements that tend to lose their valence electrons.

Metamorphic: A type of rock that forms when rocks lying deep below the Earth's surface are heated to such a degree that their original crystal structure is lost. As the rock cools, a new crystalline structure is formed.

Meteorology: The scientific observation and study of the atmosphere used to forecast weather accurately.

Meter: The standard of length in the metric system, equal to 39.37 inches or 3.28 feet.

Methane (CH_4): The simplest hydrocarbon of the paraffin series. Colorless, odorless, and lighter than air, it burns with a bluish flame and explodes when mixed with air or oxygen. Methane is a greenhouse gas.

Microbial community: The community of microbes available to biodegrade contaminants in the soil.

Microbial degradation: The natural process whereby certain microbes in soil can degrade contaminants into harmless constituents.

Microbiology: The study of organisms that can only be seen under the microscope.

Middens: Primitive dunghills or refuse heaps.

Midnight dumping: Illegal dumping of solid or hazardous wastes into the environment.

Mining waste: The earth and rock (including minerals and chemicals within) taken from a mine and discarded because the mineral or fuel content is too low to warrant extraction. This waste is an environmental problem if toxic substances leach from it into a river, stream, groundwater, or the soil.

Mitochondria: A microscopic body found in the cells of almost all living organisms and containing enzymes responsible for the conversion of food to usable energy.

Mixture: In chemistry, a substance containing two or more compounds that still retain their separate physical and chemical properties.

Mobile sources: Nonstationary sources of gaseous pollutants, including locomotives, automobiles, ships, and airplanes.

Mobilization: The mobilizing of metals in soil by the acidity of precipitation.

Modeling: Refers to the use of mathematical representations of contaminant dispersion and transformation to estimate ambient pollutant concentrations.

Molar concentration (molarity): In chemistry, a solution that contains 1 mole of a substance per liter of solvent.

Molecular weight: The weight of 1 molecule of a substance relative to carbon-12, expressed in grams.

Mole (mol): SI unit for the amount of a substance; the amount of a substance that contains as many elementary entities as there are atoms in 12 g of the isotope carbon-12.

Molecule: The fundamental particle that characterizes a compound. It consists of a group of atoms held together by chemical bonds.

Monitor wells: Wells installed specifically to provide a means to monitor a contaminant plume in soil or groundwater.

Monitoring: Process whereby a contaminant is tracked.

Montreal Protocol: International treaty that required signatory countries to reduce their consumption of chlorofluorocarbons by 20% by 1993 and by 50% by 1998.

Morphogenesis: Evolutionary development of the structure of an organism or part.

Motility: An organism's ability to move.

Municipal services sources of MSW: Restaurants, hotels, stores, motels, service stations, repair shops, markets, office building, and print shops produce such municipal solid waste.

Municipal solid waste (MSW): Municipally derived wastes, including paper, yard wastes, glass, metals, and plastics.

Mycelium: An interwoven mass of threadlike filaments or hyphae comprising the main body of most fungi; they produce the reproductive structures, or "fruiting bodies" (e.g., mushrooms).

Mycology: The branch of botany that deals with fungi.

National Ambient Air-Quality Standards (NAAQs): Standards established by USEPA at two levels: primary and secondary. Primary standards must be set at levels that will protect public health and include an "adequate margin of safety," regardless of whether the standards are economically or technologically achievable. Primary standards must protect even the most sensitive individuals, including the elderly and those with respiratory ailments. Secondary air quality standards are meant to be even more stringent than primary standards. Secondary standards are established to protect public welfare (e.g., structures, crops, animal, fabrics).

National Priorities List (NPL): Identifies the worst waste sites in the nation based on such factors as the quantities and toxicity of wastes involved, the exposure pathways, the number of people potentially exposed, and the importance and vulnerability of the underlying groundwater.

Nekton: In a water environment, the free-swimming organisms.

Neustons: In a water environment, the organisms living on the surface.

Neutrally stable atmosphere: An intermediate class between stable and unstable conditions; will cause a smoke-stack plume to take on the appearance of a cone as the edges of the plume spread out in a V shape.

Neutron: Elementary particles that have approximately the same mass as protons but have no charge. They are one constituent of the atomic nucleus.

Niche: The functional role of an organism within its community; the complete ecological description of an individual species (including habitat, feeding requirements, etc.).

Nitrates: In freshwater pollution, a nutrient, usually from fertilizer, that enters the water system and can be toxic to animals and humans in high enough concentrations.

Nitrification: The process that takes place in soil when bacteria oxidize ammonia, turning it into nitrates.

Nitrogen cycle: The natural circulation of nitrogen through the environment.

Nitrogen dioxide (NO_2): A reddish-brown, highly toxic gas with a pungent odor. One of the seven known nitrogen oxides that contribute to photochemical smog and primarily affect the respiratory system.

Nitrogen fixation: Nature accomplishes nitrogen fixation by means of nitrogen-fixing bacteria.

Nitrogen oxide (NO): A colorless gas used as an anesthetic; soil bacteria form NO from decomposing nitrogenous material.

Noncarbonate hardness: A property of water such that the hardness cannot be removed by boiling and is classified as permanent.

Non-*in situ* technology: Remediation/recycling technology that takes place away from the contamination site.

Nonmetals: An element that tends to gain electrons to complete its outer shell.

Nonpoint source: Source of pollution in which wastes are not released at one specific, identifiable point but from a number of points that are spread out and difficult to identify and control.

Nonpoint-source pollution: Pollution that cannot be traced to a specific source but rather comes from multiple generalized sources.

Nonrenewable resources: Resources that exist in finite supply or are consumed at a rate faster than the rate at which they can be renewed.

Nonspecific source wastes: Generic wastes commonly produced by manufacturing and industrial processes (e.g., spent solvents).

Nonvolatile: A substance that does not evaporate at normal temperatures when exposed to the air.

Normal lapse rate: The normal rate of temperature change with height; on average, temperature decreases 65°C/100 meters.

Nucleoid: The primitive nuclear region of the procaryotic cell.

Nutrient cycles: See *Biogeochemical cycles*.

Nutrients: Elements or compounds needed for the survival, growth, and reproduction of a plant or animal.

Nutrition: The process of nourishing or being nourished.

Oligotrophic lake: A lake with a low supply of plant nutrients.

Organelle: A specialized part of a cell that resembles and functions as an organ.

Organic chemistry: Branch of chemistry concerned with compounds of carbon.

Organic matter: Includes both natural and synthetic molecules containing carbon and usually hydrogen. All living matter is made up of organic molecules.

Organic substance: Any substance containing carbon.

Overgrazing: Consumption of vegetation on rangeland by grazing animals to the point that the vegetation cannot be renewed or is renewed at a rate slower than consumption.

Oxidation: The process by which electrons are lost.

Oxidation–reduction: The (redox) process where electrons are lost and gained.

Oxidize: To combine with oxygen.

Oxygen: An element that readily unites with materials.

Oxygen sag curve: The oxygen content in a stream or river system after organic pollution is introduced into the water body; organic pollution causes a profusion of organism growth that tends to decrease the amount of oxygen available.

Ozone (O_3): Found naturally in the atmosphere in the ozonosphere; a constituent of photochemical smog.

Ozone holes: Holes created in the ozone layer because of chemicals, especially CFCs.

Packed tower: A remediation method (scrubber) employed to clean a contaminated gaseous wastestream by exposing the wastestream to biological media or chemical scrubbing agents.

Parasite: Primary, secondary, or higher consumer that feeds on a plant or animal, known as a host, over an extended period of time.

Parent material: The unconsolidated and more or less chemically weathered mineral or organic matter from which pedogonic processes develop the solum of soils.

Particulate matter: Normally refers to dust and fumes; travels easily through air.

Pascal (Pa): A unit of pressure equal to 1 newton per square meter.

Pathogen: Any disease-producing organism.

Pedologist: A person who studies soils.

Peds: A unit of soil structure such as an aggregate, crumb, prism, block, or granule formed by natural processes.

Pellicle: A *euglena* structure that allows for turning and flexing of the cell.

Period: (1) An interval of geologic time that is a subdivision of an era and made up of epochs. (2) A horizontal row of the periodic table that contains elements with approximately the same energy.

Periodic law: The properties of elements are periodic functions of the atomic number.

Periodic table: An arrangement of all elements in order of increasing atomic numbers and grouped by similar physical and chemical characteristics into periods; based on the chemical law that physical or chemical properties of the elements are periodic functions of their atomic weights.

Permanent pond: Actually a misnomer, as no pond is permanent. Generally, a pond shallow enough to permit aquatic plants to penetrate the surface anywhere over its entire mass; its mass is not so great as to allow formation of large waves that could erode the shoreline. Such ponds have no temperature layering but rather a gradient of temperatures extending from the surface to bottom.

Permitting system: A key element of RCRA, this system works to ensure the safe operation of facilities that treat, store, or dispose of hazardous wastes.

Perpetual resource: A resource such as solar energy that comes from an essentially inexhaustible source and thus will always be available on a human time scale regardless of whether or how it is used.

Persistent substance: A chemical product with a tendency to persist in the environment for quite some time (e.g., plastics).

Pesticide: Any chemical designed to kill weeds, insects, fungi, rodents, and other organisms that humans consider to be undesirable.

pH: A numerical designation of relative acidity and alkalinity. A pH of 7 indicates precise neutrality; higher values indicate increasing alkalinity, and lower values indicate increasing acidity.

Phosphates: A nutrient substance obtained from fertilizers.

Phosphorus cycle: A biogeochemical cycle in which phosphorus is converted into various chemical forms and transported through the biosphere.

Photochemical reaction: A reaction induced by the presence of light.

Photochemical smog: Complex mixture of air pollutants in the atmosphere due to hydrocarbon and nitrogen oxide reactions under the influence of sunlight.

Photosynthesis: A complex process that occurs in the cells of green plants whereby radiant energy from the sun is used to combine carbon dioxide (CO_2) and water (H_2O) to produce oxygen (O_2) and simple sugar or food molecules, such as glucose.

Physical change: The process that alters one or more physical properties of an element or compound without altering its chemical composition. Examples include changing the size and shape of a sample of matter and changing a sample of matter from one physical state to another.

Physical weathering: The physical changes produced in rocks by atmospheric agents (e.g., wind, precipitation, heat, cold).

Pioneer community: The first successfully integrated set of plants, animals, and decomposers found in an area undergoing primary ecological succession.

Piping failure: A common equipment component failure in many different systems; it is the most common cause of underground storage tank spills.

Plankton: Microscopic floating plant and animal organisms in lakes, rivers, and oceans.

Planktonic: See *Plankton*.

Plasma membrane: See *Cytoplasmic membrane*.

Plate tower: Used for absorption scrubbing; plate towers contain perforated horizontal plates or trays designed to provide a large liquid–gas interfacial area. The polluted air stream rises up through the perforations in each plate, and the rising gas prevents liquid from draining through the openings rather than through a downpipe. During continuous operation, contact is maintained between air and the liquid, allowing gaseous contaminants to be removed and clean air to emerge from the top of the tower.

Plume: (1) The column of noncombustible products emitted from a fire or smokestack. (2) A vapor cloud formation having shape and buoyancy. (3) A contaminant formation dispersing through the subsurface.

Point source: Discernible conduits, including pipes, ditches, channels, sewers, tunnels, or vessels, from which pollutants are discharged.

Point-source pollution: Pollution that can be traced to an identifiable source.

Pollute: To impair the quality of some portion of the environment by the addition of harmful impurities.

Pond: A still body of water, smaller than a lake and often of artificial construction.

Pond succession: Pond transformation process whereby a young pond is formed and develops over time to a mature pond and then to a senescent (old) pond.

Pool zone: In a body of moving water (river or stream), the quiet or still water portion.

Positive crankcase ventilation (PCV): Technology used to control crankcase emissions.

Preliminary treatment: (1) In wastewater, treatment occurring prior to primary treatment. (2) In industrial applications, pretreatment of wastestreams before they become plant effluent and then influent into wastewater treatment plants for further treatment.

Pressure: Force per unit area.

Pressure gradient force: A variation of pressure with position.

Primary consumers: In the food chain, organisms that consume producers (autotrophs).

Primary exposure pathways: In site remediation, the exposure pathways that directly affect site operations and personnel or directly affect the cleanup levels that must be achieved by the remedial technology.

Primary pollutants: Pollutants emitted directly into the atmosphere, where they exert an adverse influence on human health or the environment. The six primary pollutants are carbon dioxide, carbon monoxide, sulfur oxides, nitrogen oxides, hydrocarbons, and particulates. All but carbon dioxide are regulated in the United States.

Primary standards: The Clean Air Act (NAAQS) air quality standard covering criteria pollutants.

Primary treatment: Wastewater treatment process in which mechanical treatment is employed to screen out large solids and settle out suspended solids.

Procaryotic: A type of primitive cell lacking a membrane-delimited nucleus.

Producers: Organisms that use solar energy (green plant) or chemical energy (some bacteria) to manufacture their own organic substances (food) from inorganic nutrients.

Profundal: Deepwater zone of a lake not penetrated by sunlight.

Proton: Component of a nucleus, 2000 times more massive than an electron; differs from a neutron by its positive (+1) electrical charge. The atomic number of an atom is equal to the number of protons in its nucleus.

Protozoa: Single-celled microorganisms; includes the most primitive forms of animal life.

Pumping well system: In control technology for leaking USTs, the preferred method used to recover free product from the water table when the spill is deep.

Radiation: The emitting of energy from an atom in the form of particles of electromagnetic waves; energy waves that travel with the speed of light and, upon arrival at a surface, are absorbed, reflected, or transmitted.

Radiative inversions: A nocturnal phenomenon caused by cooling of the Earth's surface. Inversions prompt the formation of fog and simultaneously trap gases and particulates, creating a concentration of pollutants.

Radioactive material: Any material that spontaneously emits ionizing radiation.

Rapids zone: The turbulent zone of a stream or river in which water is agitated by subsurface obstructions causing turbulence and aeration of water.

Reactive: The tendency of a material to react chemically with other substances.

Recharge area: The area in which precipitation percolates through to recharge groundwater.

Recovery zone: The zone in a stream or river where contamination is reduced by the self-purification process.

Recycle: The process of recovery and reuse of materials from wastestreams.

Recycling technology: The technology available to recycle or reuse waste products; processes such as composting and hot- and cold-mix asphalt incorporation.

Reduction: Removal of oxygen from a compound; lowering of oxidation number resulting from a gain of electrons.

Refuse: Rubbish and garbage from residential sources.

Relative humidity: The percentage of moisture in a given volume of air at a given temperature in relation to the amount of moisture the same volume of air would contain at the saturation point.

Renewable resources: Resources that can be depleted in the short run if used or contaminated too rapidly but that normally are replaced through natural processes.

Representative sample: A sample of a universe or whole, such as a waste pile, lagoon, or groundwater, that can be expected to exhibit the average properties of the whole.

Reservoir: A large and deep human-created standing body of freshwater.

Residential sources of MSW: Household waste consisting primarily of paper, glass, vegetable waste, paperboard, ash, tin cans, etc.

Resource: Something that serves a need, is useful, and is available at a particular cost.

Resource Conservation and Recovery Act (RCRA) of 1976: Act passed by U.S. Congress to control dumping of waste materials (also known as the Cradle-to-Grave Act).

Reuse: To use a product again and again in the same form, as when returnable glass bottles are cleaned and refilled.

Ribosomes: In bacterial cytoplasm, minute, rounded bodies made of RNA that are loosely attached to the plasma membrane; they are the site of protein synthesis and are part of the translation process.

Risk assessment: Evaluation of the threat to public health and the environment posed by a hazardous waste facility; considering the probability of an incident and its effects.

Risk characterization: Final step in risk assessment process estimating potential adverse health effects under the conditions of exposure found and described in the exposure assessment.

Rivers & Harbors Act (1899): The first legislative authority given to a federal agency (U.S. Army Corps of Engineers) to prevent dumping wastes into rivers and harbors.

Rotifers: A minute multicellular aquatic organism with a wheel-like ring of cilia at the anterior end.

Rubbish: Combustible waste, paper, cartons, rags, wood scraps, and combustible floor sweepings from, for example, domestic, commercial, and industrial sources.

Running losses: Evaporative emissions from internal combustion engine as a result of driving; losses also occur when the fuel is heated by the road surface and when fuel is forced from the fuel tank while the vehicle is being operated and the fuel tank becomes hot.

Runoff: Surface water entering rivers, freshwater lakes, or reservoirs from land surfaces.

Safe Drinking Water Act (SDWA): Mandated USEPA to establish drinking water standards for all public water systems serving 25 or more people or having 15 or more connections.

Saline water: Water with excessive salt content.

Salt spreading: Applying salt to roadways in the winter to help reduce ice and snow accumulations; road salts contaminate soil during runoff.

Sanitary landfill: A method of solid waste disposal designed to minimize water pollution from runoff and leaching; waste is covered with a layer of soil within a day after being deposited at the landfill site.

Sanitary wastewater: Separate sewer system designed to remove domestic wastes from residential areas.

Saprophyte: An organism that uses enzymes to feed on waste products of living organisms or tissues of dead organisms.

SARA (Superfund Amendments and Reauthorization Act of 1986): See *CERCLA*.

Saturated zone: Subsurface soil saturated with water; the water table.

Scaling: When carbonate hardwater is heated, calcium carbonate and magnesium hydroxide are precipitated out of solution, forming a rock-hard scale that clogs hotwater pipes and reduces the efficiency of boilers, water heaters, and heat exchangers.

Science: The observation, identification, description, experimental investigation, and theoretical explanation of natural phenomena.

Scientific method: A systematic form of inquiry that involves observation, speculation, and reasoning.

Sea-level rise: The natural rise of sea level that occurs in cyclical patterns throughout history; may be the result of human impacts on global warming.

Second law of thermodynamics: Natural law that dictates that in any conversion of heat energy to useful work some of the initial energy input is always degraded to a lower quality, more dispersed, less useful form of energy, usually low-temperature heat that flows into the environment; law cannot be broken even in terms of energy quality.

Secondary drinking water standards: The unenforceable guidelines based on both aesthetics, including taste, odor, and color of drinking water, as well as nonaesthetic characteristics such as corrosivity and hardness.

Secondary exposure pathways: In onsite remediation, these occur during site operations and exhibit significant decreases with time as treatment progresses (e.g., wind-blown dust).

Secondary standards: Refers to NAAQS requirement to protect public welfare.

Secondary treatment of sewage: The removal of impurities from water by the digestive action of various small organisms in the presence of air or oxygen.

Secure landfill: A land site used for the storage of hazardous solid and liquid wastes, which are normally placed in containers and buried in a restricted-access area that is continually monitored. Such landfills are located above geologic strata that are supposed to prevent the leaching of wastes into groundwater.

Sedimentary: Refers to a rock formed from materials deposited from suspension or precipitated from solution and usually being more or less consolidated. The principal sedimentary rocks are sandstones, shales, limestones, and conglomerates.

Sediments: Soil particles dislodged by rain drops that travel via runoff into streams, rivers, lakes, or oceans and are deposited there.

Self-purification: The natural phenomenon occurring in running water systems (streams and rivers) whereby physical, chemical, and biological processes work to self-purify the water.

Senescent pond: A pond that has reached old age.

Separation: A hazardous waste treatment technology (filtration and separation) whereby filtration is used to separate solid particles from a liquid stream through the use of semiporous media; driven by a pressure difference across the media and caused by gravity, centrifugal force, vacuum, or elevated pressure.

Septic zone: In the self-purification process that takes place in running water bodies (streams or rivers), the zone characterized by heavy organic pollution and low dissolved oxygen levels.

Sheet piling: In *in situ* isolation/containment technology, the physical driving of rigid sheets, pilings of wood, steel, or concrete into the ground to form a barrier for containment.

Silage liquor: The liquid drained or leached from fodder prepared by storing and fermenting green forage plants in a silo.

Sinks: Areas, whether natural or artificial, where the products or effluents from production and consumption in one place are physically exported to another for storage or dispersal.

Slope: A soil property in which the steepness of the soil layer is directly related to the degree of erosion that may occur.

Slope winds: Winds that move through a typical river valley; they flow downhill into the valley floor.

Slurry walls: In *in situ* isolation/containment, fixed underground physical barriers formed in an excavated trench by pumping slurry, usually a bentonite or cement and water mixture.

Smog: Term used to describe visible air pollution; a dense, discolored haze containing large quantities of soot, ash, and gaseous pollutants such as sulfur dioxide and carbon dioxide.

Soft water: Water with a hardness of less than 50 ppm.

Soil: A dynamic natural body in which plants grow; it is composed of mineral and organic materials and living forms.

Soil boring: Using a boring tool (such as an auger) to take soil samples for analysis.

Soil factors: In *in situ* soil remediation, soil factors include water content, porosity/permeability, clay content, and adsorption site density.

Soil fertility: The quality of a soil that enables it to provide essential chemical elements in quantities and proportions for the growth of specified plants.

Soil forming process: The mode of origin of the soil, with special reference to the processes or soil-forming factors responsible for the development of the solum, or true soil, from the unconsolidated parent material.

Soil horizon: A layer of soil, approximately parallel to the soil surface, differing in properties and characteristics from adjacent layers below or above it.

Soil pollution: Contamination of the soil and subsurface by the addition of contaminants or pollutants.

Soil profile: A vertical section of the soil from the surface through all of its horizons, including C horizons.

Soil remediation: The use of various techniques or technologies to decontaminate or dispose of contaminated soil.

Soil sampling: Conducted to analyze the type, texture, and structure of a soil; samples of contaminated soil are collected to determine the degree and extent of contamination and for other analysis.

Soil structure: The combination or arrangement of primary soil particles into secondary particles, units, or peds. These secondary units may be, but usually are not, arranged in the profile in such a manner as to give a distinctive characteristic pattern. The secondary units are characterized and classified on the basis of size, shape, and degree of distinctness into classes, types, and grades, respectively.

Soil texture: The relative proportions of the various soil separates in a soil.

Soil washing and extraction: In pollution control technology applied to USTs, process used to leach contaminants from the soil into a leaching medium, after which the extracted contaminants are removed by conventional methods.

Solid: Matter that has a definite volume and a definite shape.

Solid waste: Any normally solid material that is useless or unwanted that results from human or animal activities.

Solid Waste Disposal Act (1965): The first major step taken by U.S. legislators to promote (among other things) the demonstration, construction, and application of solid waste management and resource recovery systems to preserve and enhance the quality of air, water, and land resources.

Solid wastestream: A stream of solid waste materials as a whole.

Solidification: A stabilization technique used to convert hazardous waste from its original form to a physically and chemically more stable material; accomplished by reducing the mobility of hazardous compounds in the waste prior to its land disposal.

Solubility: The ability of a substance to mix with water.

Solute: The dissolved substance in a solution.

Solvent: The substance in excess in a solution.

Sorption: Process of adsorption or absorption of a substance on or in another substance.

Species: A group of individuals or populations potentially able to interbreed and unable to produce fertile offspring when bred with other sorts of animals and plants.

Specific gravity: Ratio of the weight of the volume of liquid or solid to the weight of an equal volume of water.

Specific heat: The amount of heat energy in calories necessary to raise the temperature of 1 gram of the substance 1°C.

Specific source wastes: Wastes from specifically identified industries, including wood preserving, petroleum refining, and organic chemical manufacturing. Typically includes sludges, still bottoms, wastewaters, spent catalysts, and residues.

Spirilla: Bacteria shape characterized as being nonflexible, helical, and curved.

Spoil: Material removed from an excavation.

Sporangiospores: Spores that form within a sac called a *sporangium*. The sporangium is attached to a stalk called a *sporangiophore*.

Spore: Reproductive stage of fungi.

Spring overturn: Lake phenomenon whereby the entire body of water within the lake overturns because of changes in water density.

Stability: Atmospheric turbulence; a function of vertical distribution of atmospheric temperature.

Stability class: Term used to classify the degree of turbulence in the atmosphere.

Stabilization: See *Solidification/stabilization*.

Stable atmosphere: Marked by air that is cooler at the ground than aloft, by low wind speeds, and consequently by a low degree of turbulence.

Standard temperature and pressure (STP): The density of a gas depends on temperature and pressure, so it is customary to define the pressure and temperature against which the volume of a gas is measured. The normal reference point is standard temperature and pressure—0°C at a standard atmosphere of 760 mmHg. All gas volumes are referred to these standard conditions.

Stationary sources: Source of air pollution emanating from any fixed or stationary point.

Still bottoms: What remains after a spent solvent is distilled (for recycling); composed of a concentrated, highly toxic mixture, far reduced in volume.

Stockpiles: Certain chemical products (such as road salt) kept in quantity for possible use; runoff from such stockpiles may contribute to soil pollution.

Stormwater: Normal stormwater containing grit and street debris but no domestic or sanitary wastes.

Stratification: Temperature–density relationship of water in temperate lakes (>25 feet in depth) that leads to stratification and subsequent turnover or overturn.

Stratosphere: A region of the atmosphere based on temperature between approximately 10 and 35 miles in altitude.

Stripping: A waste control technology whereby volatile compounds are separated from less volatile ones in a liquid mixture by partitioning the more volatile materials to a gas phase of air or steam.

Subadiabatic: The ambient lapse rate when it is less than the dry adiabatic lapse rate.

Submerged vegetation: In a pond, the submerged plants that grow where light can penetrate the water surface and reach them.

Subsidence inversion: A type of inversion usually associated with a high-pressure system, known as anticyclones, which may significantly affect the dispersion of pollutants over large regions.

Subsoil: That part of the soil below the plow layer.

Substrate: The material or substance upon which an enzyme acts.

Suggested levels: Nonenforceable guidelines for secondary drinking water standards regarding public welfare.

Sulfur cycle: The natural circulation of sulfur through the environment.

Sulfur dioxide: A primary pollutant originating chiefly from the combustion of high-sulfur coals.

Sulfurous smog: The haze that develops in the atmosphere when molecules of sulfuric acid accumulate; the resulting droplets grow in size and become sufficiently large to serve as light scatterers.

Summer stagnation: In lake stratification, a state that occurs in some lakes when the top layer of water is warmer than the bottom layer. It results in layers of different density, with the top being light, the bottom heavy. With increased temperature, the top layer becomes even lighter, and a thermocline forms. From top to bottom, we now have the lightest and warmest on top, medium weight and relatively warm in the middle, and the heaviest and coldest below, with a sharp drop in temperature at the thermocline. The water in these three layers does not mix in circulation. If the thermocline is below the range of effective light penetration, the oxygen supply becomes depleted in the hypolimnion, because both photosynthesis and the surface source of oxygen are eliminated.

Superadiabatic: The lapse rate when a parcel of air starting at 1000 m at 20°C, for example, starts moving downward and becomes cooler and denser than its surroundings. Because the ambient air is unstable, it continues to sink.

Superfund: See *CERCLA* and *SARA*.

Surface condenser: In air pollution control technology, a type of condensation equipment, normally a shell-and-tube heat exchanger. It uses a cooling medium of air or water where the vapor to be condensed is separated from the cooling medium by a metal wall. Coolant flows through the tubes, while the vapor is passed over and condenses on the outside of the tubes and drains off to storage.

Surface impoundment: (1) Another name for a garbage dump. (2) Diked or excavated areas used to store liquid hazardous wastes.

Surface origins: The surface origins of soil contaminants that include gaseous and airborne particulates; infiltration of contaminated surface water; land disposal of solid and liquid waste materials; stockpiles, tailings, and spoil; dumps; salt spreading on roads; animal feedlots; fertilizers and pesticides; accidental spills; and composting of leaves and other wastes.

Surface water: Water on the Earth's surface, exposed to the atmosphere and mostly the product of precipitation.

Surfactant: A surface-active substance (e.g., soap).

Symbiotic: A close relationship between two organisms of different species where both partners benefit from the association.

Synthesis: The formation of a substance or compound from more elementary compounds.

Tailings: The residual fine-grained waste rejected after mining and processing of ore, usually after washing.

Taste and odor: A water quality parameter.

TCLP (Toxicity Characteristics Leaching Procedure): Replaced the EP toxicity test; it is designed to identify wastes likely to leach hazardous concentrations of particular toxic constituents into the surrounding soils or groundwater.

Temperature: A measure of the average kinetic energy of the molecules.

Temperature inversion: A condition characterized by an inverted lapse rate.

Thermal circulation: The result of the relationship based on a law of physics whereby the pressure and volume of a gas are directly related to its temperature.

Thermal incinerator (afterburner): A device used in combustion whereby the contaminant airstream passes around or through a burner and into a refractory-lined residence chamber where oxidation occurs. Flue gas from a thermal incinerator is at high temperature and contains recoverable heat energy.

Thermal inversion: A layer of cool air trapped under a layer of less dense warm air, thus preventing reversing to the normal situation.

Thermal NO_x: Created when nitrogen and oxygen in the combustion air (e.g., within an internal combustion engine) are heated to a high enough temperature (above 1000 K) to cause nitrogen (N_2) and oxygen (O_2) in the air to combine.

Thermal pollution: Increase in water temperature with harmful ecological effects on aquatic ecosystems.

Thermal radiation: Heat energy directly radiated into space from the Earth's surface and atmosphere.

Thermal treatment: In non-*in situ* soil pollution control technology, the complete destruction (by incineration) of petroleum-laden contaminants.

Thermal treatment processes: In waste control technology, incineration of wastes.

Thermocline: The fairly thin transition zone in a lake that separates an upper warmer zone from a lower colder zone.

Thermosphere: A region of the atmosphere based on temperature between approximately 60 miles to several hundred miles in altitude.

Threshold of effect: In the dose–response relationship, the level of "no effect."

Threshold reporting quantity: Level set by USEPA for extremely hazardous substances that if exceeded during spill or release to environment must be reported to appropriate authorities.

Tilth: The physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its impedance to seedling emergence and root penetration.

Topsoil: The layer of soil moved in cultivation.

Total dissolved solids: The solids residue after evaporating a sample of water or effluent (expressed in mg/L).

Total Kjeldahl nitrogen (TKN): The total concentration of organic and ammonia nitrogen in wastewater.

Toxic chemicals: Term used by USEPA for chemicals whose total emissions or releases must be reported annually by owners and operators of certain facilities that manufacture, process, or otherwise use a listed toxic chemical. The list of toxic chemicals is identified in Title III of SARA.

Toxic metals: Metals, including arsenic, cadmium, lead, and mercury, that are cumulative toxins and particularly hazardous to human health.

Toxic or hazardous substance: Substances injurious to the health of individual organisms and sometimes fatal.

Toxicity: The degree of poisonousness.

Toxicological evaluation: Part of risk assessment that should answer the question, "Does the chemical have an adverse effect?"

Toxin: A poison produced by a plant or animal.

Tracking system: In hazardous waste management, a manifest document that accompanies any waste transported from one location to another.

Transformations: Chemical changes that take place in the atmosphere, such as the conversion of an original pollutant to a secondary pollutant such as ozone.

Trash: Highly combustible waste paper, wood, cardboard cartons, up to 10% treated papers, plastic, or rubber scraps.

Treatment plant site sources of MSW: Water, wastewater, and other industrial treatment processes that produce municipal solids waste (e.g., incineration ash, sludges, biosolids, general plant wastes).

Trench method: In pollution control technology for USTs, a method used to capture the entire leading edge of the contaminant plume.

Trenching: See *Excavation*.

Trophic level: The feeding position occupied by a given organism in a food chain, measured by the number of steps removed from the producers.

Troposphere: A region of the atmosphere based on temperature difference between the Earth's surface and 10 miles in altitude.

Turbidity: Reduced transparency of the atmosphere caused by absorption and scattering of radiation by solid or liquid particles other than clouds and held in suspension.

Turbulence: (1) Uncoordinated movements and a state of continuous change in liquids and gases. (2) One of the three T's of combustion.

Turnover: The mixing of the upper and lower levels of a lake that most often occurs during the spring and fall and is caused by dramatic changes in surface water temperature.

Unconfined aquifer: An aquifer not underlain by an impermeable layer.

Underground storage tanks (USTs): Tanks designed to store chemicals, especially fuels, underground.

United Nations Hazard Class Number System: A system for designating and labeling hazardous materials using a dedicated number system.

Unsaturated zone: Lies just beneath the soil surface and is characterized by crevices that contain both air and water; water contained therein is not available for use.

Unstable atmosphere: Characterized by a high degree of turbulence.

Vacuole: A small cavity in the protoplasm of a cell.

Vadose water: Water in the unsaturated zone that is essentially unavailable for use.

Valence: The net electric charge of an atom or the number of electrons an atom can give up (or acquire) to achieve a completely filled outer shell.

Valley winds: At valley floor level, slope winds transform into valley winds that flow down-valley, often with the flow of a river.

Venting: In pollution control technology, a method of remediating hydrocarbon (gasoline) spills or leaks from USTs.

Venturi: A short tube with a constricted throat used to determine fluid pressures and velocities by measurement of differential pressures generated at the throat as a fluid traverses the tube.

Vernal ponds: Spring ponds, usually of short duration.

Virus: An infectious agent with a simple acellular organization, a protein coat, and a single type of nucleic acid; reproduces only within living host cells.

Volatile: Refers to a substance (usually a liquid) that evaporates at ordinary temperatures if exposed to the air.

Volatile organic compounds (VOCs): Organic compounds that evaporate and contribute to air pollution directly or through chemical or photochemical reactions to produce secondary pollutants, principally ozone.

Volatilization: When a solid or liquid substance passes into the vapor state.

Volume: Surface area (length × width) × a third dimension (height).

Warm front: Marks the advance of a warm air mass as it rises up over a cold one.

Waste minimization: An umbrella term that refers to industrial practices that minimize the volume of products, minimize packaging, extend the useful life of products, and minimize the amount of toxic substance in products.

Waste piles: Waste piled at industrial sites and then eventually disposed of in a landfill.

Wastewater: Liquid wastestream primarily produced by five major sources: human and animal wastes, household wastes, industrial wastes, stormwater runoff, and groundwater infiltration.

Water content: In *in situ* volatilization, the influence that water content has on the rate of volatilization by affecting the rates at which chemicals can diffuse through the vadose zone. An increase in solid water content decreases the rate at which volatile compounds are transported to the surface via vapor diffusion.

Water pollutants: Unwanted contaminants that can pollute water.

Water pollution: Any physical or chemical change in surface water or groundwater that can adversely affect living organisms.

Water table: The upper surface of the saturation zone below which all void spaces are filled with water.

Water vapor: The most visible constituent of the atmosphere (H_2O in vapor form).

Waterborne pathogens: The transmission conduit for some pathogenic microorganisms.

Watershed: The region draining into a river, river system, or body of water.

Watershed divide: A ridge of high land dividing two areas drained by different river systems.

Weather: The day-to-day pattern of precipitation, temperature, wind, barometric pressure, and humidity.

Weathering: The chemical and mechanical breakdown of rocks and minerals under the action of atmospheric agencies.

Weight: The force exerted upon any object by gravity.

Wet scrubber: A treatment device (e.g., a stacked tower) in which the contaminant wastestream is passed through microorganism-laden media or through a chemical spray (e.g., a caustic one) to degrade or neutralize the harmful affects of the contaminants.

Wetland: A lowland area, such as a marsh or swamp, saturated with moisture and usually thought of as natural wildlife habitat.

White goods: Large solid waste items such as household appliances (e.g., refrigerators, stoves, dishwashers, washers, dryers).

Wind: Horizontal air motion.

Wind and breezes: Local conditions caused by the circulating movement of warm and cold air (convection) and differences in heating.

Winter kill: A condition that can occur in a lake or pond when the entire water mass is frozen, thereby killing all inhabitants.

Winter stratification: In a lake in winter, the condition that occurs when the epilimnion is icebound and is at the lowest temperature and thus lightest, the thermocline is at medium temperature and medium weight, and the hypolimnion is at about 4°C and heaviest.

Worms: In stream ecology, the presence of certain species of worms in bottom sediment indicates stream pollution.

Xenobiotics: Any chemical present in a natural environment that does not normally occur in nature (e.g., pesticides, industrial pollutants).

Young pond: In the cycle of pond evolution, the initial or earliest phase.

Zone of recent pollution: In streams or rivers, the point of pollution discharge.

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